which includes fragments of corals, hydrozoans, bryozoans, crinoids, and brachiopods. In many localities and at several stratigraphic horizons wells penetrated long sequences of even-textured light-colored limestone without notable evidence of stratification and with a minimum of recognizable fragments of such fossils as brachiopods and crinoids. These are regarded as fossil reefs composed of the remains of hydrozoans, corals, and algae.

Chert is abundant in many of the purer limestones and has been noted in a few places where the rocks are quite argillaceous. A few individual samples are composed almost entirely of chert, showing the presence of lentils of dense, massive chert up to 10 feet in thickness. In most occurrences, however, the chert is intimately intergrown with the limestone, and sometimes to such a degree as to require chemical or petrographic methods for distinction between the minerals.

Dolomitic limestones are fairly common in the Traverse group; in some localities such rocks compose the bulk of the section. The lithology of these dolomitic sediments varies from a dense to finegrained calcitic limestone enclosing minute rhombohedral crystals of dolomite, through beds which appear to be composed of limestone strata with lentils of dolomite, to pure granular holocrystalline dolomites.

Observed lithology of the Traverse group and the subdivisions herein recognized as units are shown by the sections presented in the accompanying figures.

DESCRIPTION OF LITHOLOGIC UNITS

Bell Shale

The lowest unit of the Traverse group is composed of gray shales which are only slightly calcareous, except in their basal portion, which is characterized by the presence of pyrite and an abundance of crinoids and ostracods. In the central part of the state, especially in Montcalm County, there is at the contact a black organic dolomite which contains abundant pyrite and which may belong either to the Traverse group or to the underlying series. The thickness of this bed varies from 2 to 15 feet. Beds associated with this basal member frequently yield specimens of a finely ribbed brachiopod so small that they are sometimes undamaged by the drill.

The beds above this contact zone are gray, slightly calcareous shales with only a few fossil fragments. The maximum observed thickness of the Bell shale is 110 feet in Manistee County (Fig. 3). It is nearly as thick over a considerable area, being 80 feet thick in Antrim County (Fig. 4), 75 in the Saginaw Bay region, and 70 in Alpena County (Fig. 2). The Bell shale thins southwestward from the center of the state until in Muskegon County it is only 5 feet thick. It disappears entirely in Allegan County and has not been observed farther southwestward.

In the lowest 10 to 20 feet of the Bell shale in Montcalm County (No. 8, Fig. 2) there occurs a bed of brown granular dolomitic limestone very similar to the so-called Dundee of that region. In the drilling of several wells this bed has been erroneously called Dundee until subsequent deepening revealed the error.

The samples from one well in Manistee County indicate that there is a 5-foot bed of shale carrying large quantities of anhydrite about 25 feet below the top of the Bell. However, since similar occurrences have not been recognized in other wells and since anhydrite beds were exposed in the open hole above this point while drilling was in progress, the authenticity of this one is open to question.

Rockport Limestone

Above the Bell shale there is a variable thickness of beds more calcareous than those either above or below it. In the northeastern part of the state this unit is a relatively pure limestone (Fig. 2) and is probably approximately equivalent to the beds exposed in the Rockport quarry.[1] It is generally highly fossiliferous and locally cherty. In most of its occurrences it contains so much shale that it is our custom to describe it as a limy shale. In many sets of samples it is represented only by a notable abundance of calcareous fossils.

To the southwest this unit loses its identity because of the increasing lime content of the overlying beds, and southwest of Lake and Montcalm counties (Figs. 2-3) the writers have not been able definitely to recognize any equivalent for it. To the northwest, in Roscommon and Antrim counties (Fig. 4), there is a 60- to 80-foot thickness of relatively pure, fossiliferous, locally dolomitic gray limestone near the base of the Traverse section, which is correlated with the Rockport.

The writers have been unable to recognize the Rockport in samples from wells in northern Shiawassee County, where the relationships between the logs (Nos. 33-35, Fig. 4) suggest that the Traverse loses thickness by progressive southward overlap.

Middle Shale and Limestone Unit

Above the Rockport there is a series of shales, limy shales, muddy limestones, cherty limestones, and dolomites which attains a maximum thickness of about 220 feet (Figs. 2, 4) in the region surrounding Saginaw Bay. It thins to 190 feet in Alpena County and is not over 120 feet thick in Livingston County. It is characterized by the presence of gray shales with a varying lime content interbedded with varying thicknesses of limestone. The majority of the inter-bedded limestones are brown to black; they contain less chert than the limestones of the higher members of the Traverse group.

This unit in Alpena County is believed to contain the equivalents of the Long Lake stage of Grabau,[2] which includes the Ferron Point, Genshaw, and Killians of

Warthin and Cooper.[3] A black limestone, probably equivalent to Warthin and Cooper's Killians limestone, is recognized as the upper of two heavy limestones in the logs of wells No. 17 and No. 18 in Alcona and Alpena counties (Fig. 2). Comparison of the logs of some of the wells in the central part of the state suggests that this middle shale and limestone unit contains large lenticular bodies of limestone (Fig. 2), which are usually dark brown and highly organic but which are locally black like the Killians.

The identity of this unit is lost in the western part of the state, where it seems to have been replaced by massive limestone and dolomite. Whether this was accomplished by change of facies in contemporaneous sediments or by overlap cannot be determined definitely at present. The authors are inclined to favor the idea of lateral gradation from shales and limestones to massive limestone.

To the south this member seems to be disappearing by overlap, but in northern Lenawee County well No. 36 (Fig. 4) drilled 70 feet of limy shale enclosing 10 feet of dense limestone, which is regarded as belonging to this unit. This shale is probably also equivalent in part to the Silica shale of Ohio.[4]

Middle Massive Limestone Unit

The most prominent lithologic unit of the Traverse group is composed almost wholly of massive limestones and dolomites with varying large amounts of chert. In an eastward direction the limestone is displaced by intercalated shales to such an extent that in northern Huron County the apparent stratigraphic position of this limestone member is occupied by shales, with a few relatively thin beds of cherty limestone.

In the central part of the state, where the identity of this unit is fairly well established over a considerable area (Fig. 2), its thickness ranges between 250 and 300 feet. The majority of the limestones are light gray to white, and appear to be composed principally of fossil remains. Corals, brachiopods, crinoids, and bryozoans are especially abundant throughout.

Chert occurs in varying amounts from top to bottom of this unit, some beds being almost pure. It is sometimes dense and massive, which suggests the presence of large lentils or heavy beds, but often it is so intimately intergrown with the limestone as to render its detection difficult. In color it varies from light brown through shades of gray to pure white. The cherty zones are capable of fairly accurate correlation over distances of from 6 to 10 miles.

The writers have been unable to subdivide this unit satisfactorily into individual members or strata, because in a general way it is much alike throughout its thickness, and in minor characteristics it is extremely variable. In nearly every set of samples there occurs at least one and sometimes several thick zones of dense, even-textured, light-colored limestone, with only minor quantities of recognizable fossil material and most of that consisting of tiny fragments of corals. These sections, which are interpreted as reefs, constitute one of its principal characteristics.

Dolomitic limestones and dolomites occur in several positions in the unit and have been recognized in numerous localities throughout the state. In the central and eastern part dolomitic strata make up only a small fraction of its total thickness. One exception to this statement is well No. 14 (Fig. 2), in which it was found to be dolomitic through more than half of its thickness. The reason for such an occurrence gives rise to much interesting speculation, but so far no satisfactory explanation has been formulated. Dolomitic limestones are thicker and more frequent in the Traverse group in the southwestern part of the state. One or two sets of samples examined were found to be almost entirely pure dolomite.

In Muskegon County the upper portion of the lower half of the Traverse section contains a thick series of dolomites and anhydrites (Fig. 2). This member has not been positively identified outside Muskegon County, but similar sediments, in a similar stratigraphic position, have been recognized in wells in several of the westernmost counties. A persistent dolomite, which may be partly equivalent to the member, has been observed in a number of wells in Kent County. In several sets of samples from Muskegon, Manistee, Antrim, Lake, Newaygo, Kent, and Montcalm counties dolomitic zones were noted in the upper part of the Traverse group. These may prove to be approximately contemporaneous, but their equivalence has not been definitely established. Like cherty zones, the dolomitic horizons are useful as markers for local stratigraphic and structural purposes within limited areas, but do not appear to be sufficiently uniform and continuous for regional correlations.

In the upper part of this unit there are porous zones that contain salt water and, locally, oil and gas. These porous zones do not seem to be confined to a single definite horizon, but are usually near the top of the highest chert.

Beds of shale are present within this predominantly limy unit, but they are not very prominent west of Gladwin and Saginaw counties. East and southeast of these counties shales increase so rapidly in number and thickness as to suggest that this entire series of cherty limestones must disappear somewhere under Lake Huron.

The logs of wells in Alcona and Alpena counties (Nos. 17-18, Fig. 2) indicate that what is here called the middle massive limestone unit of the Traverse group includes the Alpena limestone in its lower portion and probably among its upper members equivalents of the beds to which Warthin and Cooper[5] have applied the names Norway Point, Potter Farm, and Partridge Point (Thunder Bay stage of Grabau[6]).

The writers have been unable to make a satisfactory correlation between their subdivisions of the Traverse group and those of the Petoskey section as described by Pohl.[7] This is partly because the samples from the nearest well (No. 27, Fig. 4) were an imperfect set, and partly because Pohl's descriptions of rocks examined by him emphasize characteristics which are not easily recognized in well samples.

Fifty feet of massive limestone and cherty dolomitic limestone represents this middle massive limestone unit in well No. 36 (Fig. 4) in Lenawee County, and these limestones may be equivalent to the cherty limestones exposed on Ten Mile Creek in Ohio.[8]

Upper Shale Unit

Above the middle massive limestone unit there is a very persistent and rather uniform gray shale, which attains a maximum observed thickness of 90 feet in southern Arenac County (well No. 15; Fig. 2). From this region it thins to the west, south, and north, but information from the east is not available. The thinning of this shale unit from its area of maximum thickness takes place rather rapidly at first and then more slowly. In southern Saginaw County and in Gratiot, Isabella, Clare, and Roscommon counties this unit is not over 40 feet thick. It is recognizable in Lenawee County (well No. 36, Fig. 4), where it has a thickness of 35 feet, but it is absent on the Howell anticline in Livingston County (well No. 35, Fig. 4). Southwestward it is recognized as far as Kent County (well No. 4, Fig. 2), but it has not been identified westward beyond Isabella County (well No. 22, Fig. 3), nor has it been recognized in the extreme northwestern part of the state.

In most of the well sections this shale unit appears as a light gray shale, uniform in character and texture, and rather poor in fossil content. To the northeast it becomes more calcareous, and in Ogemaw (well No. 16, Fig. 2) and Huron counties it contains some intercalated beds of limestone.

No definite correlation has been made between this shale and formations described from surface exposures because well No. 18 (Fig. 2) started in what is believed to be the upper part of the Alpena limestone and well No. 17 (next nearest to the type localities) does not appear to have any section which can be definitely identified as the Partridge Point or Potter Farm of Warthin and Cooper,[9] although this shale is believed to occupy a stratigraphic position immediately below their Squaw Bay limestone.

Squaw Bay Limestone

The uppermost member of what is here included in the Traverse group is a fine-grained, light brown, usually dolomitic limestone. On the basis of similarity of appearance and stratigraphic position this unit is correlated with the Squaw Bay limestone of Warthin and Cooper.[10] It has been recognized in well sections about as widely throughout the state as has any other unit of the Traverse group. Its thickness ranges from 15 to 40 feet, the variations appearing to be due to local conditions rather than to any systematic regional influences. It has been recognized in almost every set of samples seen by the writers from Huron and Alcona counties on the northeast, through Lenawee County on the south, Kent County on the southwest, Montcalm County to the west, and Roscommon County to the northwest. It has not been identified in Muskegon, Lake, or Antrim counties.

This unit is generally porous and salt-water bearing, and in some localities yields oil and gas. In the earlier times of oil development in Michigan it was spoken of as the "Saginaw sand."

Overlying Transition Zone

After the deposition of the Squaw Bay limestone there was sporadic and intermittent deposition of gray shales similar in character to those of the Traverse group. In some places also thin beds of gray limestone were deposited in association with these gray shales. These gray beds are interbedded with black shales typical of the Antrim formation. In the western part of the state a series of gray shale, with a few limy beds, rests on typical Traverse limestone and has been generally accepted by geologists as the uppermost member of the Traverse group. Eastward, however, these upper shales and limestones are found to be very discontinuous. Rocks in the corresponding stratigraphic position are chiefly black shales of the distinctive Antrim type, with one or several thin beds of gray shale of the Traverse type. Locally the gray sediments are entirely missing in samples from this horizon, which may be significant or may be due to poor sampling.

Because this zone does not constitute a definable lithologic unit and because it is largely composed of rocks which definitely are not of the Traverse type, it has here been excluded from the Traverse group and is recognized only as a transition phase between the Traverse group and the Antrim formation.

HISTORICAL GEOLOGY

Because of the fact that fossils are almost always broken into very small fragments before being recovered from wells the writers have believed that in all probability such fossil material as is available from well cuttings would be so imperfect as to prove of little use for purposes of correlation or faunal zoning. On that account and because of the necessity of logging a large number of wells in a limited time, they have done no systematic collecting of fossils during the progress of the sample examination. Some small collections were made from a few of the wells described in this paper, but the reports of paleontologists who undertook the examination of this material have not yet been received. In the absence of a knowledge of the distribution of individual faunas or of faunal affinities, the writers' notions of historical geology

are necessarily based entirely on lithologic variations within the group.

Since much shale occurs in the lower and upper portions of this group, and the intervening strata are of nearly pure limestone, it appears to record the invasion of the area by a sea which spread so far beyond the limits of the state that little clastic material was delivered into central Michigan during a considerable part of Traverse time. Because the group as a whole contains increasing amounts of shale to the south, east, and northeast, it seems reasonable to conclude that the shores of this sea lay in those directions from central Michigan. The Traverse thins to the northeast and very rapidly to the south, and therefore it is reasoned that this sea probably advanced from the west and northwest and that any temporary regressions during the deposition of the Traverse group were probably toward the west and northwest.

