DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D.WALCOTT, DIRECTOR

## GEOLOGIC ATLAS

OF THE

## UNIT'E'D STAS'ES

## ANN ARBOR FOLIO

MICHIGAN

descriptive text
areal geology map
descriptive text
topographic map

# UNV STATE <br> GEOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES. 

The Geological Survey is making a geologic map of the United States, which is being issued in parts, alled folics. Each folio includes a topographi together with explanatory and descriptive texts.

THE TOPOGRAPHIC MAP
The features represented on the topographic map are of three distinct kinds: (1) inequalities of sur face, called rehef, as plains, plateaus, valleys, hill and mountains; (2) distribution of water, calle drainage, as streams, lakes, and swamps; (3) the works of man, called culture, as roads, railroad, oundaries, villages, and cities.
Relief.-All elevations are measured from mean tea level. The heights of many points are accu rately determined, and those which are most mportant are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the outline or for or all slopes, and to lines of hrol lation evel, the altitudinal 'interval represented by the el, between lines being the 1 byto each map. These lines are called contours, and the niform altitudinal space between each two contours is called the contour interval. Contours and elevations are printed in brown.
The manner in which contou
orm, and grade is shown in the following sketch and corresponding contour matp (fig. 1).

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The sketch represents a river valley between two hills. In the foreground is the sea, with a bay which is partly closed by a hooked sand bar. On each side of the valley is a terrace. From the
terrace on the right a hill rises gradually, while from that on the left the ground ascends steeply, forming a precipice. Contrasted with this precipice orming a precipice. Contrasted with this precipice the map each of these features is indicated, directly beneath its position in the sketch, by contours. The following explanation may make clearer the manner in which contours delineate elevation form, and grade:

1. A contour indicates a certain height above 50 feets this illustration the contour interval is 50 feet; therefore the contours are drawn at 50 , 100,150 , and 200 feet, and so on, above mean sea ovel. Along the contour at 250 feet lie all points he contour at 200 feet, all points that are 200 feet above sea; and so on. In the space between any two contours are found elevations above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, while that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above sea. The summit of the higher hill is stated to be 670 feet above sea; accordingly the contour at boo feet sur ounds it. In this frem are numbered, and those for 250 and 500 feet are ccentuated by being made heavier. Ustanly then the accentuating and numbering of certain them-say every fifth one-suffice for the heights of others may be ascertained by counting up or down from a numbered contour.
noothly are continuous horizontal lines, they wind noothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing
about prominences. These relations of contour curves and angles to forms of the landscape can be raced in the map and sketch.
2. Contours show the approximate grade of any lope. The altitudinal space between two contou is the same, whether they lie along a cliff or on a gentle slope; but to rise a given height on a gentle slope one must go farther than on a steep slope, and herefore contours are far apart on gentle slopes and near together on steep ones
For a flat or gently undulating country a small contour interval is used; for a steep or mountainous country a large interval is necessary. The smallest interval used on the atlas sheets of the regions like the Mississippi delta and the Dismar wamp. In mapping g.al 250 , or i liste rlif contour intervals of 10,20 , 5,50 , and 100 feet are used
Drainage.-Watercourses are indicated by bl drawn unbroken, but if the entire year the line of the year the line is broken or dotted. Where tream sinks and reappears at the surface, the sup posed underground course is shown by a broken lue line. Lakes, marshes, and other bodies of vater are also shown in blue, by appropriate co ventional signs.
Culture.-The works of man, such as roads, railoads, and towns, together with boundaries of townships, counties, and states, are printed in black. Scales.-The area of the United States (excluding Alaska and island possessions) is about $3,025,000$ square miles. A map representing this area, draw to the scale of 1 mile to the inch, would cover $3,025,000$ square inches of paper, and to accommodate the map the paper would need to measure
about 240 by 180 feet. Each square mile of ground about 240 by 180 feet. Each square mile of ground
surface would be represented by a square inch surface would be represented by a square inch of
map surface, and one linear mile on the ground map surface, and one linear mile on the ge map.
would be represented by a linear inch on the This relation between distance in nature and corresponding distance on the map is called the scals The scale. may be cexpressed also thy a fraetio, The scale may be expressa also by action of which the numerator is a length on the ma and the denominar the correspong leng is there are 63 exp inches in a mile, the scale " 1 mile to an inch" is expressed by $\frac{1}{6,530}$.
a inch" is expressed by $\frac{1}{6,5350}$.
Three scales are used on the atlas sheets of the Geological Survey; the smallest is $\frac{1}{250.000}$, the intermediate $\frac{1}{150,000}$, and the largest $\frac{1}{6.5050}$. These correspond approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the cale $\frac{1}{c^{2} \text { min }}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale
 about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three waysby a graduated line representing miles and parts of miles in English inches, by a similar line indicating di
fraction.
Atlas sheets and quadrangles.-The map is being published in atlas sheets of convenient size, which represent areas bounded by parallels and meridians. These areas are called quadrangles. Each sheet on the scale of sanan contains one square degree -i. e., a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{\text { is,w, con }}$ contains one-fourth of a square degree; each sheet on the scale of $\frac{1}{\text { taskub }}$ contains one-sixteenth of a square degree. .he ares of the corresponding quadrangla
1000 , and 250 square miles.
and sheets, being only parts of one ma line United States, disregard political boundar hips. To and to the quadrangle it represents is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet the names of adjacent sheets, if published, are printed.
Uses of the topographic map.- On the topographic of the quadrangle represented. It should portray
ot the observer every characteristic feature of the landscape. It should guide the traveler; serve he investor or owner who desires to ascertain the position and surroundings of property; save the nailways, prelminary surveys in locating ditchs, provide educational material for schools and homes and be useful as a map for local reference.

## THE GEOLOGIC MAPS.

The maps representing the geology show, by colors and conventional signs printed on the topo graphic base map, the distribution of rock masse on the surface of the land, and the structure sections show their underground relations, as far
known and in such detail as the scale permits.
kINDS of Rocks
Rocks are of many kinds. On the geologic ma hey are distingu Inco
Igneous rocks.-These are rocks which have throm a state of fusio rom time to time been forced material ha fissures or channels of various shapes and sizes to or nearly to the surface. Rocks formed by the consolidation of the molten mass within these channels--that is, below the surface-are called intrusive. When the rock occupies a fissure with approximately parallel walls the mass is called a dike; when it fills a large and irregular conduit the mass is termed a stock. When the conduits for molten magmas traverse stratified rocks they often send off branches parallel to the bedding planes he rock masses filling such fissures are called sills or sheets when comparatively thin, and laccoliths when occupying larger chambers produced by the force propelling the magmas upward. Within rock inclosures molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. When the channels reach the surface the molten material poured out through them is called lava, and lavas often build up volcanic mountains. Igneous rocks thus formed upon the surface are called earnaive. Lavas cool rapidy in the air, and acquire a glassy or, more often, a pac

 mons. The less por Explons are usu, panies voleanio eruptions cancing eections of duash and lare fragments. These materials whe consolidated, constitute breccias, arglomerates, and tuffs. Volcanic ejecta may fall in bodies of water or may be carried into lakes or seas and form edimentary rocks.
Sedimentary rocks.-These rocks are compose of the materials of older rocks which have be broken up and the fragments of which have been arried to a different place and deposited.
The chief agent of transportation of rock débris is water in motion, including rain, streams, and the in larg lakes and of the sea. The materials are deposit part carried as solid particles, and the are gravel, then said to be mechanical. Such dated into sand, and clay, which are later consolismaller portion the materials are carried in solu smaller portion the materials are carried in solu-
tion, and the deposits are then called organic if formed with the aid of life, or chemical if formed without the aid of life. The more important rocks of chemical and organic origin are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the deposits may be separately formed, or the different materias may be intermingled many ways, producing a great variety of rocks. And; and liod . The mot charactistic of the wind-borne or eolis deposits is loess, a fine-prained euth; the most char deposits is loess, a che ite charmixture of bowlders and pebbles with clay or sand Sedimentary rocks are usually made up of layen or beds which can be easily separated. These layers are called strata. Rocks deposited in layers are said to be stratified.
The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks, with reference to the sea, over wide expanses; and as it rises or
ubsides the shore lines of the ocean are chat ged. As a result of the rising of the surface, marine sedimentary rocks may become part of the land, and ocks.
Rocks exposed at the surface of the land are acted upon by air, water, ice, animals, and plants. They are gradually broken into fragments, and the more soluble parts are leached out, leaving the less soluble as a residual layer. Water washes residual mateial down the slopes, and it is eventually carried by rivers to the ocean or other bodies of standing water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it is called alluvium. Alluvial deposits, glacial deposits (collectively known as drift), and eolian deposits belong to the surficial class, and the residual layer is commonly included with them. Their upper par, whor plans, constine soins and subsols, he solls being organic matter. $\quad$.
Metamorphic rocks.-In the course of time, and by a variety of processes, rocks may become greatly changed in composition and in texture. When the newly acquired characteristics are more pronounced than the old ones such rocks are called metamorphic. In the process of metamorphism he substances of which a rock is composed may enter into new combinations, certain substances nay be lost, or new substances may be added. There is often a complete gradation from the priary to the metamorphic form within a single quartzite, limeston into marble, and modify other rocks in various ways.
From time to time in geologic history incous and sedimentary rocks have been deeply buried and later have been raised to the surface. In this process, through the agencies of pressure, movement, and chemical action, their original structure may be entirely lost and new structures appear. Often there is developed a system of division planes along which the rocks split easily, and these planes may cross the strata at any angle. This structure called cleavage. Sometimes crystals of mica or other foliaceous minerals are developed with their laminæ approximately paralle, in such cases the structure is
schistosity.
As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are important exceptions.

## formations

For purposes of geologic mapping rocks of all the kinds above described are divided into formahons. A sedimentary formation contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as, for example, a rapid alternation of shale and limestone. When the passage from one nod of rocks to another is gradual it is sometimes necessary to separate twq contiguous formations by dependrary line, and in some cases the distinction An ins almost entirely on the contained fossis. ane formation is constituted of one or more bodies either containing the same kind of igneous netamorphic formation may consist of rock of uniform character or of seeveral rocks having commion haracteristics
When for scientific or economic reasons it is desirable to recognize and map one or more specially : developed parts of a varied formation, such parts are called members, or by some other appropriate term, as lentils.

## hges of rocks.

Geologic time.-The time during which the rocks were made is divided into several periods. Smaller time divisions are called epochs, and still smaller ones stages. The age of a rock is expressed by naming the time interval in which it was formed, hen known!
The sedimentary formations deposited during a period are grouped together into a system. The Any aggregate of formations less than a series is called a group.

As sedimentary deposits or strata accumulate the younger rest on those that are older, and the rela-
tive ages of the deposits may be determined by tive ages of the deposits may be determined by except in regions of intense disturbance; in regions sometimes the beds have been reversed, and it is often difficult to determine their relative ares from their positions; then fossils, or the remains and imprints of plants and animals, indicate which of two or more formations is the oldest.
Stratified rocks often contain the
imprints of plants and animals which, at the time the strata were deposited, lived in the sea or were washed from the land into lakes or seas, or were buried in surficial deposits on the land. Such rocks are called fossiliferous. By studying fossils it has been found that the life of each period of the earth's history was to a great extent different from that of other periods. Only the simpler kinds of marine life existed when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived peculiar forms, which did not exist in earlier times and have not existed since; these are characteristic types, and they define the age of any bed of rock in which they are found. Onher types passed on from period to period, and thus linked the systems together, forso a chain of from the time of the oldest fors other and it is impossible to observe their relative positions, the characteristic fossil types found in porm may determine which was deposited first. Fossil remains found in the strata of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.
It is often difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can sometimes be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it.
Similarly, the time at which metamorphic rocks were formed from the original masses is sometimes shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not of their metamorphism.
Colors and patterns.-Each formation is shown on the map by a distinctive combination of color and pattern, and is labeled by a special letter symbol.


Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea or in lakes. Patterns of dots and circles represent alluvial, glacial, and colian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure
planes. Suitable combination patterns are used for metamorphic formations

## Thery or of igneous origi

The patterns of each class are printed in various are used to indicate age, a particular color colors assigned to each system. The symbols by which formations are labeled consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters. The names of the systems and recognized series, in proper order (from new to old), with the color and symbol assigned to each system, are given in the preceding table.