The extent to which the terrain may have been subjected to subaërial erosion prior to inundation by the Traverse sea is a question which must be solved by a detailed study of the Dundee and older formations. The very gentle slopes displayed by the upper surface of the Dundee formation (if post-Marshall structural influences are neglected) indicate that this terrain was one of very low relief. The apparent absence of anything which could be termed a basal conglomerate at the contact between the Traverse and the rocks upon which it rests argues that the advance of the Traverse sea involved no considerable amount of wave cutting.

In the western part of the state the waters of the Traverse sea must have been remarkably clear throughout most of the period represented by the group, for in that part of the state the outstanding characteristic of the rocks of the Traverse group is the almost complete absence of clastic material. It may be that the reefs which are so abundant in the group prevented the transportation of much clastic material from the littoral zones into that part of the Traverse sea which covered what is now southwestern Michigan.

The repeated deposition of relatively pure limestone in the predominantly shaly lower part of the Traverse section in the more southerly and easterly parts of the state seems to record periods when the seas of this region were less muddy than usual. These periods of calcareous deposition may have been when the shores of the Traverse sea were temporarily at very low topographic relief or when climatic conditions were such as to produce but little erosion, or when the subsidence of the basin of deposition proceeded at a sufficient rate to produce relatively deep water.

The presence of anhydrites just below the middle of the Traverse section in Antrim County (Fig. 4) and the occurrence of a dolomitic zone in a similar stratigraphic position in Muskegon, Kent, and Montcalm counties (Fig. 2) suggest a time of concentration of the waters and possible separation of part of the Traverse sea from the oceanic waters of the time, perhaps by a system of barrier reefs.

A decrease in the area of the Traverse sea, or at least a decrease in the depth of its marginal waters, is recorded by the rather pure shales which overlie the Alpena limestone and constitute a wedge (Fig. 2) extending from the east into the central portion of the middle massive limestone unit of this report. It seems possible that this suggested contraction of the area may have been contemporaneous with the increased salinity which promoted the deposition of anhydrite in the upper part of the Traverse group in Antrim County (Fig. 4). It is perhaps a significant observation that a very persistent dolomitic zone occupies substantially the same stratigraphic position in southern and southeastern Michigan.

After Alpena time the Traverse sea may have been temporarily deprived of part or all of its connection with the open oceans of that time and this event may have been accompanied by a retreat of the littoral zone and a concentration of the waters of the Traverse sea, thus permitting the zone of shale deposition to advance toward the center of the basin and causing the deposition of anhydrites and dolomites or rocks which later became dolomites.

A subsequent period, when the Traverse sea was relatively shallow and mud-laden over a large part of Michigan, is recorded by the shale series which is here designated the upper shale unit. The return of clear-water conditions, presumably caused by further regional subsidence, is indicated by the purity of the Squaw Bay limestone.

The unit here called the overlying transition zone records the final withdrawal of the Traverse sea or the alteration of the paleogeography in such a manner as to cause cessation of the Traverse type of deposition in the area and inception of the deposition of the distinctive black organic shale of the Antrim formation.

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[1] Smith, R. A., "Limestones of Michigan," *Mich. Geol. and Biol Survey,* Publ. 21, Geol. Ser. 17, p. 174 (1916).

[2] Grabau, A. W., "Stratigraphy of the Traverse Group of Michigan," *Geol. Surv. Mich., Ann. Rept. for 1901*, pp. 163-210. 1902.

[3] Warthin, A. S., Jr., and Cooper, G. A., "New Formation Names in the Michigan Devonian," *Journ. Wash. Acad. Sci*., Vol. 25, No. 12. 1935.

[4] Stewart, Grace A., "Ostracods of the Silica Shale, Middle Devonian of Ohio," *Journ. Geol*., 16 : 739. 1936.

[5] *Op. cit*.

[6] *Op. cit*.

[7] Pohl, Erwin R., "The Middle Devonian Traverse Group of Rocks in Michigan: A Summary of Existing Knowledge," *Proc. U. S. Nat. Museum* 76, Art. 14, 1-34. 1929.

[8] Stauffer, C. R., "Middle Devonian of Ohio," *Geol Surv. of Ohio, Bull. No. 10*, Fourth Series, pp. 145-146. 1909.

[9] *Op. cit.*

[10] *Op. cit.*

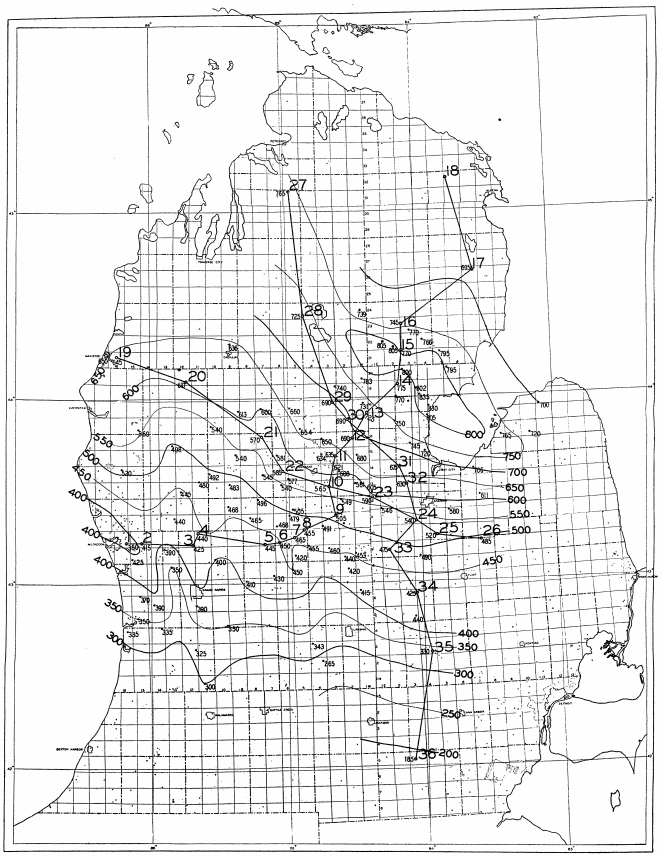

FIG. 1. Lower Peninsula of Michigan, showing observed thickness of the Traverse group and locations of wells used in accompanying sections (Figs. 2-4)

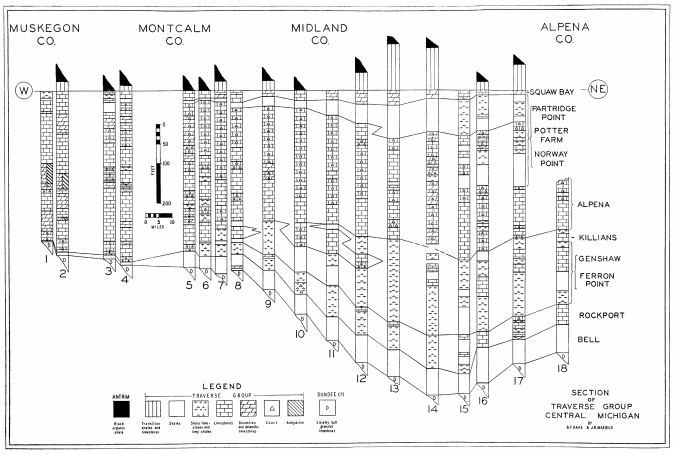

FIG. 2

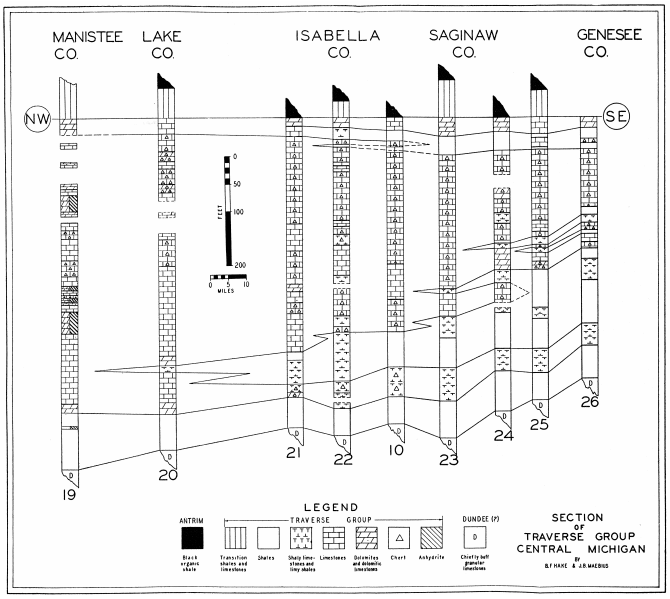

FIG. 3

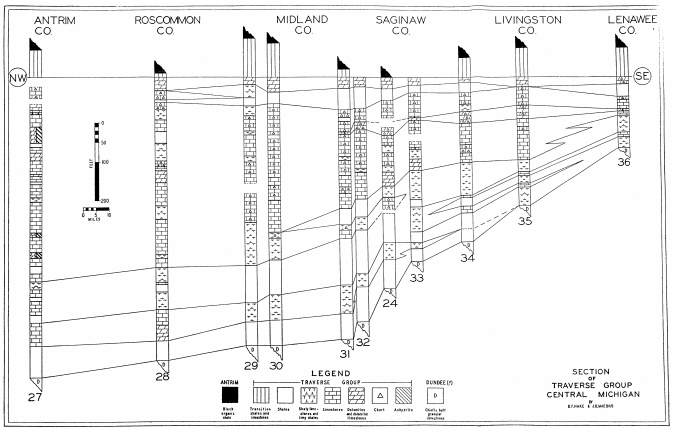

FIG. 4

GEOPHYSICAL MEASUREMENTS IN LIVINGSTON COUNTY, MICHIGAN

WILLIAM G. KECK

IN THE fall term of 1935 an elementary course in applied geophysics was introduced into the curriculum of the Applied Science Division of Michigan State College. It was considered imperative that a certain amount of field work in some of the geophysical methods be incorporated into this course. It is the manner of making these field measurements, and the interpretation of data taken by students engaged in this study, with which this paper is concerned.

In accordance with suggestions made by the State Geological Survey the area to the north and west of Howell, Livingston County, Michigan, was selected as a suitable proving ground for such measurements. Considerable geologic information pertaining to this region is available, and it is near enough to the college campus to permit short field excursions. In selecting the type of measurements to be made the factors of time and expense became very important. The time a student can devote to such work is of necessity limited, and only instruments which are regular equipment in a physical laboratory are available. The method should also be reasonably successful in revealing the known geologic structure. In view of the covering of glacial drift over all of Livingston County this last requirement became especially difficult to meet. Hubbert's[1] work on a similar problem indicates that an areal resistivity survey would be best able to answer all needs.

THEORY OF MEASUREMENT

Several methods of measuring "earth resistivity" are in practical use, differing mainly in the electrode configuration by which current is supplied to the earth and the potential due to this current is measured. The method introduced theoretically by Wenner[2] and practically applied by Gish and Rooney[3] was employed throughout this work. It will be described briefly.

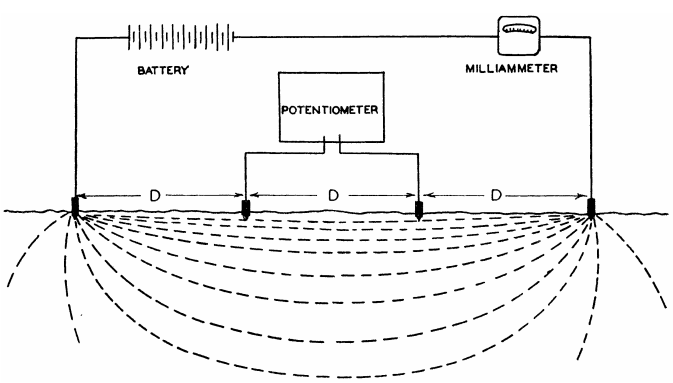

FIG. 1. Schematic diagram of Wenner method of measuring resistivity, showing instruments, arrangement of electrodes, and profile of current distribution between electrodes

As may be seen by reference to Figure 1, current, measured by means of a milliammeter, is supplied to the earth through two outer electrodes, from a "B" battery source. The voltage of this source ranges from 22 to 500 volts, depending upon the resistance of electrodes to earth. As a result of this flow a potential is developed across the two inner electrodes which is measured with a potentiometer capable of reading to one ten-thousandth of a volt. These potential electrodes are placed on a line with the two outer current electrodes and divide the total distance into three equal parts, which we shall designate by the letter *D*. If we call the current through the earth *I* and the potential across the inner electrodes *F*, the resistivity of the earth material is given, according to Wenner, *op. cit.*, by the equation:

$$\rho = 2\pi D \frac{V}{I}.$$

Gish and Rooney, *op. cit.*, state that this value of resistivity is effective for a hemicylindrical volume of length *D* and radius *D* situated with its axis between the two potential electrodes.

Having developed the basic principle of making resistivity measurements, we are now ready to consider the two fundamental techniques which govern its field application:

1. Horizontal exploration,[4] or method of the resistivity map. In this method a series of measurements are carried out at various stations, with the same electrode spacing maintained. Thus a horizontal layer of uniform depth is explored.

2. Vertical exploration. A series of measurements is made with increasing electrode spacings at one or several stations. By this means the variation of apparent resistivity with increasing depth of penetration of the current is investigated.

Hubbert[5] has used the horizontal exploration method to detect a buried anticline of massive Devonian limestone, flanked on both sides by younger Mississippian and Pennsylvanian shales and sandstones. Except for a heavier mantle of glacial drift, our problem is very similar to his. To overcome the difficulties introduced by drift materials a modification of the horizontal method has been developed. A description of the theory follows.