## surface forms.

Hills and valleys and all other surface forms have een produced by geologic processes. For example, most valleys are the result of erosion by the streams that flow through them (see fig. 1), and the alluvial plains bordering many streams were built up by
the streams; sea cliffs are made by the eroding the streams; sea cliffs are made by the eroding action of waves, and sand spits are built up by waves. Topographic forms thus constitute part of the record of the history of the earth.
. Some forms are produced in the making of deposits and are inseparably connected with them. The hooked spit, shown in fig. 1, is an illustration. To this class belong beaches, alluvial plains, lava of till) and (sworane (ridges of drift made the edges of placiers) Other forms are producel by edges of glaciers). Other forms are prodaced by of the associated material. The sea cliff is an illustration; it may be curved from any To this class belong abandoned river channels, olacial furrows, and peneplains. In the making
glass glacial furrows, and peneplains. In the making
of a stream terrace an alluvial plain is first built and afterwards partly eroded away. The shaping of a marine or lacustrine plain, is usually a double process, hills being worn away (degraded) and valleys being filled up (aggraded).
All parts of the land surface are subject to the action of air, water, and ice, which slowly wear them down, and streams carry the waste material to the sea. As the process depends on the flow of water to the sea, it can not be carried below sea level, and the sea is therefore called the base-level of erosion. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the even surface thus produced is. called a peneplain. If the tract is afterwards uplifted the peneplain at the top is a record of the former relation of the tract to sea level
the various geologic sheets.
Areal geology map.-This map shows the areas occupied by the various formations. On the margin is a legend, which is the key to the map. To ascertain the meaning of any colored pattern and
its letter symbol the reader should look for that its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he mation. If it is desired to find any given formmation. If it is desired to find any given formaits color and pattern noted, when the areas on the map corresponding in color and pattern may be map corres
traced out.
The legend is also a partial statement of the geologic history. In it the formations are arranged in columnar form, grouped primarily according to in columnar form, grouped primarily according to
origin-sedimentary, igneous, and crystalline of unknown origin-and within each group they are placed in the order of age, so far as known, the youngest at the top.
Economic geology map.-This map represents the distribution of useful minerals and rocks, showing their relations to the topographic features and to the geologic formations. The formations which appear on the areal geology map are usually shown on this map by fainter color patterns. The areal geology, thus printed, affords a subdued back-
ground upon which the areas of productive formations may be emphasized by strong colors. A mine symbol is printed at each mine or quarry, accompanied by the name of the principal mineral mined or stone quarried. For regions where there are important mining industries or where artesian basins exist special maps are prepared, to shov these additional economic features.

Structure-section sheet.-This sheet exhibits the relations of the formations beneath the surface. In cliffs, canyons, shafts, and other natural and artificial cuttings, the relations of different beds to one nother may be seen. Any cutting which exhibits those relations is called a section, and the same term is applied to a diagram representing the relations. The arrangement of rocks in the earth is the earth's structure, and a section exhibiting this arrangement is called a structure section.
The geologist is not limited, however, to the natural and artificial cuttings for his information concerning the earth's structure. Knowing the out the relations among the beds on the surface, he can infer their relative positions after they pass beneath the surface, and can draw sections representing the structure of the earth to a considerable depth. Such a section exhibits what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

ing a vertical seetio
landscape beyond.
The figure represents a landscape which is cut off sharply in the foreground on a vertical plane, so as to show the underground relations of the rocks. The kinds of rock are indicated by appropriate symbols of lines, dots, and dashes. Thes are generally used in sections to represent the commoner kinds of rock:


Schists


## Fig. 3.-Symb

 of rocks.The plateau in fig. 2 presents toward the lowe land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes, as shown at the extreme left of the section. The broad belt of lower land is trav ersed by several ridges, which are seen in the sec tion to correspond to the outcrops of a bed of sand of this bed form the surface. The upherediate valleys follow the outcrops of limestone and calcareous shale.
Where the edges of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred. The direction that the intersection of a bed with a horizontal plane will take is called the strike. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the dip.
Strata are frequently curved in troughs and arches, such as are seen in fig. 2. The arches are called anticlines and the troughs synclines. But the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets; that they are now bent and folded is proof that forces have from time to time caused the earth's surface to are broken across and the parts have slipped past are broken across and the parts have slipped past
each other. Such breaks are termed faults. Two each other. Such oreaks are terme
kinds of faults are shown in fig. 4.

On the right of the sketch, fig. 2, the section is mposed of schists which are trayersed by masses and the
 and (b) a thrust fault.
inferred. Hence that portion of the section delineates what is probably true but is not known by observation or well-founded inference.
The section in fig. 2 shows three sets of formations, distinguished by their underground relations. The uppermost of these, seen at the left of the section, is a set of sandstones and shales, which lie in a horizontal position. These sedimentary strat are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has been raised from a lower to a higher level. The strata of this set are parallel, a relation which is called conformable. The second set of formations consists of strata which form arches and troughs. These strata were once continuous, but the crests of the arches have been removed by degradation. The beds, lik those of the first set, are conformable
the horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set at the left of the section. The overlying
deposits are, from their positions, evidently younger deposits are, from their positions, evidently younger
than the underlying formations, and the bending than the underying formations, and the bending and degradation of the older strata must have and the accumulation of the younger. When and the accumulation of the younger. When of older rocks the relation between the two an uncon formable one, and their surface of contact is an unconformity.
The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were plicated by pressure and traversed by eruptions of molten rock. But the pressure and intrusion of igneous rocks have no affected the overlying strata of the second set Thus it is evident that a considerable interval elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists suffered metamorphism; they were the scene of eruptive activity; and they were deeply eroded. The contact between the second and third sets is another unconformity; it marks a time interval between two periods of rock formation.
The section and landscape in fig. 2 are ideal, but they illustrate relations which actually occur. The sections on the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profile of the surface in the
 ge surface ony inal and drom he surface of any mineral-producing or waterbe measured by using the scale of the map.
Columnar section sheet.-This sheet contains a
concise description of the sedimentary formations which occur in the quadrangle. It ppresents which occur in the quadrangle. It presents a
summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits. The rocks are briefly described, and their characters are indicated in the columnar diagram The thicknesses of formations are given in figure which state the least and greatest measurements, and the average thickness of each is shown in the column, which is drawn to a scale-usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangementthe oldest formation at the bottom, the youngest at the top.

The intervals of time which correspond to events of uplift and degradation and constitute interrup tions of deposition are indicated graphically and by the word "unconformity."

## CHARLES D. WALCOTT,

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# DESCRIPTION OF THE ANN ARBOR QUADRANGLE. 

GEOGRAPHY.