Let us assume that at a given station two measurements have been made, each at a different electrode separation. The resistivity at separation D_1 may be called ρ_1, that at D_2, ρ_2. Let us assume, further, that D_2 is larger than D_1. At any change in the apparent resistivity ρ_2 from that of ρ_1 must then be proportional to the amount by which the material between depth D_2 and D_1 differs from that between D_1 and the surface. If we designate the resistivity of the material in the interval between depths D_1 and D_2 by symbol ρ, we have:

$$(\rho_2 - \rho_1) \propto (\rho - \rho_1). \qquad (1)$$

Moreover, any change in apparent resistivity must be directly proportional to the amount, and inversely proportional to the average depth, of the newly added material.

$$(\rho_2 - \rho_1) \propto \frac{2(D_2 - D_1)}{(D_2 + D_1)}. \qquad (2)$$

When these proportionalities are combined and solved for ρ

$$\rho = \frac{k}{2}\frac{(\rho_2 - \rho_1)(D_2 + D_1)}{(D_2 - D_1)} + \rho_1. \qquad (3)$$

Inspection shows that in the event ρ_2 equals ρ_1, ρ will also equal ρ_1, which is a necessary physical requirement. It remains only to evaluate the constant of proportionality. This must be done empirically. The criterion of a satisfactory value of k is that it be of such magnitude that under no conditions of observed values of ρ_2 and ρ_1 do we obtain computed values of ρ less than zero, since negative resistivity has no physical meaning. Attention should be called to the fact that Wenner's formula holds only for a homogeneous earth. For this reason the apparent resistivity values cannot be accurately interpreted as average values. His formula also holds that the shape of the current path through the earth is such that our assumptions in equation (2) are only approximate. Thus, since we are to interpret equation (3) only as providing a means of comparing relative resistivity values, it follows that an accurate evaluation of k is unnecessary. A value of $k = 1$ has been found satisfactory.

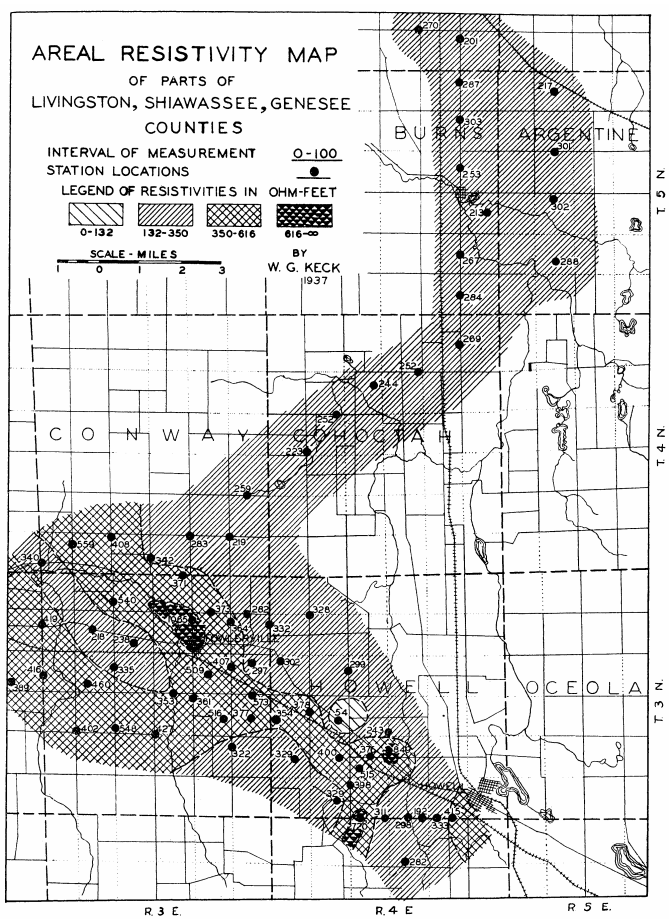

FIG. 2

EXPERIMENTAL DATA

Seventy-one stations have been completed in this area, the locations of which are given on the accompanying maps (Figs. 2-4). At each of these stations three separate determinations of apparent resistivity were made, at electrode separations of 100, 200, and 300 feet. From these data it has been possible to compute resistivities, according to the method described above, for the material in the interval between the surface and a depth of 100 feet; between 100 and 200 feet; and between 200 and 300 feet. The experimentally determined apparent resistivities and the interval resistivities computed from them for each station are tabulated at the end of this paper. Each map gives the areal distribution of resistivities for one of these intervals.

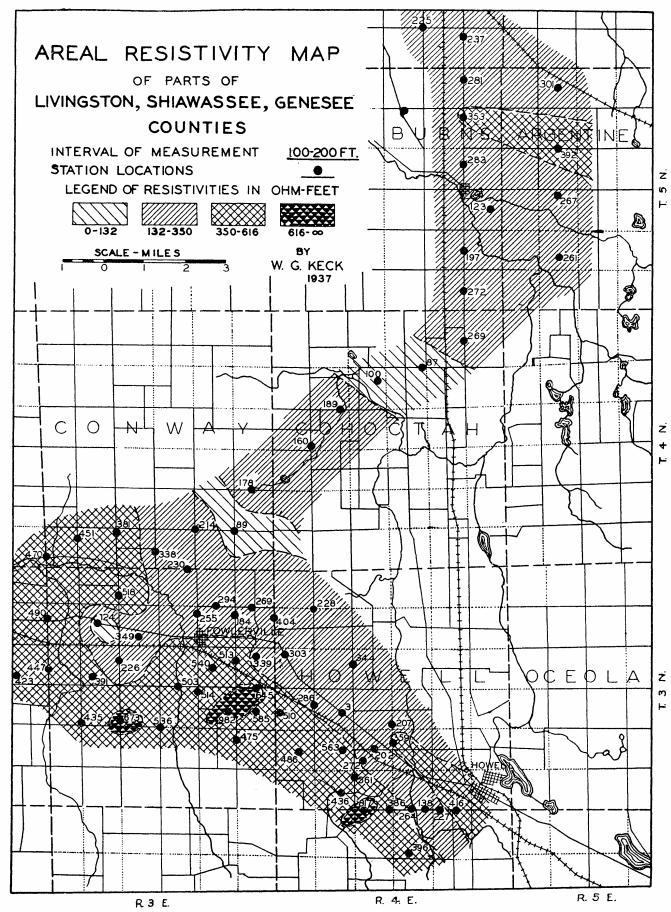

FIG. 3

INTERPRETATION OF RESULTS

The large Howell anticline has been dealt with at length by Newcombe.[6] In his publication a structural map with contours drawn on the top of the Berea, as well as an areal outcrop map, is given. The axis of the anticline is shown to extend in a general northwest-southeast direction, plunging moderately to the northwest. Its southwest flank is very steep, but the northeast side has comparatively small dip. The highest part of the structure occurs in the southwest part of the city of Howell, where the Berea sandstone outcrops under, or

very close to, the base of the drift. The Coldwater shales, Marshall sandstones, Napoleon sandstones, and Michigan Series members, successively younger beds, outcrop on the flanks of the structure to give the characteristic areal geologic map for a plunging asymmetrical fold.

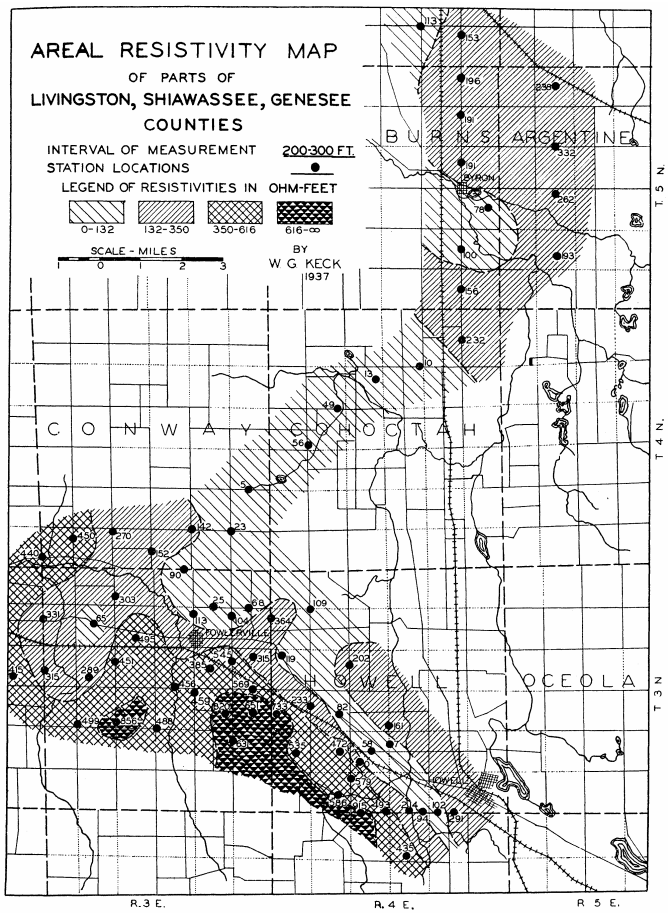

FIG. 4

The first map of resistivities (Fig. 2), which depicts the interval from the surface to a depth of 100 feet, does not reveal any pattern which might be construed as reflecting subsurface structure. This we should expect, since this interval is occupied almost entirely by glacial drift materials. A tabulation of twenty-five wells which have penetrated to bedrock in this region gives proof of this fact.

Drift thickness in wells in feet	*No. of wells*
150 or more	2
125 or more	4
100 or more	11
75 or more	19
74 or less	6

It is to be noted, however, that a zone of high-resistant materials exists in the southwestern part of the area. Wells in Handy Township show an average thickness of drift of 87 feet. It is conceivable, then, that electrically high-resistant sandstones are contributing to these measurements.

Figure 3, for the interval from 100 to 200 feet, should give the resistivity pattern for the bedrock materials immediately under the drift. It ought, therefore, to resemble very closely the areal outcrop map for the region. This resemblance is quite evident. It is to be noted that in the scale of resistivities values higher than 250 ohm-feet may be interpreted as representing the inclusion of considerable sandy material in the interval of measurement. The high-resistant zone to the southwest indicates the presence of the Marshall and Napoleon formations, and the steep dip of this flank is clearly revealed by the rapid change in resistivity in that direction. Correspondingly, the low dip side is shown by a low rate of change of resistivity in the northeast direction.

Figure 4 exhibits essentially the same features, except that the high-resistant zones have receded farther from the axis and, in general, lower values of resistivity are obtained on the crest of the anticline. This, it is readily seen, must be a consequence of the deeper interval of measurement.

A more detailed check upon these results will be possible when the new map of the areal geology of Michigan, which has been prepared by Helen A. Martin for the Michigan State Geological Survey, is made available.

ACKNOWLEDGMENTS

The writer is indebted to members of the State Geological Survey and to Dr. S. G. Bergquist, of the Department of Geology, Michigan State College, for many helpful suggestions made during the course of this work.

MICHIGAN STATE COLLEGE
EAST LANSING, MICHIGAN

[1] Hubbert, M. K., "Results of Earth-Resistivity Survey on Various Geologic Structures in Illinois," *Trans. A. I. M. E.*, Vol. 110. 1934.

[2] Wenner, F., "A Method of Measuring Earth Resistivity," *Bulletin No 258*, U. S. Bureau of Standards. 1916.

[3] Gish, O. H., and Rooney, W. J., "Measurement of Resistivity of Large Masses of Undisturbed Earth," *Terrestrial Magnetism and Atmospheric Electricity*, 30: 161. 1925.

[4] Schlumberger, D. and M., and Leonardos, E. G., "Electrical Exploration of Water-covered Areas," *Trans. A. I. M. E.*, Vol. 110. 1934.

[5] *Op. cit.*

[6] Newcombe, R. B., "Oil and Gas Fields of Michigan," *Michigan Geological Survey*, Publ. 38, Geol. Ser. 32. 1933.

TABULATION OF RESISTIVITIES FOR ALL STATIONS

The three measurements at each station are for depths of 100, 200, and 300 feet, respectively.

Station	Apparent resistivity ohm-feet	Interval resistivity ohm-feet
1	SW ¼ of NW ¼ of NW ¼ of Sec. 33, T 3 N, R 4 E	
	398	398
	507	561
	534	574
2	SE ¼ of SE ¼ of NW ¼ of Sec. 28, T 3 N, R 4 E	
	376	376
	260	202
	179	58
3	SW ¼ of NW ¼ of SW ¼ of Sec. 22, T 3 N, R 4 E	
	243	243
	219	207
	196	161
4	SE ¼ of SW ¼ of SW ¼ of Sec. 33, T 3 N, R 4 E	
	720	720
	800	840
	846	915
5	SW ¼ of SE ¼ of SW ¼ of Sec. 34, T 3 N, R 4 E	
	298	298
	274	262
	250	214
6	SE ¼ of SW ¼ of SE ¼ of Sec. 35, T 3 N, R 4 E	
	415	415
	416	416
	366	291
7	SE ¼ of SW ¼ of SW ¼ of Sec. 3, T 2 N, R 4 E	
	282	282
	358	396
	389	435
8	SE ¼ of SE ¼ of SE ¼ of Sec. 33, T 3 N, R 4 E	
	311	311
	361	386
	414	493
9	SW ¼ of SE ¼ of SE ¼ of Sec. 34, T 3 N, R 4 E	
	192	192
	156	138
	131	94
10	SE ¼ of SW ¼ of SW ¼ of Sec. 35, T 3 N, R 4 E	
	333	333
	262	227
	198	102
11	NE ¼ of SE ¼ of NE ¼ of Sec. 28, T 3 N, R 4 E	
	849	849
	522	359
	316	7
12	SE ¼ of NW ¼ of SW ¼ of Sec. 28, T 3 N, R 4 E	
	515	515
	353	272
	219	18
13	SE ¼ of SW ¼ of NE ¼ of Sec. 32, T 3 N, R 4 E	
	324	324
	399	436
	474	586
14	SW ¼ of NE ¼ of NW ¼ of Sec. 18, T 3 N, R 4 E	
	302	302
	236	203
	189	119

TABULATION OF RESISTIVITIES (*Continued*)

Station	Apparent resistivity	Interval resistivity
15	NW ¼ of NE ¼ of SE ¼ of Sec. 20, T 3 N, R 4 E	
	54	54
	20	3
	45	82
16	SW ¼ of SW ¼ of NE ¼ of Sec. 29, T 3 N, R 4 E	
	400	400
	509	563
	494	472
17	SE ¼ of SW ¼ of NE ¼ of Sec. 30, T 3 N, R 4 E	
	329	329
	430	480
	472	535
18	SW ¼ of NW ¼ of NW ¼ of Sec. 25, T 3 N, R 3 E	
	322	322
	424	475
	507	631
19	SW ¼ of SW ¼ of NW ¼ of Sec. 19, T 3 N, R 4 E	
	354	354
	458	510
	568	733
20	NE ¼ of SE ¼ of NE ¼ of Sec. 19, T 3 N, R 4 E	
	378	378
	310	276
	279	233
21	NE ¼ of SE ¼ of NE ¼ of Sec. 17, T 3 N, R 4 E	
	299	299
	329	344
	278	202
22	SE ¼ of SE ¼ of NE ¼ of Sec. 23, T 3 N, R 3 E	
	576	576
	705	982
	751	820
23	SE ¼ of SW ¼ of NE ¼ of Sec. 24, T 3 N, R 3 E	
	377	377
	516	585
	570	651
24	NW ¼ of NW ¼ of NE ¼ of Sec. 24, T 3 N, R 3 E	
	513	513
	581	645
	576	569
25	NW ¼ of SW ¼ of NE ¼ of Sec. 13, T 3 N, R 3 E	
	297	297
	325	339
	321	315
26	NE ¼ of NE ¼ of NE ¼ of Sec. 7, T 3 N, R 4 E	
	328	328
	261	228
	200	109
27	SW ¼ of NW ¼ of NW ¼ of Sec. 7, T 3 N, R 4 E	
	332	332
	404	440
	388	364
28	SE ¼ of SE ¼ of SW ¼ of Sec. 1, T 3 N, R 3 E	
	282	282
	273	269
	195	68
29	NW ¼ of SW ¼ of NW ¼ of Sec. 13, T 3 N, R 3 E	
	407	407
	478	513
	505	545
30	NW ¼ of NW ¼ of NW ¼ of Sec. 23, T 3 N, R 3 E	
	361	361
	463	514
	461	458

TABULATION OF RESISTIVITIES (*Continued*)

Station	Apparent resistivity	Interval resistivity
31	NW ¼ of NW ¼ of NE ¼ of Sec. 22, T 3 N, R 3 E	
	353	353
	463	503
	460	456
32	SW ¼ of SW ¼ of NW ¼ of Sec. 14, T 3 N, R 3 E	
	509	509
	530	540
	472	385
33	SE ¼ of NE ¼ of NE ¼ of Sec. 11, T 3 N, R 3 E	
	364	364
	244	184
	188	104
34	NW ¼ of NW ¼ of NE ¼ of Sec. 11, T 3 N, R 3 E	
	373	373
	320	294
	202	25
35	SW ¼ of NW ¼ of NW ¼ of Sec. 11, T 3 N, R 3 E	
	1065	1065
	525	255
	360	113
36	NW ¼ of NW ¼ of SW ¼ of Sec. 22, T 3 N, R 3 E	
	427	427
	500	536
	495	488
37	SW ¼ of SW ¼ of NW ¼ of Sec. 21, T 3 N, R 3 E	
	548	548
	631	673
	721	856
38	SW ¼ of SW ¼ of NW ¼ of Sec. 16, T 3 N, R 3 E	
	335	335
	289	266
	354	451
39	NE ¼ of SE ¼ of SW ¼ of Sec. 9, T 3 N, R 3 E	
	238	238
	312	349
	385	495
40	SW ¼ of NW ¼ of SW ¼ of Sec. 4, T 3 N, R 3 E	
	540	540
	525	518
	436	303
41	NE ¼ of NW ¼ of NE ¼ of Sec. 3, T 3 N, R 3 E	
	371	371
	277	230
	204	90
42	SE ¼ of SE ¼ of NE ¼ of Sec. 31, T 4 N, R 3 E	
	554	554
	485	451
	471	450
43	NW ¼ of SW ¼ of SW ¼ of Sec. 31, T 4 N, R 3 E	
	340	340
	427	470
	433	440
44	SW ¼ of SW ¼ of NW ¼ of Sec. 7, T 3 N, R 3 E	
	419	419
	471	497
	415	331
45	NE ¼ of NE ¼ of SE ¼ of Sec. 33, T 4 N, R 3 E	
	342	342
	339	338
	264	152
46	NW ¼ of NW ¼ of NW¼ of Sec. 35, T 4 N, R 3 E	
	283	283
	237	214
	199	142

TABULATION OF RESISTIVITIES (*Continued*)

Station	Apparent resistivity	Interval resistivity
47	NW ¼ of NW ¼ of NW ¼ of Sec. 33, T 4 N, R 3 E	
	408	408
	390	381
	342	270
48	NE ¼ of NW ¼ of SW ¼ of Sec. 13, T 3 N, R 2 E	
	389	389
	412	423
	412	412
49	NE ¼ of NE ¼ of SE ¼ of Sec. 13, T 3 N, R 2 E	
	416	416
	437	447
	388	315
50	SE ¼ of SE ¼ of NE ¼ of Sec. 19, T 3 N, R 3 E	
	402	402
	424	435
	454	499
51	NE ¼ of SE ¼ of SW ¼ of Sec. 17, T 3 N, R 3 E	
	460	460
	414	391
	364	289
52	NE ¼ of NE ¼ of SW ¼ of Sec. 8, T 3 N, R 3 E	
	218	218
	155	124
	119	65
53	SE ¼ of SE ¼ of SE ¼ of Sec. 26, T 4 N, R 3 E	
	219	219
	132	89
	88	23
54	SE ¼ of SE ¼ of SW ¼ of Sec. 24, T 4 N, R 3 E	
	259	259
	205	178
	125	5
55	SE ¼ of SE ¼ of SE ¼ of Sec. 18, T 4 N, R 4 E	
	223	223
	181	160
	131	56
56	SW ¼ of SE ¼ of SE ¼ of Sec. 8, T 4 N, R 4 E	
	252	252
	209	189
	145	49
57	SW ¼ of SE ¼ of NE ¼ of Sec. 9, T 4 N, R 4 E	
	244	244
	148	100
	94	13
58	NE ¼ of NE ¼ of NE ¼ of Sec. 10, T 4 N, R 4 E	
	252	252
	142	87
	89	10
59	NE ¼ of NE ¼ of SE ¼ of Sec. 2, T 4 N, R 4 E	
	269	269
	269	269
	254	232
60	NE ¼ of NE ¼ of SE ¼ of Sec. 35, T 5 N, R 4 E	
	284	284
	276	272
	228	156
61	NE ¼ of NE ¼ of SE ¼ of Sec. 26, T 5 N, R 4 E	
	267	267
	220	197
	172	100
62	NE ¼ of NW ¼ of SE ¼ of Sec. 24, T 5 N, R 4 E	
	213	213
	153	123
	123	78

TABULATION OF RESISTIVITIES (*Concluded*)

Station	Apparent resistivity	Interval resistivity
63	SW ¼ of SW ¼ of NW ¼ of Sec. 13, T 5 N, R 4 E	
	253	253
	273	283
	240	191
64	SW ¼ of NW ¼ of NW ¼ of Sec. 12, T 5 N, R 4 E	
	303	303
	336	353
	280	196
65	NW ¼ of SW ¼ of NW ¼ of Sec. 1, T 5 N, R 4 E	
	287	287
	283	281
	248	196
66	SW ¼ of SW ¼ of NW ¼ of Sec. 36, T 6 N, R 4 E	
	201	201
	225	237
	196	153
67	NW ¼ of NW ¼ of NW ¼ of Sec. 35, T 6 N, R 4 E	
	270	270
	240	225
	189	113
68	SE ¼ of SE ¼ of NW ¼ of Sec. 5, T 5 N, R 5 E	
	217	217
	273	301
	259	238
69	SE ¼ of SE ¼ of SW ¼ of Sec. 8, T 5 N, R 5 E	
	301	301
	362	392
	350	332
70	NE ¼ of NE ¼ of NW ¼ of Sec. 20, T 5 N, R 5 E	
	302	302
	279	267
	272	262
71	NE ¼ of NE ¼ of SW ¼ of Sec. 29, T 5 N, R 5 E	
	288	288
	270	261
	239	193

IMPOUNDED EARLY ALGONQUIN BEACHES AT SUCKER CREEK, GREY COUNTY, ONTARIO

GEORGE M. STANLEY

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INTRODUCTION

THE beaches to be described are neither conspicuous nor extensive, but are interesting for the remarkable circumstances of their preservation at Sucker Creek, and especially because they furnish tangible evidence of a lake stage which previously had been only inferred, since nearly everywhere else its shore has been destroyed.

Discovery of these features was incidental to a study of Algonquin and later beaches of northeastern Grey County, Ontario, in September, 1936. Most of the elevations of such beaches here given are taken from a report[1] on this study, which was aided by a grant from the Penrose Fund of the Geological Society of America. The measurements at Vail's Point were made in September, 1934, as one part of a survey financially aided by the Faculty Research Fund of the University of Michigan.

The sketch maps presented are merely what the term designates, for no real method of horizontal control was employed, and the courses of roads and streams on available maps are only approximated. Probably many small features are sadly distorted from their true position. On the other hand, considerable care was exercised in the instrumental determination of elevations, which, after all, is the only reliable method of approach to a study of changes in level.

The writer acknowledges the fine assistance of Mr. Richard Bilbie, of Ann Arbor, in the field work and the courtesy of Mr. Walter Carson and Mr. Robert Patterson, both of Cape Rich, in supplying local information and implements.

PRELIMINARY DISCUSSION

Methods of Measurement

Spirit leveling was employed in determining the altitudes of nearly all the beaches as well as of other features. This procedure involved starting from Georgian Bay as a base datum (578.2 feet elevation; September, 1936) and sighting against stadia rod with either a pocket level or a telescopic level on tripod. The results are probably reliable in most cases to within 1 or 1½ feet. Most of the figures plotted on diagrams have been taken to the closest even foot. A few aneroid observations included on the diagrams are indicated as such (an.), and though checked usually to some near-by, spirit-leveled point, they cannot be relied on to closer than about 10 feet.

Succession of Lake Stages in Georgian Bay

The following summary of lake history is based on the work of Leverett and Taylor,[2] with certain modifications.[3]

Algonquin

Lake Algonquin is the earliest, known ancestor of the Great Lakes in the northern Lake Huron and Georgian Bay basins. The highest Algonquin shore line is so marked a feature of the landscape that the geologist can scarcely visit the area without becoming aware of its physiographic importance. Generally it is conspicuous at some distance from the present lake as a rocky cliff, or a high bluff cut into the surface deposits, setting off in great contrast with the lower lacustrine plain the glacial features on the hills above the shore line. It extends across occasional embayed lowlands as an imposing

depositional bar. The Algonquin beach has experienced a remarkable deformation. From an area south of the hinge line in southern Lake Huron, where it is horizontal and only 25 feet above lake level, it rises northeastward until it is several hundred feet above Georgian Bay, with a tilt of 3 or 4 feet per mile.

Several stages of Lake Algonquin are recognizable. They are listed here in chronological sequence:

1. Possibly an incipient stage when discharge was at Port Huron and the lake was limited to southern Lake Huron, since the glacier still occupied northern Lake Huron and Georgian Bay. This is a hypothetical stage, for which no beach has ever been reported, although certain terraces along the St. Clair River may have been deposited at this time.

2. The Fenelon Falls (Kirkfield) stage, when the glacier had retreated enough to open the Trent valley and allowed the lake to drain eastward to Lake Iroquois (Lake Ontario basin). This was a prolonged stage, marked by considerable erosion in the Trent valley, but no beach for the lake has hitherto been reported.

3. The "two-outlet" stage, inaugurated when uptilting in the north had elevated the Trent valley and the surface of the lake until discharge began at Port Huron (and at Chicago perhaps). It was during this period of drainage at both Port Huron and Fenelon Falls that "the Algonquin beach" or highest Algonquin beach was formed. The great erosion performed by Lake Algonquin at this time, or during the rise in level which led up to it, quite generally obliterated the previous beaches and left the strong Algonquin shore line, which is prominent. In the discussion that follows it is this stage or its beach that is referred to by the simple term "Algonquin," since such is the practice on maps and in other reports. The beaches which are the principal subject of the paper are called "early Algonquin" because they antedate "the Algonquin beach," and they ostensibly belong to the second stage of Lake Algonquin noted above.

4. Later stages which formed the "upper group of Algonquin beaches." These are a closely spaced series extending below the highest Algonquin beach (for 40 feet, more or less), found generally in the north and obviously formed during a gradual recession of the lake. Probably continued tilting was now lifting the Trent outlet above the level of the lake, which continued to drain at Port Huron.

Lower Algonquin

After the lowest beach of the upper Algonquin group had been formed rapid lowering seems to have occurred. Several stages ensued, each apparently set off from the earlier and the later ones by an abrupt drop in the lake. Presumably new and lower outlets were becoming available as the glacier melted away from the highlands east of Georgian Bay. Thus followed the Wyebridge, Penetang, Cedar Point, Payette, and perhaps other stages as yet unreported. Only slight tilting took place during the four stages enumerated, for all the water planes are close to parallel, and nearly parallel also with the highest Algonquin plane. The positions of these outlets have not yet been located.

Nipissing

Ultimately the North Bay-Mattawa valley carried the discharge of the lakes, and this was the lowest outlet to be opened. Further tilting elevated this outlet and caused the lake to rise until it again overflowed at Port Huron. At this time the well-known Nipissing beach was formed. Resulting from a rise in water, it is similar to the highest Algonquin in prominence and in the abundance of its eroded bluffs. Earlier shore lines were similarly destroyed during the course of its formation.