## civic relations.

The Ann Arbor quadrangle, embracing an are 884.85 square miles, is in the southeastern par of the Southern Peninsula of Michigan, the city of Ann Arbor being near its geographic center. It is bounded by parallels $42^{\circ}$ and $42^{\circ} 30^{\prime}$ north latind comprises a large part of Washtenaw County nd small adjacent portions of Livingston, Oakland, Wayne, Monroe, and Lenawee counties
The first settlement within this quadrangle was made in 1809 by French traders, who established a post on the site of the present city of Ypsilanti, wide extent of country intersected. In 1811 about 2500 acres were patented to these traders in accordance with an act of Congress, and the survey of these claims antedated the rectangular land sur ey begun in 1816, a fact that accounts for pecularities of boundary lines and absence of section lines in Ypsilanti and the district immediately south and west of that city. By the treaties of 1819 and 1821 all the lands in this region were thrown open to settlement, and in 1823 a number English-speaking families built houses on the banks of the Huron immediately below Y psilanti During the Wilthin this quangle started ow two cities Ann Arbor and Ypilonti, and now two cities, Ann Arbor and Ypsilanti, and Dexter, Saline, Milan, Clinton, and Tecumseh. In ddition these there are 40 smaller villages and hamlets.
According to the census of 1900 the quadrangle ad then a population of about 57,000 , of which 4,509 were in Ann Arbor and 7378 in Ypsilanti, hile the seven incorporated villages comprised opulation of 7220 , leaving nearly half the inhabtants in the rural districts and in villages and hamlets not separately enumerated.
The cities and nearly all the villages are on the banks of streams. These streams are not navigable, but the location of the early settlements on them was determined by the water power they afforded for gristmills and sawmills-power which has been tilized later for other manufacturing establishments. Within the past few years the scenic e northern part of the quadrangle have become factors in peopling that region.
topography.
general statement.
The topography of the present surface is strikingly different from that of the surface of the bed rock. It is the product of glacial deposition, repeated several times, supplemented to a slight degree by the action of lakes, streams, and the wind. The latest and perhaps some of the earlier glaciation resulted from a westward movement of ice from the basin of Lake Erie and the southern end of Lake Huron. This glacial mass covered the entire quadrangle except its extreme northwestern corner, which was occupied by ice moving southward from the Saginaw basin. These two ice lobes are known as the Huron-Erie and the Sag inaw lobes. The glacial deposits produced by them are very thick and are so massed that even the salient features of the underlying preglacia surface are completely concealed.

Relief.
Conspicuous features.-The glacial features that give variety to the surface-such as moraines, *The general geology, mineral waters, and mart deposite
are described by I. C. Rassell; the topography and drainage Quaternary geology, and water resources by Frank Lreverett,
the epat deposits by Charles A. Davis; the Paleozoie history the peat deposits by Charles A. Davis; the Paleozoic history
by E. M. Kindle. The Michigan State Geological Survey has by E. M. Kindle. The Michigan State Geological Sorvey has
freely given its records and assistance, which have been o
kames, eskers, outwash aprons, basins, till plains gravel plains-are noted and described in the diston is her gral geology, and thereore athe onographic belts. These belts strongly marked prom east to west (1) the lake plain; (2) the morainic system on the western porn, (2) the lake plain; (3) the intermorainic strips with nearly plane surfaces; (4) the interlobate moraine, with its included gravel plains, lying between the Saginaw and Huron-Erie ice lobes
The lake plain.-'T
outheastern part of the quadrangle. It extends far northwest as the 800 -foot contour, which follows approximately the highest beach of a large glacial lake, discussed below. This plain occupies parts of several counties in southeastern Michigan and a still larger area in northwestern Ohio, bordering Lake Erie, to ward which it gradually slopes. The sandy portion of its bed is characterized by low dunes, 5 to 20 feet high, but the clayey portion is remarkably smooth. Beaches occur at various
levels, their altitudes corresponding to those of sevevels, their altitudes corresponding to those of sevral outlets opened for the discharge of the lakes by the withdrawal of the ice sheet. Although ing a height of more than 15 feet, yet their form ing a height of more than 15 feet, yet their form
and continuity attract attention, and from the earliand cons of settlement they have been recognized as old lake shores. These beaches were mapped in part by the First Geological Survey of Miehigan,
prior to 1840.
Morainic ri
plain lies a system.-Immediately back of the lake plain lies a system of morainic ridges running from rangle and occupying a belt 8 to 12 miles wide. Valley-like depressions between the ridges serve as onvenient courses for streams, which have in consequence assumed a trellis-like arrangement.
Three more or less distinct moraines appear in his system, of which the westernmost is far more prominent than the others. This moraine includes the highest points within the quadrangle, one exceeding and several approaching 1100 feet in altitude-indeed, much of the land that stands above 1000 feet. In the southwestern part of the uadrangle this high moraine constitutes the divide between the tributaries of the Huron and the Raisin,
while in the northeastern part it separates the waters of the in northeastern part it separates the waters and Raisin find passase southeastward through deep raps in this ridge and farther along in their course pass through similar aps in the lower ridges to pass through similar gaps in the lower ridges, to to Lake Erie. The most prevalent type of morainic topography in this system is the swell and sag in which there is a gradual rise from sag to swell and very little sharp undulation. At certain points, however, there are knobs and basins with steep slopes. Most of the sharpest knobs are gravelly hills known as kames.
The intermorainic strip.-Outside the belt of moraines just described, in the interval between it and the interlobate system of moraines and grave plains, lies a long area that is rather difficult to describe because of the great variety of its features. Parts of it are flat surfaced, or nearly free from knolls or ridges, while other parts present sharp undulations, as strongly marked as the knolls. and ridges of the moraines though not so systematically related. This area contains also a
large number of marshy depressions, which large number of marshy depressions, which break they lie Some of these are one-fourth to whalf mile wide and several miles long and many of them lie in the courses of streass and form parts of river systems. A chain of gravel ridges known as the Lystems. A chain of gravel ridges known as the The topography of this district apparently owes its The topography of this district apparently owes its
irregurity to variations in rate of deposition and in drainage at the margin of the Huron-Erie ice lobe during its recession from the interlobate
moraine to the first well-defined moraine southeast of it. In addition to the features mentioned, his district is traversed by several lines of glacial bate belt. These are much broard into the interlosions just noted being in some plas mor mile wide, and are flled with flaterfaced of sand and gravel left by the streams that formed them.
The
The interlobate moraine and included gravel plains.-A conspicuous system of moraines appears in the northwestern part of the quadrangle, north of a line from South Lyon, passing Whitmore Lake, to Fourmile Lake. The surface of this morainic system is much more irregular than that of the system just considered, sharp knolls 100 to 200 feet in height being here closely associated with basins, some of which, now occupied by lakes, exceed 100 feet in depth. This morainic system is traversed by sandy plains that mark lines of
glacial drainage and with its included lakes and glacial drainage and with its included lakes and streams it forms part of a great interlobate tract
developed along the junction of the Saginaw and developed along the junction of the Saginaw and
Huron-Erie ice lobes. Its northwestern border is Huron-Erie ice lobes. Its northwestern border is beyond the limits of the quadrangle.