The Nipissing shore line has been tilted only gently as compared with the Algonquin, for it has been uplifted scarcely more than 100 feet at the most northeasterly points. While this movement was taking place discharge continued at Port Huron, and a group of post-Nipissing beaches were formed, frequently found in the north as a number of closely spaced ridges lying in continuous series between the Nipissing beach and the present shore.

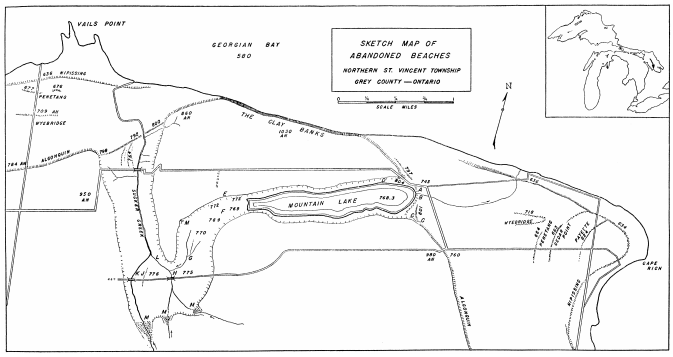

FIG. 1. Sketch map of main features of Sucker Creek-Cape Rich area. Inset shows location, at tip of peninsula between Owen Sound and Meaford, Georgian Bay. Hachured lines indicate wave-cut bluffs and steep hillsides; dotted rows, depositional lake bars or deltas

Highest Algonquin Shore Line

Among the various lake levels already enumerated the highest Algonquin is especially relevant to the subject in hand, and its beaches in the locality deserve some description. Further details on the lower beaches are given elsewhere.[4]

The highest Algonquin shore, which is a strongly cut terrace and bluff about the entire peninsula between Owen Sound and Meaford, lies a mile or more inland from Vail's Point and Cape Rich. The tip of the peninsula, together with its general location, is shown in Figure 1, on which the Algonquin bluff is represented by a hachured line. Surely this must have been a forbidding coast in Algonquin time, for the bluff is very high and for long stretches towers fully 200 feet above the terrace. North of Mountain Lake about a mile of the Algonquin shore has been cut away by Georgian Bay to form "the Clay Banks," a shore cliff of extraordinary

height for the Great Lakes region, since it stands nearly 500 feet above the water.

On the opposite sides of the Clay Banks two deep valleys break the continuity of the former shore cliff. Across Sucker Creek valley stretches a magnificent Algonquin shingle bar, which is rather striking for its bold position and perfection of contour (Pl. I, Fig. 1). It ties to the Algonquin bluff at either end, where it reaches an elevation of approximately 800 feet arid is accompanied by short spit beaches in the rear (see Fig. 2). The bar declines to about 792 feet near the middle, where Sucker Creek has cleft it with a deep gorge (Pl. II, Fig. 1). Arrayed along the front slope of the bar are a series of lower beaches, the upper Algonquin group. The lagoon waters have cut into the back of the bar a distinct bench at about 775 feet elevation (Pl. I, Fig. 1).

The valley of Mountain Lake causes a somewhat narrower break in the Algonquin shore cliff to the east of the Clay Banks. Overlooking the southeast corner of the lake is an Algonquin spit beach at an elevation of 801 feet, but for some reason it extends only part way northward across the valley. A little flat terrace (804) at the north corner of the lake, along the road and below the steep hill to the west, seems also a part of the Algonquin shore, as does, of course, a ridge (797) just north of the road. Northeast and east from the ridges at 797 and 801 feet are a series of lower beaches which cover exactly the same range in level (801-762) as the upper Algonquin group at Sucker Creek. To avoid complicating the available space these beaches are not plotted in Figure 1.

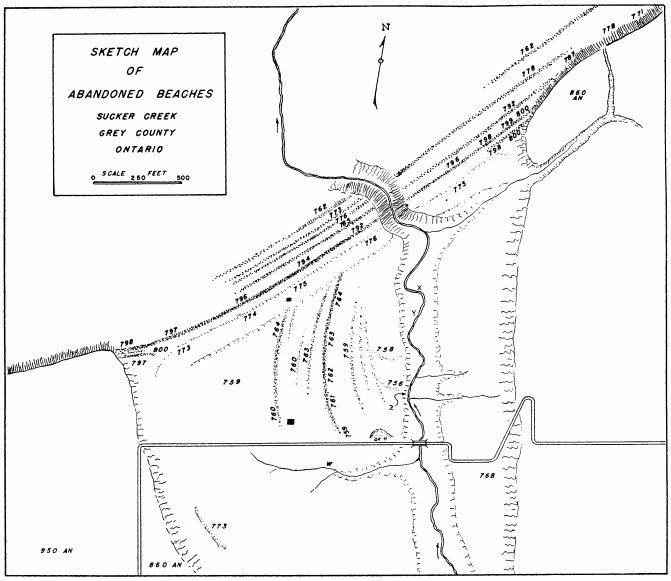

FIG. 2. Plat of beaches and their elevations in Sucker Creek valley. Elevations designated "an." Are by aneroid; all others are by spirit level

EARLY ALGONQUIN FEATURES

Shingle Deposits

The first place to suggest the possibility of early Algonquin lake deposits at Sucker Creek was the little gravel pit just west of the highway bridge (Fig. 2). The nicely rounded and stratified shingles in the thick deposit here immediately suggested a shore origin (Pl. I, Fig. 2; Pl. V, Fig. 3). Yet the top of the deposit (758) was clearly some 30 feet lower than the great bar across the mouth of the valley. The waves could not have reached into the creek valley past the bar to work the material, which is spread over a rectangular, level plain stretching nearly a quarter mile south from the great bar. The shingle is exposed not only in the gravel pit but also as talus (Pl. II, Fig. 2) along the west bank of Sucker Creek all the way from the bridge down to the deep gorge. Along the south side of the road across from the gravel pit the shingle stands at a repose slope, occasionally sliding down into the little gully tributary to Sucker Creek. This gully seems to mark roughly the farthest extent of the shingle deposits up Sucker Creek valley. No such rounded material is to be seen anywhere along the creek beyond. The characteristic stream rubble is angular and poorly assorted, utterly different from the nicely rounded shingles, which could scarcely have been worn otherwise than along the shore of the big lake. The only well-rounded, stream-deposited rubble to be seen is at points *X*, *Y*, and, especially, *Z* (Fig. 2), where Sucker Creek has undermined, rehandled, and deposited the typical lake shingles. In an exposure of a little creek terrace at point *Z* the shingles lie like a string of fallen dominoes, all dipping upstream, as fiat pebbles are often found in a river bed.

Impounded Spit Beaches

The surface of the shingle plain undulates very gently in a series of flattish north-south ridges. These are all more subdued than the bold Algonquin beach ridges to the north. Some are so obscure that they almost escape recognition, but two or three are sufficiently definite to draw attention to the rest. The most prominent is in the center of the group, with five elevation values plotted on its crest (Fig. 2). The next one to the west (763) is also definite, and the most westerly is very pronounced. Shingle is to be found on the ridges in small quantities, especially near plow furrows and woodchuck holes, as though brought up from a depth of several feet. The surface is largely of clay. All the ridges are more or less curved and convex to the west. They uniformly reach a maximum elevation of 764 feet, and all extend northward to the fore edge of the bench in the back slope of the great Algonquin bar. From the manner in which they meet this bench they seem almost to pass into and beneath it and beneath the bar itself. Indeed they do, as is shown on pages 486-487. If prolonged lakeward, the converging ridges might come together somewhere north of the high bluff adjoining the northeast end of the Algonquin bar.

It is clear from their form and material that these ridges are wave-formed beach spits, built southward into Sucker Creek bay during an early stage of the lake. Their topographic position makes it certain that they were extended in this direction, as does also the southward decline of two of the ridges. That they antedate the highest Algonquin beach is certain, for they are truncated and overlain by it. Also, since these earlier beaches are nearly thirty-five feet lower than the Algonquin, the lake in which they were formed was here much lower than the two-outlet stage of Lake Algonquin. This is the third situation in which the writer has found fragments of an earlier and lower shore line preserved and protected within an embayment and behind the bar of a higher lake.[5] The older beaches are thus "impounded beaches" and excellent examples of the phenomenon. The impounded Payette beach at Cape Rich has been described elsewhere, but its similar situation is shown in Figure 1. As this map shows, it is unconformable with the Nipissing beach, just as the impounded beaches at Sucker Creek are with the highest Algonquin, and it, too, was submerged at the later stage of the lake and covered with clay.

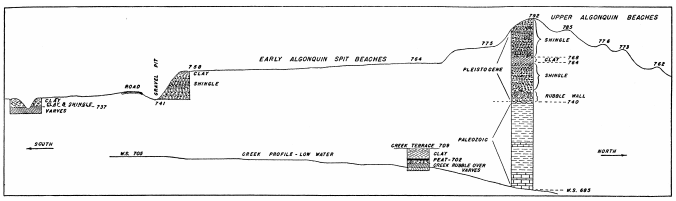

FIG. 3. Idealized profile extending north and south across Algonquin and earlier beaches at Sucker Creek, as shown in Figure 2

The material of the impounded beaches at Sucker Creek must have been derived from rock ledges in the bluffs at the side of this former bay; to judge from the curvature of the ridges, it would appear to have come from the easterly bluff. Without doubt the high hill (860) which furnished the material extended farther north at that time. The very character of the Algonquin shore line implies considerable erosion and cliff recession. Moreover, a little gully in this hill may be traced north to the very brow of the Algonquin bluff (Fig. 2), where the gully is still six or seven feet deep. It seems as though the hill must then have extended several rods north of the present bluff in order to furnish sufficient drainage to cut this channel.

Thus only the distal portions of the beach spits remain. The principal and headward portions of the features, along with the source point of material, were long ago consumed by the avid rising waters of Lake Algonquin. In fact, at the two-outlet stage Lake Algonquin so completely obliterated its earlier shore line that the preservation of the fragments described is truly remarkable; so far they are the only ones on record.

Exposures in the Gorge

The deep canyon where Sucker Creek penetrates the Algonquin bar has been cut down about halfway through Pleistocene deposits and about half through Paleozoic rocks to a total depth of about 110 feet. The precise contact at the bedrock surface is difficult to spot, but seems to be at the base (740) of the very resistant conglomeratic layer, referred to here as the "rubble wall." Beneath this is a thin horizon of angular limestone blocks at the top of the Paleozoic strata, underlain by much-weathered, slumping shales, which, interrupted by one or two harder horizons, continue to the bottom of the gorge (see Fig. 3 and Pl. II, Fig. 1).

The rubble wall is a strongly cemented layer which extends for some distance up and down the valley, at an apparently uniform level (Pl. III, Fig. 1; Pl. V, Figs. 1-2). A three-foot conglomerate mass from this layer was found lying in the gorge below, and its solidity and the embedded stones broken off flush with its surface illustrate the great strength of the rubble deposit. Boulders in it are well rounded and somewhat coarser than the overlying lake gravels, and when they break out their forms are perfectly preserved in the abundant cement (see Pl. III, Fig. 2; Pl. V, Fig. 2). The thickness of the rubble wall is from 7 to 10 feet, though not exactly measurable, inasmuch as it grades into the shingle above. In many places the wall has withstood disintegration better than have the underlying Paleozoic rocks, and it has recesses arid caves beneath it. Occasionally a thin vein of cemented sand occurs at the base of the rubble (Pl. III, Fig. 1).

TABLE I

ELEVATIONS OF DEPOSITS EXPOSED IN SUCKER GORGE*

	Cut I	Cut II	Cut III	Cut IV	Cut V	Cut VI
Base of upper shingle deposit, shingles in clay, overlying pure clay	.....	767.3	767.7	768.2	.....	.....
Sandy streak...	.....	.....	.....	766.3	765.7	.....
Solitary pebble in clay.....	.....	.....	.....	.....	765.0	.....
Summit of lower shingle deposit, clay in interstices....	.....	.....	.....	.....	764.2	764.2
Shingle permeated with clay, at base of cut.	761.0	.....	.....	.....	.....	.....

* The cuts are about 5 or 6 feet apart on the upper part of the west gorge wall, and range from 30 to 60 feet south of the crest line of the Algonquin bar. They were excavated at different levels, each for only a small depth. This explains why figures for a single contact are not given in all columns of the table. Cut I is the most southerly, Cut VI the northernmost.

It seemed at first that the deposits above the rubble wall were one continuous pile of shingle, for a talus of this material masks most of the steep slope. However, an abundance of clay among some of the shingle led to another discovery. Suspended by an eighty-foot line, Mr. Bilbie made six excavations in the hazardous west slope of the gorge and revealed a layer of clay separating the shingle deposits into two beds, one above and one below. Levels were then run down the gorge wall to obtain the elevation of the clay. The results are given in Figure 3 and in Table I. The position of the cuts is shown in Plate II, Figure 1, and in Plate V, Figure 4. The material in the cuts is variously illustrated in Plate VI. The layer of solid clay is 4 feet thick, but clay also

permeates the lower shingle and is only gradually replaced by the shingle above.

The lower shingle deposit reaches an elevation (764) precisely the same as that of the summit of the impounded spit beaches to the south. One need not hesitate to conclude that these ridges continue north beneath the bench and the Algonquin bar, as at first inferred, and that they crop out as the lower shingle deposit in the side of the gorge. Only the upper shingle, and perhaps only the upper part of it, is to be correlated with the highest Algonquin beach and the two-outlet stage of Lake Algonquin.

Interpretations

Any geologist may go to Sucker Creek and read on the ground the facts which have just been presented. Several matters, however, appear to complicate a full interpretation. Two rather different reconstructions may be visualized.

The history of Lake Algonquin as outlined on pages 479-480 calls for a shore line connecting with the Trent outlet, which was everywhere drowned or destroyed to the south by the two-outlet stage. The impounded beaches would seem at once to be a representative of this inferred shore line. The abundance of worn shingle in the features would imply that this early Trent stage was a long one, perhaps fully as long as the stage which formed the Algonquin beach, and would indicate that it was probably much greater than the Wyebridge, Penetang, and other lower Algonquin stages.

It is not difficult to picture the changes brought about at Sucker Creek by the climbing lake level which resulted from uplift of the Trent region. After construction of the westernmost impounded beach, or perhaps a later one, the mouth of the valley may have been graded up to the 764-foot level and a bar thus formed completely across it. As the lake rose, erosion and longshore currents supplied to this bar quantities of material from the neighboring sea cliffs, and the waves steadily heaped the bar to greater heights. The surf now spent its force on this feature, while films of clay were dropped in the quiet waters behind.

Some shoreward migration of the entire bar accompanied its upward building, and it gradually came to cover part of the clay which previously had been deposited in the protected waters behind it. The solitary shingle in Plate VI, Figure 3, was perhaps thrown far back from the limits of the bar by a storm wave, or may have been rafted over its present position by an ice cake. The diminishing mixture of clay with the shingle above the homogeneous clay layer (see Pl. VI, Fig. 4) is a condition which would naturally arise from the deposition of clay over and among additions of shingle to the submerged back slope of the bar. With the culmination of the lake at the two-outlet stage the summit of the Algonquin bar was completed, and continued uplift caused the waters to recede from this feature and form the series of lower beaches on its fore slope.

No doubt some might interpret the short spits in back of the two ends of the Algonquin bar as formed when the lake stood near the 800-foot level and before the long bar was ever stretched in front of them across the valley. The amassed evidence does not favor this view. That the short spits were developed by surf from the open lake, and not by the waters of the embayment to the rear, is to be inferred from their course and their parallel position with the great bar. Undoubtedly, at the culmination of the two-outlet stage, the ends of the great bar were submerged for some time and the surf which overrode them constructed the diminutive features behind.

It seems curious that the impounded beach spits were built into or up the valley of the embayment, whereas the highest Algonquin beach, at Sucker Creek, as generally elsewhere, formed as a bar directly across the mouth of the bay and shut it off from the rest of the lake. This contrast is probably attributable to some fundamental difference in the conditions of the two lake stages compared, though not enough is known of the earlier stage to enable one to say just what the difference is. Spits are built so as to hook into bays probably because the longshore currents (or surf zone) are unable to traverse the mouth of the bay, and waves or currents deflect the drifting material inward. It seems that great width or depth of the bay might naturally effect construction of hooked spits near the entrance, but that bars might be thrown across the entrance when narrow or shallow. The prevalence of bars enclosing deep embayments of Lakes Algonquin and Nipissing probably traces from the fact that the bars were first completed in shallow water and were then built to greater height as flooding proceeded.

The impounded spits at Sucker Creek suggest a dominance of northeast storms, but there is positive evidence that the Algonquin bar is a product of storms from both westerly and northeasterly quarters, since comparative elevations indicate that material was drifted across the bay in both directions. Theoretically, an absence of westerly storms might have induced the impounded spits to take the course they did.

If, in contrast to the gradual flooding which formed Algonquin and Nipissing bars, a lake was abruptly raised in level, as if by ice advance obstructing the outlet, then river valleys would be immediately and deeply drowned and storm waves could easily sweep into the resulting embayments. Such a condition might easily lead to the formation of hooked spits rather than bay-mouth bars. There is scarcely sufficient evidence to enable one to conclude that such a change in level occurred to develop the impounded spits at Sucker Creek, yet there are grounds for believing that the lake which formed them had previously been lower.

There is a certain uniformity in level of the lowest shingle or lake deposits, 740 feet at the base of the rubble wall,

shingle down to 741 or lower in the gravel pit, shingle mixed with clay at several points around 740 along the sides of the gully south of the pit and reaching a minimum level of 737 (PI. IV, Fig. 1). Extensive shingle deposits at 741 feet do not necessarily imply that the lake stood at or even close to this level when they were deposited. But to this depth at least the valley must have been cleared of such earlier glacial deposits as probably were left there. If Sucker Creek accomplished the degradation, Georgian Bay could have been scarcely higher in level, and therefore an early Algonquin stage may have existed at about the 740-745-foot level here. Probably at that time the stream followed much more closely the west side of the valley mouth than does the present creek. The shingle mixed with mud at *W* in Figure 2 (see also Pl. IV, Fig. 1) would appear to result from occasional pebbles being carried up the valley and lost among fine stream deposits.

Sucker Creek is just 20 miles south of the isobase through the Trent outlet at Fenelon Falls, where the Algonquin beach has an elevation of 870 feet. The average slope of the Algonquin (two-outlet) shore line in this distance is 3.6 feet per mile. An earlier water plane connecting the outlet with the 764-foot beach at Sucker Creek would have the steep slope of 5.3 feet per mile. If tilting alone raised the water from a possible 740-foot level at Sucker Creek to 800 feet, this hypothetical water plane was deformed to a slope of 6.5 feet per mile, but actual knowledge of the 740 stage is wanting. A second line might be taken to explain the change in lake level from the impounded Algonquin spits to the Algonquin bar. An unconformity (730) in the former sandy lake deposits at Jackson, Point in the Simcoe basin has been reported by Johnston.[6] The locality happens to fall on about the same isobase as Sucker Creek, for the Algonquin beach at both places lies close to 795 or 800 feet, and this should facilitate comparison.

Johnston interprets the barren sands below the unconformity as the product of an early stage of Lake Algonquin at least 50 feet below the two-outlet level at that place. The sands just above (730-735) contain shells identical with those in the highest Algonquin beach deposits near by. The low lake stage (740) which the writer has already suggested for Sucker Creek may well be the same as that which produced the unconformity at Jackson Point. It also seems possible, but less likely, that the 764-foot stage at Sucker Creek is rather to be so correlated with it. Johnston mentions no evidence of a stage near this level.

Johnston supposes, on account of the magnitude of rise at Jackson Point, so close to the Trent outlet, that the flooding could not have been due to uplift alone, but perhaps should be attributed to readvance of the ice. Glacial obstructing of the outlet might similarly be used to explain the rise to the 800-foot level at Sucker Creek, but it would militate against the method of Algonquin bar construction explained in the preceding pages; Taylor's theory of uplift instigating this change seems to the writer more probable.

OTHER FEATURES AND PROBLEMS

Varves

Typical varved clays were seen at numerous points along Sucker Creek. They are exposed in the bank of the creek, at points *X* and *Y* shown in Figure 2, at elevations of 698-702 feet; at several places along the gully south of the gravel pit and up to an elevation of 736, at point *W*; in little gullies in the east bank of Sucker Creek across from the spit beaches, at about 750; at point *L* in Figure 1, elevation 739-758; and at numerous other spots along Sucker Creek. In many places the varves are tilted, dipping 20, 30, or even 70 degrees over a distance of several yards, the reason for which is not understood (PI. IV, Fig. 2). Possibly some of the varves or laminated clays were deposited in the flooded valley at the Algonquin two-outlet stage, but it seems that most, if not all of them, are generally referable to a much earlier period, when the ice border was near. No counts were made, but if any of the varves are indeed of Algonquin age, they might furnish a good opportunity to read its duration. The varves are overlain at *L* by creek rubble, at *W* by shingly clay, and at *X* and *Y* by other deposits to be described.

Buried Peat Bed

Incised creek terraces (709) at points *X* and *Y* reveal sections like that illustrated in Plate IV, Figure 2, and in Figure 3 (insert). The former creek bed is indicated by the rubble overlying the varves, but this in turn is covered with a horizon of peat from which many sticks and logs protrude. A thick layer of muddy clay surmounts this and furnishes the surface of the terraces. The peat and the mud are obviously features of the post-Algonquin Sucker Creek. The extent and the thickness of the deposits render it unlikely that they have resulted from some recent landslide or winter damming of the gorge. They may represent a limited flooding of the creek at the Wyebridge stage of the lake, when perhaps slight tilting raised the outlet[7] farther north and caused the lake to drown Sucker Creek. Wyebridge beaches cover an interval of 705-718 feet near Cape Rich.[8] A terrace was noted by aneroid (at 709 feet) on the road up from Vail's Point and is shown on Figure 1. An aneroid reading was also taken on a wooded bench (700-705) just to the north of the lowest beach (762) noted on the west side of Sucker Creek, but the bench is not shown on the maps. It seems likely that the buried peat and the overlying mud exposed in the Sucker Creek terraces are contemporaries of all these Wyebridge shore features.

Miscellaneous Benches

From any high point a number of bouldery, undulating, and ancient-looking terraces at accordant levels may be seen extending for miles up Sucker Creek. They are represented at the spots marked 860 an. on Figure 2. They surely indicate a part played in the history of

Slicker Creek, but probably so early as to antedate all phases so far discussed. At 830 feet along the lower valley there are a few faintly suggested benches whose meaning is unknown. A distinct bench was found also at point E on Figure 1, elevation 846 feet, but no sure interpretation can be offered.

Problem between Sucker Creek and Mountain Lake

The presence of an abandoned valley connecting the basin of Mountain Lake with Sucker Creek valley offered prospects of explaining puzzling facts at both places. Investigation not only failed to yield a clear solution but resulted in a deeper puzzle well worth noting.

Mountain Lake was measured at 768.3 feet (water surf ace), but fluctuates seasonally. At about 772 feet a terrace and bluff, an ancient high-water mark, lie back of a narrow beach in many places. This bluff line was found to continue westward at a uniform elevation through the abandoned valley. The deep, broad valley is swampy and wooded near Mountain Lake, with a floor at 769 feet. Toward the southwest end it is cleared, seems slightly higher (770), and is shallowly incised by little tributaries to Sucker Creek, with their bottoms at 768.0-769.4 feet near point *G* on Figure 1, at 765.9 feet near *H* by the bridge. Water surface in the creek was measured at 740.0 feet at *L* and 753.3 at *K* (main branch of Sucker Creek). It is at 705 feet by the highway bridge a mile north. Mountain Lake would have to rise only two or three feet to drain into Sucker Creek; such drainage has occasionally occurred, according to the inhabitants. The writer noted in the woods at point *F* (769) a wooden raft which was probably stranded at such a stage. The old valley is much too great to have been made by this wayward backflowing of Mountain Lake. It was undoubtedly cut by Sucker Creek at some time when diverted from its present lower valley. The bottom of Mountain Lake slopes eastward, for it is said to be deepest at that end. The valley may have been first cut in preglacial times.

The Algonquin flooding of these valleys is witnessed by numerous deltas at 798-802 feet (*M*), by benches at 795 (*D*) and 800 (*E*), and by the fine red clay surface of the flats (775, 776, etc.) around *G*, *H*, and *J*. The clay meets the slopes of the surrounding hills rather sharply and actually seems to "drown" them. It extends down the entire valley of Sucker Creek and is the same kind of clay which covers the spit beaches and crops out in the gorge. A foot or so of it covers the uppermost shingle in the gravel pit, and forms the surface here (758), as is indicated in Figure 3. A buff-colored stony clay in the high banks overlooking point *X* on the east side of Sucker Creek is different, however, and, though very poorly exposed, is apparently a till deposit.

Why benches are so definitely registered at about 775 feet in the lower part of the Sucker Creek bay is not clear. This seems peculiar in view of the gradual succession of lower beaches formed on the outer slope of the Algonquin bar as the lake withdrew; and perhaps it is a coincidence that the bench along the abandoned valley and the high-water mark of Mountain Lake are at practically the same level. Apparently a close successor of this ponded stage (775) is a rubble terrace (770) of Sucker Creek cut into the higher clay flat (776) at *J*.

It is difficult to understand how the present drainage evolved as the Algonquin water withdrew from these valleys. Since the Algonquin bar (792) must have once extended unbroken across Sucker Creek valley, why, as the lake withdrew, did not the entire creek drain through Mountain Lake to the east? How did it come to dissect the Algonquin bar and to drain north? Certainly no gully could have worked headward on the north slope of the bar, and through it, so as to effect a capture. The beach material is too easily drained.

If the east end of Mountain Lake was once closed off up to the 792- or 800-foot level by a bar similar to that at Sucker Creek, there is no indication of it today. The beaches (797, 801, 804) found there make only a partial attempt at this, and there intervenes a broad gap of low ground 777 to 782 feet in elevation at points *A* and *B* (Fig. 1) which has certainly not been cut away by Mountain Lake creek. In fact, the lake at normal stage, as it was when observed by the writer, seeps eastward underground for a short distance and the water reappears in depressions east of the lake to continue as a creek. Mr. Carson says that it never did naturally overflow here, and overflows now only occasionally in high-water periods by a narrow logging chute which was cut through years ago. Downstream the creek is only a tiny one, its valley scarcely comparable to that of Sucker Creek. There is something curious about the irregular knolls and rolling ground near A and B which mystified the writer even before the drainage problem had appeared. They have no shape such as might have been imparted by waves, nor do they admit of creek formation or seem artificial. Their irregularity actually suggests some disturbance since the waves abandoned this level. One might conceive of an ice jam thrusting in here during the declining stage of Lake Algonquin and damming the east end of Mountain Lake valley so as to drive Sucker Creek to its present course, but this seems highly improbable because the beach lines do not appear to have been so mistreated anywhere else.

Perhaps the answer to the problem is one of solution. Percolating underground water could possibly have dissolved out limestone beds or lake rubble beneath *A* and *B* and have allowed the whole surface in the vicinity to cave or to settle irregularly. It would seem a phenomenal amount of solution work for so small a trickle of water. On the other hand, apart from these considerations and to judge only from the strength of the Algonquin bars elsewhere, it is a matter of wonder if the bar at 801 feet was never completely extended across this narrow valley.

There remains one final riddle. A narrow little trench (*C*-*C*) has been cut through the south end of the bar (801), with bottom elevation of 796.3 feet. It is just about the size that might be cut by an overflow from Mountain

Lake. How was this cut if the lake could freely drain east over the low ground farther north, or, barring this escape, find another lower exit over the bar (792) at Sucker Creek and four feet below the trench in question?

CONCLUSIONS

1. Fragmentary spit beaches of an early Algonquin lake stage have been preserved at Sucker Creek. They are "impounded" behind a strong Algonquin bar which truncates and partly covers them. They are superior examples of the type of "impounded beaches" which the writer has discovered elsewhere and previously described.