## drainage.

Streams.-The streams of this quadrangle flow either directly or indirectly to the western end of Lake Erie. A large part of the quadrangle is by Raisin River and its tributaries
Huron River, a stream tributarie
Habis Ren 150
ows southward from its source in miles in length land County, to the northern edge of the quad rangle, and then makes a curve southwestward southward, and southeastward through the quadrangle, and continues in a southeastward course to its mouth at the extreme head of Lake Erie. Nearly all the tributaries of Huron River are small, the most important lying within the limits of this quadrangle.
Raisin River, a stream perhaps 160 miles in length, drains, with its tributaries, much of the southern end of the quadrangle, though the main stream traverses only its southwestern corner. From the source near Jerome, in northern Hillsale County, it flows north of east into Washtenaw western limits of the to 45 miles. Near the swings around to a southwest corner of the quadrangle and continues nearly to the Ohio State line, where it again takes an eastward course, flowing into Lake Erie.
Saline River, the most important tributary Raisin River within this quadrangle, has its principal source in Columbia Lake a few miles west of the village of Saline, and its meuth just outside the southern limits of the quadrangle. The stream is about 45 miles long and in its entire course descends about 230 feet, the altitude of Columbia Lake being 864 feet and that of the river's mouth being about 634 feet.
Macon River embraces a widely branching drainage system which gathers the waters from a district west of Saline River, in the southwestern part of the quadrangle, and joins Raisin River within a nile above the mouth of Saline River. The ources of the several headwater branches are at altitudes of 800 to 850 feet, so that the stream Raisin River. Both the streams eand erably, the distance from source to mouth probably exceeding 30 miles.
Swan Creek, Sandy Creek, and Stony Creek with its tributaries Paint Creek and Sugar Creek drain a small area in the southeastern part of the of Lake Erie through a district lying betwee Huron and Raisin rivers.
Rouge River, a stream entering Detroit River near the southern limits of the city of Detroit and
draining a large part of Wayne County, also drains a narrow area along the eastern border of the northern half of the Ann Arbor quadrangle.
Lakes.-Within the limits of the
Lakes.-Within the limits of the quadrangle water whe nearly 150 small bodies of standing be debarred from ready drainace. Sufient depth to bodies arre without outlet; streams through bordering swamps with no definite channel of outflow; but, as may be seen by the topographic map, most of them have definite outlets, and a few stand in the course of streams. Nearly all of these are termed lakes, and more than 50 of them have received names. These do not include the bodies of water held in by artificial dams and called mill ponds, nor those which have become extinct, for several marshes mark the site of old water bodies whose basins have become so nearly filled with peat, marl, and sediment that they are no longer mapped as lakes.
Of the lakes indicated on the Ann Arbor topographic sheet 134 lie within the area drained by Huron River, and only 11 in the portion drained by the Raisin and its tributaries, Saline and Macon
rivers; while none occur in the portion drained by rivers; while none occur in the portion drained by Rouge River, Stony Creek, Swan Creek, and Sandy Creek. Most of them are found in the nortwestern part of the quadrangle and there are none on
the plain in the southeastern part, though that the plain in the southeastern part, though that
plain, as already indicated, was for a long time plain, as already indicated, was lor a long the waters of great glacial lakes. The lakes abound in the part of the quadrangle where the irregularities of surface are greatest, and the flatness or regularity of the surface in the southeastern part accounts for their absence there. Few of the lakes cover an area of a square mile, and most of them cover less than one-fourth of a square mile. Several of those which are named fall within the limits of a 40-acre lot; those without names have ordinarily an area of but 5 to 10 acres, though some cover 40 acres or more. Few of the lakes have been systematically sounded to determine maximum depths, but enough soundings have been made to show that even some of the smaller lakes
are 50 to 60 feet deep, and that a few have are 50 to 60 feet deep, and that a few have
depths of more than 100 feet. Nearly all the lakes are so deep that they are not only protected from extinction by artificial drainage but also from early filling by sediments and organic growths and precipitates. They will therefore continue to be
attractive features in the scenery of this region hundreds and probably thousands of years.

## GEOLOGY.

bed-rock surface
General statement.-The bed-rock surface of the Ann Arbor quadrangle was completely covered by glacial deposits and is now exposed only at a
quarry in the southeast corner, where the rock is reached by stripping off a thin sheet of drift. Numerous wells, however, distributed widely over the quadrangle, furnish sufficient information in reference to the bed-rock surface to warrant a general statement concerning its topography. The altitudes of the bed-rock sur
by wells are shown in fig. 1.

## wells are shown in fig. 1 .

The Erie lowland.-In the southeastern part of he quadrangle the rock surface stands not far from 600 feet above sea level and is composed of several rock formations of dissimilar composition, the Monwater. (See the generalized section, fig. 2, p. 2.) These several formations appear to have bee ciently beveled off at their outcrops to Eneplain-an extensive lowland bordering Lak Michigan and northwestern Ohio, and extending westward across northern Indiana into Illinoiswhich may appropriately be termed the Erie lowland. The northwestern edge of this lowland, as indicated by altitudes of bed-rock surface given in fig. 1, crosses the Ann Arbor quadrangle near a
line running from Tecumseh northeastward past Ann Arbor and leaving the quadrangle near its


Frg. 1.-Sketch map of Ann Arbor quadrangle, showing out-
erop of Pateozocic formations beneath the drift and altitudes
of the bell-rock surface crop of Paleozoic format
of the bel-rock surface.

northeast corner. Within a few miles west of this line there is a rise of about 200 feet to a table-land in which the Marsliall sandstone forms the bedrock surface.
The Marsluall table-land.-This table-land covers
several counties in southeastern Michigan and runs northeastward into Huron County along the outcrop of the Marshall sandstone and other sandstones of Carboniferous age. In an area comprising a few townships near the corners of Jackson, Hillsdale, Calhoun, and Branch counties the rock surface rises to altitudes of 1000 to 1150 feet above sea level, but generally it lies below 900 feet, and on passing northward into Huron County it gradually grows lower, though holding a height of 750 feet as far north as that county.
Preglacial drainage lines.
ment the preglacial drainage - In the above statement the preglacial dranage lines have been disre-
garded. Borings indicate that the main preglacial valleys were cut to levels about 100 feet below the Erie plain (or to not far from 500 feet above sea level), though many of the tributary valleys were cut only 50 to 75 feet into this lowland. The valleys in the Marshall table-land were cut deeper, yet their floors stand at a higher level, being near the sources of the streams. As would naturally be inferred and as is indicated by the borings, the valleys discharged eastward from the table-land across the lowland, and appear to converge toward Detroit, where the rock surface is but little above 450 feet. The borings or data concerning the valleys are, however, too few to warrant even a general mapping of the main preglacial drainage lines of this region.
Effect of glaciation.—Attention has been called to the presence of broad, very shallow troughs in
the rock surface in Monroe and Wayne the rock surface in Monroe and Wayne counties,
which follow the belts of outcrop of the weaker rock formations, and the sucgestion has been made that these troughs were dased hy the iee at time when its movement conformed very nearly to the strike of the rock formations. (See "Ice work in strike of the rock formations. (See "Ice work Jour. Geol., vol. 10, 1902, pp. 194-216) The troughs are much broader and shallower than the preglacial drainage lines. It may be difficult at present to demonstrate that the troughs were appreciably enlarged by the ice, since there is a likelihood that prior to the glacial epoch the weaker rock formations would have been broken down to formations.