2. These early beaches would appear to bear out the former existence of a strong shore line associated with the Trent valley outlet of Lake Algonquin, previous to and lower than the principal Algonquin beach, just as was long ago inferred by Taylor and others. They are the first recorded bits of such a shore line.

3. This earlier water plane seems to have been tilted nearly 50 per cent more than the principal Algonquin plane.

4. There may possibly have been a still lower, more steeply tilted, previous water plane.

5. The impounded beaches afford evidence of a rise of Lake Algonquin somewhat similar to that found in the southern Simcoe Basin.

6. There is indication of an upward fluctuation or drowning of the lake for the Wyebridge (lower Algonquin) stage.

7. An abandoned valley and an unsolved drainage complex relate Mountain Lake to the valley of Sucker Creek.

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[1] Stanley, George M., "Lower Algonquin Beaches of Cape Rich, Georgian Bay," *Bull Geol. Soc. Am.*, 48: 1665-1686. 1937.

[2] Leverett, Frank, and Taylor, F. B., "The Pleistocene of Indiana and Michigan and the History of the Great Lakes," *U.S. Geol. Surv., Mon. 53*, pp. 328-332. 1915.

[3] Stanley, George M., "Lower Algonquin Beaches of Penetanguishene Peninsula," *Bull. Geol Soc. Am.*, 47: 1933-1960. 1936.

[4] Stanley, as cited in note 1.

[5] Stanley, as cited in notes 1 and 3. The term "impounded beach" was proposed in the paper referred to in note 1.

[6] Johnston, W. A., "The Trent Valley Outlet of Lake Algonquin and the Deformation of the Algonquin Waterplane in Lake Simcoe District, Ontario," *Geol. Surv. Can., Mus. Bull 23*, pp. 15-17. 1916.

[7] Stanley, p. 1958, as cited in note 3; p. 1684, as cited in note 1.

[8] Stanley, as cited in note 1.

STANLEY PLATE I

FIG. 1. Part of the great Algonquin bar (795) across Sucker Creek valley. The bench in the back slope is distinctly visible. The man is standing on the principal impounded beach spit (764). View north-northwest

FIG. 2. Beach shingle of the impounded spits; view at gravel pit (see the map shown in Fig. 2)

STANLEY PLATE II

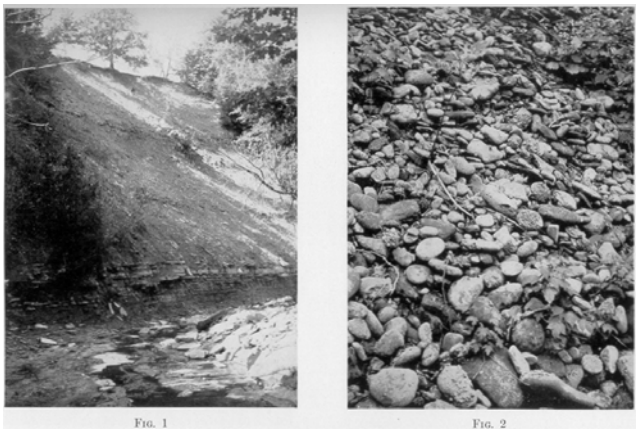


FIG. 1. Northwest view through Sucker Creek gorge. The tiny figure near the large tree at the top of the canyon is excavating in the clay layer. The line of the rubble wall may be seen below

FIG. 2. Talus of early Algonquin beach shingle on the west bank of Sucker Creek

STANLEY PLATE III

FIG. 1. Base (740) of the rubble wall, and recesses where the Paleozoic rocks have weathered out below

FIG. 2. Close-up of the rubble wall, showing the heavy cement moulds of detached pebbles

STANLEY PLATE IV

FIG. 1. West view of gully at point *W* on the map (Fig. 2), showing the shingly clay overlying varves. In some places the contact (737) is marked by a thin blue marl or clay

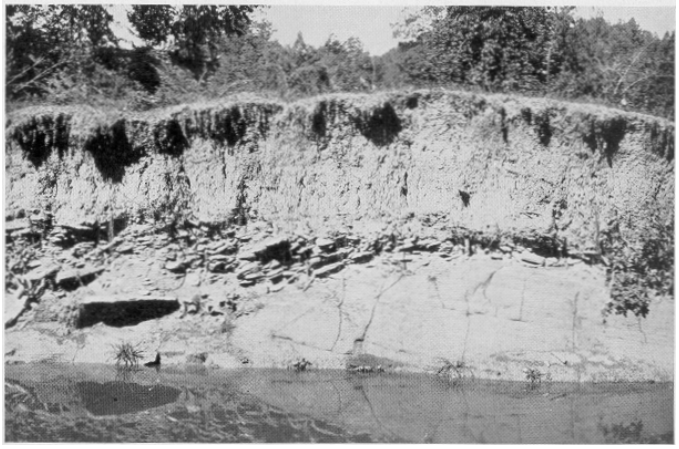
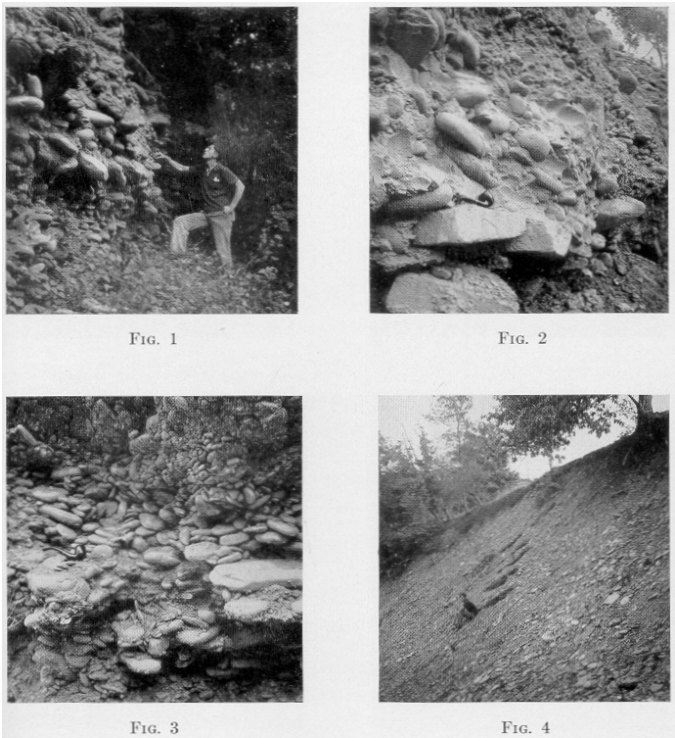


FIG. 2. Exposure of terrace on west side of Sucker Creek at point *Y* on the map (Fig. 2). The basal varves are tilted about 20 degrees. The overlying stream rubble consisting of early Algonquin shingle is covered by peat (702), sticks, and several feet of clay (see Fig. 3). The clay is apparently Wyebridge in age

STANLEY PLATE V



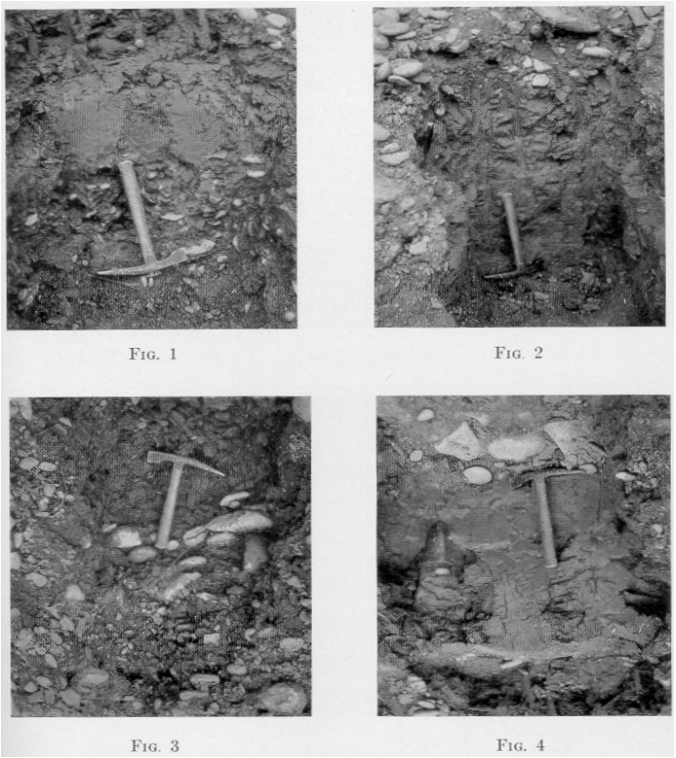
EARLY ALGONQUIN BEACH DEPOSITS

FIG. 1. The rubble wall

FIG. 2. Close-up view of the rubble wall; contact with Paleozoic rocks at the pipe, or a half foot below (739.8-740.3)

FIG. 3. Early Algonquin shingle in gravel pit. The extent of this thoroughly rounded material indicates a long stand of the lake

FIG. 4. South view of excavations in west wall of the gorge (761-770)



EXCAVATIONS IN ALGONQUIN CLAY

FIG. 1. Summit (764.2) of lower shingle, permeated with clay; cut VI

FIG. 2. Clay and lower limit (768.2) of upper shingle; cut IV

FIG. 3. Clay and summit of lower shingle (764.2) and solitary shingle pebble (765.0); cut V

FIG. 4. Lower limit (767.3) of upper shingle, which is thoroughly mixed with clay; cut II

AN OCCURRENCE OF NONWETTING SAND AT MUSKALLONGE LAKE, LUCE COUNTY, MICHIGAN

GLENN C. TAGUE

LOCATION

MUSKALLONGE LAKE is situated in northern Luce County, Michigan. It occupies most of Sections 1 and 2 and parts of Sections 11 and 12, T. 49 N., R. 11 W., and extends into Section 6, T. 49 N., R. 10 W. (Fig. 1). It is approximately two miles long and one mile wide (Fig. 2). Its northern shore is, on an average, one quarter of a mile from the southern shore of Lake Superior.

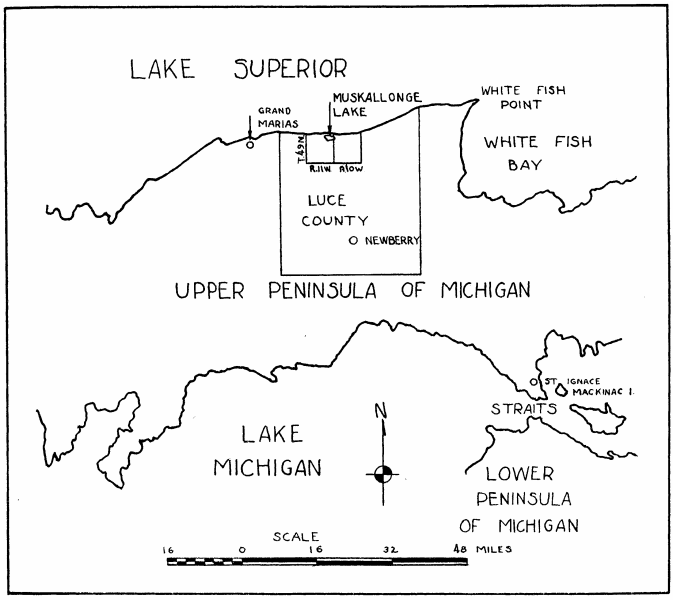


FIG. 1. Location of Muskallonge Lake

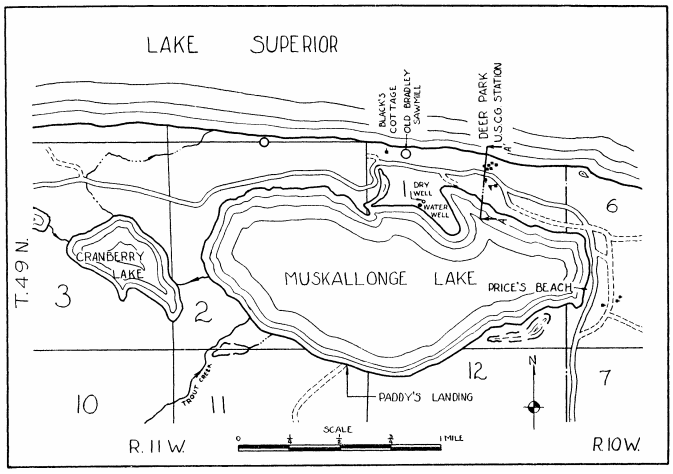


FIG. 2. Detailed map showing Muskallonge Lake and vicinity

PREVIOUS WORK

Until recent years little work has been done in this area. In 1911 Leverett[1] published a map of the surface geology of the Upper Peninsula of Michigan. According to Westerman,[2] no intensive studies of Muskallonge Lake have ever been made, although in 1925 Metzelaar and Langlois reported depths ranging from three to six meters. He notes, further, that the Land Economic Survey records the depths of Muskallonge Lake as ranging between ten and twenty feet, with an area of 760 acres. A study of the glacial features and glacial lake beaches within the area has recently been made by Bergquist,[3] who gives a detailed survey of the surface geology of Luce County.

Nipissing beaches separate Muskallonge Lake from Lake Superior, an indication that the former lake was a lagoon cut off from Lake Nipissing. Further, it is observed that Muskallonge Lake today stands at the approximate level of this old glacial lake.

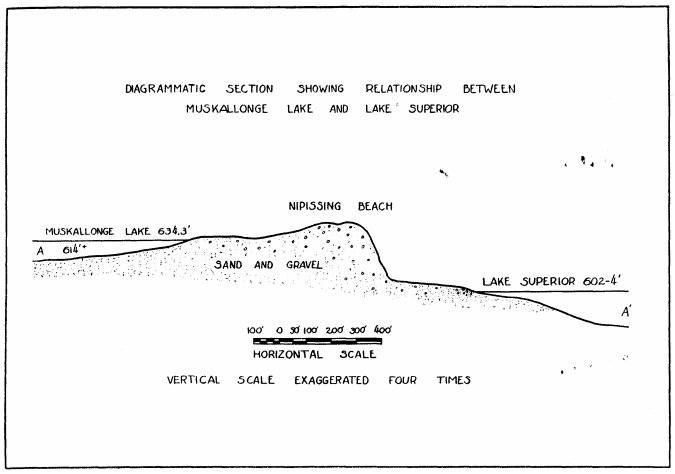


FIG. 3

LAKE SAND CHARACTERISTICS

During the summer of 1935, in connection with a road materials survey of the Lake Superior State Forest, it was noted that the sand in the immediate vicinity of Muskallonge Lake exhibited peculiar characteristics when subjected to immersion in water. These characteristics led to further investigations.

A series of levels shows a difference in elevation of 32.3 feet (Fig. 3) between this lake and Lake Superior. Although the lakes are only 610 feet apart at one place, and although the area between consists of sand and gravel, there is very little evidence of drainage by seepage.

Muskallonge Lake has one small outlet at its west end, which is swampy. This outlet drains into Cranberry Lake, which, in turn, empties into Lake Superior by means of an intermittent stream. During the periods of observation this outlet was dry.

Trout Creek, a spring-fed stream, enters Muskallonge Lake from the southwest. It seems improbable, if there is unrestricted seepage between Muskallonge and Lake Superior, that this small inflow could maintain the high water level observed in the lake during the summer of 1935 and again at the close of the summer of 1936. At Price's Beach, along the eastern end of the lake, the state highway from Newberry to Deer Park, which at this point passes within seventy feet of the shore, lies two feet below the level of the lake.

During the spring of 1935 an attempt was made to drive a well to supply the needs of a new state camp ground on the north shore of Muskallonge, in Section 1, T. 49 N., R. 11 W. The well was driven down approximately seventy feet from the shore, but the project was abandoned when water had not yet been encountered at a depth of fifty feet. Later, starting a few inches above the lake level, the Ground Water Survey "washed in" a well thirty feet from the shore. It was dry to a depth of ten feet. This well penetrated only sandy material, and no clay horizon was observed. These facts seem to indicate that the water of the lake does not readily penetrate the sand, and hence causes the water table to drop sharply a short distance away from the shore.

During logging operations in this area a large sawmill was in operation at Deer Park between Muskallonge Lake and Lake Superior. At that time pine logs were floated across Muskallonge, many of which went to the bottom as "deadheads." At the close of logging operations it was considered worth while to attempt to recover the sunken logs. In an effort to drain the lake a channel was dredged northward toward Lake Superior, a few feet east of the line between Sections 1 and 2. This project was stopped by the Government after the channel had been cut to within 610 feet of Lake Superior.

Sand along the beach of Muskallonge Lake displays the marked characteristic of resisting the penetration of water. A handful of dry sand can be held under water for several seconds; when removed, it is found dry on the inside, with a film of wet sand surrounding the dry core. On the other hand, sand along the shore of Lake Superior, a few hundred feet distant, fills with water instantly when submerged.

On calm days patches of sand may be observed floating on the surface of the lake at many places along the shore. Close observation indicates that such sand is unable to break the surface tension of the water.

LABORATORY ANALYSIS

Muskallonge sand, when poured through a funnel under water, takes on a peculiar ropelike appearance (Pl. I, Fig. 1) and remains in this condition for several minutes. Dry sand, when poured into a beaker of water, forms irregular masses (Pl. I, Figs. 2-3) of sand and air. When allowed to stand many of these masses rise to the surface and assume spherical form.

A brief microscopic examination indicates little difference in the mineral content and the grain size between

samples of the floating sand and the beach sand. Such study shows that the sand is made up principally of well-rounded quartz grains, some of which contain inclusions of zircon and rutile needles. Some grains were found to be coated with iron oxide. Small amounts of tourmaline, apatite, and altered feldspar were also identified.

Muskallonge Lake sand was (*a*) heated, (*b*) extracted with solvents, and (*c*) treated with inorganic acid in an effort to remove its impervious characteristic. The following results were obtained:

(*a*) Heating the sand to white heat for two hours caused it to lose its imperviousness to water.

A sample was boiled in water for thirty minutes under a reduced pressure of approximately 20 cm. of mercury without noticeable effect on its imperviousness.

Gas was driven off by heating the sand in a large, hard-glass test tube. Carbon dioxide was the only gas detected.

(*b*) Thorough washing of the sand with water failed to change its partial imperviousness to water. Much colloidal material was obtained in the wash water. This failed to settle out completely after a period of one week. The colloid failed to deposit even after two hours in the centrifuge.

A concentrated aqueous extract, made by boiling the sand with water, was tested for traces of tannic acid. Negative results were obtained.

A sample of the sand was boiled for one hour in carbon tetra-chloride, by means of a reflux condenser. When filtered and dried, the sand was found to have retained its imperviousness to water. The same procedure was followed with the solvents benzene and ether, arid like results were noted.

(*c*) Sand was boiled with three-molar hydrochloric acid for thirty minutes. When washed and dried, it was found to have lost part of its characteristic imperviousness to water. The filtrate contained iron and aluminum. Sand treated with hot concentrated sulphuric acid in the same manner shows a complete absence of the property and will wet instantaneously when immersed in water.

CONCLUSIONS

It seems probable that Muskallonge Lake retains its relatively high level above Lake Superior because of the somewhat impervious sand that surrounds and may lie beneath it, although only a short distance separates the two bodies of water. The exact cause of this unusual condition of the sand has not been fully determined. It has been established that treatment of the sand with hydrochloric acid partly removes this impervious characteristic, and an analysis of the acid extract shows the presence of iron and aluminum. Further, it has been demonstrated that heating the sand to a temperature of white heat or treatment with sulphuric acid will completely remove this imperviousness.

Further investigation is being undertaken. It is hoped that suggestions will be offered by readers and that similar conditions observed elsewhere will be called to the attention of the author.

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[1] Leverett, Frank, Map of the Surface Formations of the Northern Peninsula of Michigan, 1911.

[2] Westerman, F. A., personal communication.

[3] Bergquist, S. G., "Surface Geology of Luce County, Michigan," *Pap. Mich. Acad. Sci., Arts, and Letters,* 14 (1930): 437-452. 1931.

TAGUE PLATE I

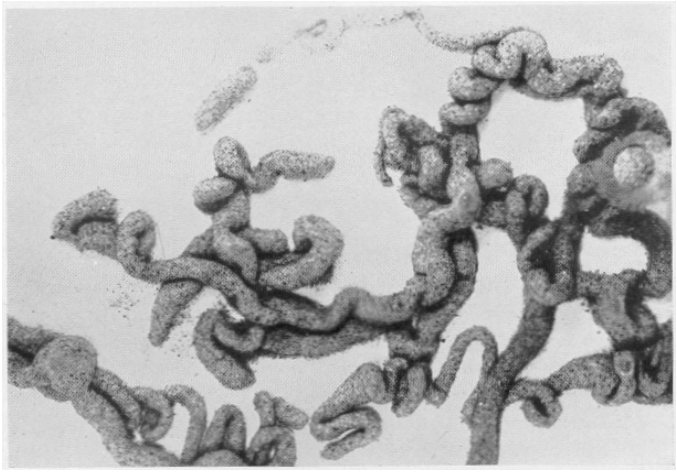

FIG. 1. Ropelike appearance of Muskallonge sand when placed under water through a tube. Note exposed sand on right

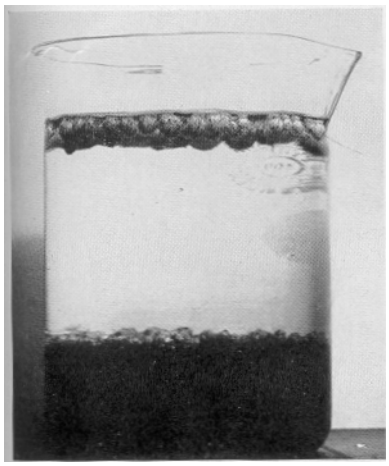

FIG. 2. Muskallonge sand immersed in water. Note globules of sand floating on surface. This appearance was retained for several weeks

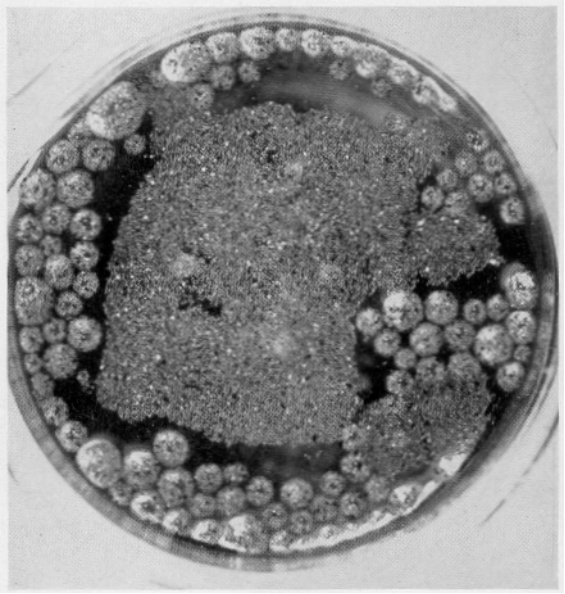

FIG. 3. Surface view of Figure 2

GEOLOGY IN RELATION TO PEDOLOGY

JETHRO OTTO VEATCH

THE geologist's conception of soil has been purely geological. The "kinds" of soil which he has recognized have been determined upon the basis of the origin of the parent material, and he has classified soil by using such terms as "residual," "transported," "alluvial," "eolian," "glacial," "cumulose," or simply according to the kind of rock or the geological formation which might happen to lie beneath it. However, there has been a very considerable divergence, beginning about 1880 in Russia and about 1914 in this country, from this purely geologic concept; and a new science, pedology, has come into being. The pedologist regards soil as a function of: (1) parent material, inorganic or organic; (2) climate; (3) relief and moisture conditions related thereto; and (4) age, or completeness of soil-profile development. The work of the pedologist really begins where that of the geologist leaves off. The pedologist is primarily concerned with what has happened to very recent geologic formations after their deposition and appearance as new land surfaces; and to the residue of rock weathering, or regolith, after its formation on very old land surfaces. He is concerned with the changes effected by elements of climate and by biological forces acting upon the inert or passive parent material. In working out the classification, or taxonomy, he prefers to employ the intrinsic characteristics of the soil itself, rather than causative or environmental factors.

This brief introduction is presented for the purpose of harmonizing the viewpoints of the geologist and the pedologist and making the position of the writer more understandable in the following .discussion. The geologist, if not always contributing directly to soil science, supplies foundational knowledge which is necessary for a full explanation of the phenomena of the soil profile and for the differentiation of land into natural divisions upon the basis of combinations of topographic and soil components.

This paper is mainly concerned with Michigan. In reading the publications of the Geological Survey of Michigan it is doubtful whether a single description of a soil profile will be found. This is not to be wondered at, since the conception of the soil profile is of very recent date, even among soil scientists. However, there are numerous references in the publications to the texture and the lithologic composition of the glacial deposits, and inferentially the soil, and to drainage and topography in relation to agriculture and land use. Several instances of relationships between native vegetation and geologic formations are found, and the classic description of the peat deposits of the state by C. A. Davis ("Peat," *Geol. Surv. Mich., Ann. Report for 1906*, pp. 93-361) will be admitted as basic information for the classification of organic soils. Publication 25 (Geol. Ser. 21) of the Geological Survey, *Surface Geology and Agricultural Conditions of Michigan*, by Frank Leverett, has contributed perhaps a greater amount of geological information bearing upon soils and land-type classification than any other single publication.

The chief interest of the pedologist lies in the glacial formations of the state, since these constitute the parent material of most of the soil and also the landforms which must be considered in making a land-type map. The pedologist, however, will not agree that a geologic map of glacial formations is *per se* a soil map. The surface veneer which has resulted from soil-forming processes constitutes the soil proper. The changes due to weathering, which are so important to the pedologist, probably are more extensive than geologists realize. Mature soil profiles are common throughout the state, which implies that marked physical and chemical alterations have taken place in the drift deposits. The processes which make the soil under any particular climate and moisture condition are: (1) accumulation of organic matter on the surface and, concomitantly, soil fauna and flora; (2) leaching and downward movement of soluble matter, formation and translocation of colloids; and (3) the action of water runoff, wind, frost, root penetration, and burrowing animals. The changes from the original character of the drift deposits in Michigan are not great when measured by the thickness of the separate horizons, or members of the soil profile, but nevertheless are sufficient to effect differences in the growth of plants and the agricultural use of land. In general, leaching, the removal of carbonates, and the formation of a B horizon have taken place to depths of 3 to 5 feet, and beneath the B the parent material exhibits in extreme instances some alteration by surficial weathering to depths of 12 to 15 feet. The highly podsolized horizons may vary from clean harsh sand to pulverulent or faintly laminated compact silt. The silt of a soil profile may be mistaken for a thin deposit of loess, and the whole soil profile and the weathered C horizon mistaken for a deposit belonging to a later stage of

glaciation than the unweathered till underlying. It should be noted, however, that not all the area of the state exhibits a complete mature or climax soil profile, since perhaps more than a third is occupied by geological soils or those which exhibit only incipient profiles.

FIG. 1

Logically, according to the concepts of rock weathering and soil formation held by the geologist, there should be a close relation between soils and the surface formations of glacial origin. The pedologist will agree that a relationship does exist, but will argue that the relationship to glacial features, such as moraines, till plains, and outwash plains, is local and, therefore, not predictable unless other factors, such as the lithologic character of the glacial deposit, the age of the land surface, the details of relief or topography, the climate, and the vegetal cover, are known. The facts which the geologist has supplied regarding the origin of landforms, the age of land surfaces, and the thickness of drift deposits are, of course, basic knowledge which the pedologist should have in order to account fully for the phenomena of the soil profile and the distribution of his soil and land types.

The lithologic composition of the surface deposits, in particular, has a very direct value in the differentiation and the mapping of the soils. Some broad relationships between soils and the lithologic character of the drift may be easily discerned from the accompanying sketch map of the state (Fig. 1).

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