## momentary rocks.

The entire quadrangle is covered by a sheet of unconsolidated material, deposited by glaciers and streams or in lakes, which ranges in thickness from tion available concerning the stratified sedimentary rocks or geological formations lying beneath these
surface deposits is derived from the records of a a series of concentric although irregular rings or few deep wells, some of them outside the quadranby the rocks of a single quarry and fragments the underlying rocks contained in the surficial deposits.

## The w

The work of the Michigan State Geological Sur vey has shown that the formations present in the stones, dolomites, sandstones, and shales which, as is proved by fossils, were deposited in ocean waters That is, during nearly all of the immensely great periods of time in which the rock foundations of Michigan were being laid down, the ocean occupied the area, the only known rocks not deposited in the sea being the coal beds, and possibly some of the shales associated with them, in the central portion of the Southern Peninsula. It is probable also that beds of salt and of gypsum found in certain of the formations were produced by the concentration, through evaporation, of saline matter in land locked hasins.
In geological age the youngest of the formations
beneath the glacial drift belongs to the Corbonifbeneath the glacial drift belongs to the Carbonif succession, occur Devonian, Silurian, Ordovician succession, occur Devonian, Silurian, Ordovician,
and probably still older formations. Beneath these stratified rocks the crystalline rocks of the Archean system are no doubt present, but these have not yet been reached by the deepest drill holes bored in the Southern Peninsula. The subdivisions of the systems just mentioned which have been recognized in the Ann Arbor quadrangle, and their places in the general scheme of geological history as determined by the State Survey are indicated in fig. 2.


FIG. 2.-Generalized section of the roeks of the Ann Arbor quadrangle, a.
. southeru Michigan.

The various members of these systems of sedimentary or stratified rocks were deposited in essentially horizontal sheets of various thicknesses, ranging from a few score feet to over a thousand moderately disturbed by movements in the earth's crust which have resulted in tilting the rocks toward the central part of the Southern Peninsula. The amount of this tilting or inclination in the region occupied by the Ann Arbor quadrangle is about 35 feet per mile. In their present position the sheets of rock resemble a pile of shallow saucers, one placed within another, the one at the top, or the one last added to the series, being the coal-bearing formation of the Carboniferous.
About the borders of this formation, which oceupies a central geographic position, the edges of the older formations below appear at the surface in
a series of concentric athough irregular rings or
belts. After the beds had assumed their presen long time so that the entire area of the Souther Peninsula was planed away to a generally uniform
measuring 2 to 4 inches across. None of thes minerals occur in sufficient abundance to be phur were collected a few years ago and sold
level. This long period of erosion preceded the deposition of the present surface sheet of glacial drift. The rock surface beneath the drift in this quadrangle, as shown principally by the records of wells (see fig. 1), is a fairly smooth plain except in he north western part, where the presence of ancien hills and valleys is evident.
The relations of the Ann Arbor quadrangle to the Southern Peninsula in general, supplemented by records of deep wells drilled in the quadrangle show that the rocks which would appear in this area if the covering of drift were removed range in ge from Mississippian (Lower Carboniferous), rep resented by the Marshall sandstone, in the north west corner, to Silurian, represented by the Monro formation, in the southeastern portion. It is not now practicable to map accurately the boundarie of the several formations that lie beneath the manre known approximately gad are indirat on geologic sketch map forming fig. 1 mortan system.
anof formation.
At only one locality in the Ann Arbor quadrande do the rocks beneath the drift approach near nough to the surface to be quarried-at the Wool ith quarry, near Maybee, in the extreme southea ar the quadrangle. At this place a loca

Brown, gray, and yellowish sandstone. Bands of iron concre-
tions near base.

Light.eolored. green, bluish, and gray shales, with calcareous
lavers sand thin beds of limestone.

Black, bituminous shale.
Coarse gray sandstone. "Third" brine horizon. Dark , hale in in places black and bituminous. Contains iron
pyrite, oil, and gas.

Gray and yellowish bituminous limestone with sand and chert.
Gray and drab oolitic and sandy dolomite, in part thick bedded
Fine, incoherent, sparkling white sandstone.
8. D
9. Dolomite, highly siliuecous-..-.-.......assing upward
wwitout a break into No. 9
. Dolomite, light gray, siliceous, compact,
3 to 4

tains sand grains which, under the micro-
scope show seondary

Samples of the beds numbered 5 and 10 in the bove section have been analyzed, with the follow ing results:

Analyses of aotomile from the
${ }_{\text {I By }}$ Eugene C. Sullivan.

| Constituents. | Bet 5. | Bed 10. |
| :---: | :---: | :---: |
| Silica ( $\mathrm{SiO}_{3}$ ) | 1.30 | 1.77 |
| Alumina $\left(\mathrm{Al}_{2} \mathrm{O}_{3}\right)$ - | . 16 | . 01 |
| Ferrous oxide ( $\mathrm{Fe}_{4} \mathrm{O}_{3}$ ) | . 20 | 1 |
| Magnesium oxide ( Mg O ) | 19.79 | 20. 84 |
| Calcium oxide (CaO) - | 31.14 | 29.65 |
| Water ( $-\mathrm{H}_{\mathrm{z}} \mathrm{O}$ ) absorbed. | . 18 | 12 |
| Water ( $+\mathrm{H}_{2} \mathrm{O}$ ) chemically combined | 57 | 48 |
| Carbon dioxide ( $\mathrm{CO}_{3}$ ) | 45. 18 | 46. 40 |
| Phosphoric acid ( $\mathrm{P}_{2} \mathrm{O}_{3}$ ) | Trace | Trace |
| Sulphurie anhydride ( $\mathrm{SO}_{3}$ ) | 1.15 | . 33 |
| Manganie oxide ( MnO ) | Trace | Trace |
|  | 99.67 | 100.01 | Eacl

Eum.
The Sylvania sandstone, reached by a drill hol in the bottom of the quarry, is a medial member of the Monroe formation. It is a widely extended sheet of remarkably pure white color, and is but the village of Sylvania, Ohio, where it is utilize

## Section at Wool mith quarry [Arranged by W. H. Shererer.] <br> 1. Glacial till, a blue stony elay containing bowlders, extending downward to surface of highest bed of dolomite, which is in <br> tensely glaciated -----------------------

 creamy white but blot thed and streaked
with browni; in places porous and caveru-
ous owing to the sol vent ous owing to the solvent action of peroo-
lating water; where not weathered, soft,
mealy, and gritty to the touch. On weathered, surfaces strometopocralike weath-
tionina-
tore conspieuous; these are probably tious are conspieuous; these are probably.
foosils resembing corat; the upper part of
the bed contains molds and casts of gas. varies, principally on anceount of the uneOoliticic dolomite, dark gray in color, con-
taining spherical grains, about 0.4 milli-
meter in diameter, made up of delicate eoncentric shells somposed of minute inter-
locking resytals of dolomite. Small cavi-
ties ties contain erystals of ealcite, eelestite,
and native sulphra, Laminated ins basal
portion, where iregular hummocks oceur on the surface of the bed beneath. brown and ranging in texture from a compact, tough, homogeneous to a cavernous
and soft or rotten condition. Hemmocky and sott or rotten condition. Hummocky
at the unface, the elevations several feet in diameter being composed of concencatrie
lamine.. Large cavities contain celestite, laminæ. Large cavities contain eelestite,
ealeite, and sulphur. At top and bottom
surfaces there are lamino of back impure surffaces there er ere eminino of banck, botinpure
asphaltum, in connection with which sty asphaltum, in connection with
lolites due to pressure are presen
 toward blue; couponent layers, from 2 2 ot 8
inches thick, laminated with streaks of inches thick, laminated with streaks of
blue, gray, and brow dolomite and deli-
cate films of carbonaceooss material; compact, mostly free from mineral-bearing
cavities; somewhat impregnated with
petroleum; loeally contains shells of the ostracod crustacean Leperditio and the smal coiled shells of a worrn, Spirorbis $s$ -
Dolomite, dark brown, blotehed with black, cellular and eavernous in texture, impreg.
nated with petroleum; ;ives ofr a strong bituminous odor; contains casts
molds of shells. Numerous cavities, mold of shells, Numerous cavities, mos
of them elliptical, ranging in diamete
from 1 or 2 inches to 8 feet, contain beau tiful crystals of calcite, ecelestite, and sul sul-
phur. Portions of the bed are compact
and suitable tor buil phur. Portions of the bed are compact
and suitable for builing stone ....-.-.
Sandy dolomite, blishs, sritty \%. Sandy dolomite, bluish, gritty, $\begin{gathered}\text { a sandstone in certain layers; } \\ \text { especially in }\end{gathered}$ a sandstone in certain layers: penetrated,
especially in the npper part of the bed, by
nearry cylindrical channels about 3 milli.
$\qquad$

50 (?) herzer (Geology of Michigan, vol. 7, part 1,
The minerals in next column.
ing in mavities in the celestite, and sulphur, occu
ring in cavities in the dolomite of the Woolmith
quarry, have been deposited from solution by percolating water since the The deposition of sulphur is still going on. Th are remarkably beautiful and large, some of them
which is not fully exposed but is seemingly about one-half mile in diameter. In the quarry the beds dip about $\mathrm{S} .65^{\circ} \mathrm{W}$. at an angle of $2^{\circ}$ to $3^{\circ}$. The rocks are principally magnesian limestones or dolpeculiar character and were formerly quarried for use as building stone and termed sandstone. The section exposed in the quarry and in part revealed a drill hole in its bottom, reported by W. 1 , 900 ), is given in the next column rystals of celestite (strontium sulphate) in particula
in Michigan near Ottawa Lake, about 13 miles northwest of Toledo, and extends northeastward across Monroe County to Trenton, but throughout nearly all of this distance its presence is concealed by surface deposits. Its thickness increases from about so feet in the northern portion of Ohio to 95 feet at Trenton. The records of a well at fig. 3.) The width of its outcrop in Michigan

varies from about one-half mile to about 4 miles. From its line of outcrop the bed dips in general northwestward, and in the university campus well at Ann Arbor it was reached at a depth of above and below the Sylvamia sandstone is highly siliceous and contains quartz grains of the same peculiar character as those in the bed of sandstone

Chemical analyses show that the sandstone tains 96.50 per cent of silica, is free from iron, and is valuable for glass making. Usually it is very friable and so incoherent that it crumbles between the fingers. Its most interesting feature, which may be observed with the aid of a microscope, is the fact that the originally rough, angular, or eroded grains of sand have been enlarged by the deposition of silica upon them, which has given them crystalline faces and eiges. This secondary enlargement or the grains, many of which have this beco the sand a peculiarly brilliant luster. The peculiarity just referred to is well displayed by samp of the sandstone taken from the Campus well at Ann Arbor.

## pevonlan system <br> dundere tumestone

The Monroe formation is the surface rock over only a few square miles in the southeast corne of the quadrangle in the southern part of Exeter Cownship, Monroe County. On its northwe. horder is an area ahout 5 miles wide extending from northeast to southwest across the quadrangle through Sumpter, north western Exeter, and southeastern London townships, in which limestone of
the Dundee formation is the surface rock. Numer-

Ann Arbor.
ous farm wells enter it at depths ranging from 50 to 100 feet or more. It is also penetrated by deep wells at Milan, Ypsilanti, and Ann Arbor. Its thickness at the Milan well, as interpreted by Lane, is 125 feet, at Ann Arbor 185 feet, and at Britton, just south of the limits of the quadrangle, 100 feet. Samples from the Britton well are reported to be points it is reported to be of white or ar an points it is reported to be of white or gray colo arries is generally charged more or less with hydrogen sulphide.

The traverse formation includes blue argillaceous limestones and shales with reefs of limestone (some dolomite), of about the same age as the Hamilton and Marcellus formations, of the New York serie. It forms the surface rock in a narrow area running from northeast to southwest through southern Van Buren, northwestern Sumpter, southeastern Augusta, southeastern York, north western London, central and southeastern Milan, and southeastern
Macon townships. It has been reached by numerMacon townships. It has been reached by numer nos farm wells in Augusta, Lon fon, an is penetrated by deep wells at Ypsilanti, Ann Arbor, Milan, and Britton. Its thickness is 65 feet at Ann Arbor and 190 feet at Britton, at each of which points it is completely covered by later rock formations. At Milan, where its upper part has probably been partly removed, since it forms the surface rock, its thickness appears to be only 140 feet. At this point however, the boundary between the Traverse and the Dundee is somewhat uncertain.

## antrim shalif.

The Antrim or black shale forms the surface rock in a narrow strip in Canton, Van Buren, Ypsilanti, Augusta, York, Saline, Milan, and Macon oownships, but it is generally covered to a depth of about 100 feet by glacial deposits. It has heen reached by a few farm wells in the township Ypsilanti, Ann Arbor, and Britton
Ypsilanti, Ann Arbor, and Britton.
It is not present in the Milan deep well but is reached by private wells in the northern part of the
village. Its thickness at Ann Arbor is 160 feet in the campus well as interpreted by Lane, and it appears to have a thickness of 175 feet at the court-house well as interpreted by Rominger. At
Britton its thickness is 117 feet, but there it has prohably been partly removed.

## arbonferous system

berkà sanistone.
This formation is not easily separable in well sections from the next younger formation, the Coldwater, which, thdugh largely shale, contains can only be stated that the Berea sandstone underlies a narrow area immediately northwest of the black Antrim shale. The thickness of the entire formation in the campus well at Ann Arbor, as
interpreted by Lane, is 120 feet, but of this only interpreted by Lane, is 120 feet, but of this only 15 feet is described as sandstone. In the court-
house well at Ann Arbor Rominger found 92 feet of Berea sandstone.
coldwatrr shale.
The Coldwater shale, as indicated in fig. 1 , is the surface rock beneath a large part of the
quadrangle. It consists mainly of shale, but the quadrangle. It consists mainly of shale, but the shale is in places sandy and the formation comIt is reached by only a few deep wells, since the drift covering it in this quadrangle is very thick. The section of the campus well at Ann Arbor is shown in fig. 4 and sections of other wells that penetrate the formation at $Y$ psilanti and Ann Arbor are given below
At Ypsilanti three deep wells have been drilled for the purpose of obtaining mineral water. A fourth well has been drilled with the hope that oil or gas will be discovered in paying quantities The first of these wells, known as the Cornwell, was drilled on the flood plain east of Huron River, near the present pumping station of the city waterworks, where the surface stands about 680 feet above sea level. The section passed through is reported to be as follows:

Section of Cornvell well, Ypsilanti.

|  |  |  |
| :---: | :---: | :---: |
| Earth, clay, gravel, sand, etc., unconsoli | $\begin{aligned} & 109 \\ & 240 \end{aligned}$ |  |
| "Slate" (probably shale) .- |  |  |
| "Flint" |  |  |
| Sandstone |  |  |
| Soft " slate" or sandstone (sandy sthale). | 157 |  |
| "Bed rock" (hard limestone") | 20 |  |

Mineral water was oltained, but the well is not ow in use.
The Moorman well, located near Huron street in the business portion of the city, at an elevation of about 703 feet above tide, is 950 feet deep. No reliable record of the strata passed through known. The mineral water obtained (see analysi under heading "Water resources," on p. 14) is use or baths and other purposes.
The Owen or "Atlantis" well, located near the Michigan State Normal College (surface elevation bout 760 feet above sea level), passed through the ollowing beds

Netton of Alantis well, Ypsianti.
[From manuseript notes by Alexander Wivechell!


At Ann Arbor two deep wells have been drilled the first in 1871, in the court-honse square (surface elevation 835 feet), and the second during 189 di 1900, in the campus of the University of Hichigan (surface elevation 880 feet). The recor of the campus well as determined by State Geol ogist Lane, is given in fig. 4. The section passel through by the court-house well, condensed from

the report published in vol. 5 of the Michigan Geological Survey, is as follows

Section of court-house well, Ann Arbor

| Soil, gravel, clay, ete., (glacial deposits). (According to Winchell thickness of drift is 164 feet.) |
| :---: |
| Shale, blue, arenaceous, with seams of fine grained sandstone |
| Shale, black, bituminous, with gas and drops of oil |
|  |
|  |
|  |
| Shale, dark blue, arenaceons, with pyrite, traces of fossils |
| Shale, black, bituminous, with pyrite |
| Limestone, bluish, eherty |


| $\substack{\text { minect } \\ \text { neter } \\ \text { feet }}$ | ${ }_{\substack{\text { a }}}^{\substack{\text { Totalat } \\ \text { in feet }}}$ |
| :---: | :---: |
| 158 | 155 |
| 150 | 30.5 |
| 28 | ${ }^{333}$ |
| 92 | 425 |
| 100 | 525 |
| 85 | 610 |
| 22 | ${ }^{632}$ |
|  | 780 |

In sec. 23, Bridgewater Township, a well wa rilled for oil to a depth, as reported, of about 1000 feet, but a record of the material passed through has not been obtained.
A deep well was also drilled for oil and gas at South Lyon, of which no record has been obtained
marshall sandstone.

The Marshall sandstone is present in the western part of the quadrangle from Freedom Townshi northward to the northern border. Its eastern alge is very irregular and the quadrangle seem to include only its projecting points, for the Coldwater shale forms the surface rock at some place in the northwestern townships as far west as the limits of the quadrangle. As indicated in the dis cussion of the bet-rock surface this sandstone seems to form an escarpment that stands 100 to 200 fee above the bordering areas, in which the Coldwater formation is the surace rok. The distace to the quadrangle is ouly 50 to 100 feet, or scarcely one hial the rall listane to the Celwater bal that
The format
Western edge of the quadrangle by borings on the western edge of the quadrangle, consists of alter-
nations of soft sandstone and shaly material. In its outcrops farther southwest, in Jackson and Hillsdale counties, it is a firm sandstone, which has been quarried for use as building stone, and in places for grindstones. The thickness of this sandtone penetrated by wells at Hillsdale appears to reach about 1000 feet, but at Jackson the drillings, as interpreted by the Michigan Geological Survey show a thickness of only 100 feet. At Albion and Marshall the formation is not far from 200 feet thick. It thus appears to vary greatly in thick ness within short distances. The principal exposures outside of Jackson and Hillsdale counties are Huron County, east of Saginaw Bay, and th Hock there varies considerably in texture, ranging conglomerate and including beds suitable for rindstones.
ormation underlies the coal-bearing strata o Michigan called the "Coal Measures" and extend few miles beyond their limits, not only in southern Michigan but in the western, central, and eastern portions of the Southern Peninsula. It should be remembered that the so-called "Coal Measures" of Michigan occupy a lower place in the geological column than the strata to which that name ha been applied in the Appalachian basin and have received this name simply because they bear coal In its outcropping or border portions the Marshal andstone constitutes one of the principal source of drinking water and its supply is preferred to the waters of the drift because it is softer. In its deepying portions, howerer, under the "Coal Measures," his formation is filled with brines.
sitrficha geology
pleistocene deposits.
nerio givial featupe
Complexity of the glacial drift.--The glacial drift of North America is separable into deposits or formations of somewhat different age and origin, on formation being superimposed on the weathered and eroded surface of another, or separated from it by a bed of peat or a well-defined soil. The degree of weathering displayed by some of the buried land surfaces is greater than the weathering
found on the surface of the uppermost sheet of
drift; from which it is inferred that the time involved in the interglacial weathering was longer lown
Centers of ice accumulation.-There were severa enters of ice accumulation, from which the ice pread in all directions. One of these centers, from which radiated what is known as the Keewatin ice sheet, was in central Canada, west of Hudson Bay; another ice mass, the Labrador was centered on the Labrador Peninsula; a third lay west of the Rocky Mountains in Canada; while Greenland is still largely covered by a fourth great ice sheet. It is only with the first and second ice From the Keewatin of Michigan has any relation outh as northerem Kansas and contral Misouri It may possibly also have spread southeastwar may possibly also have spread southeastwar that case it must have withdrawn in an early part f the glacial epoch prior to the oreat invasio from Labrador. From the Labrador center the ice tits maximum extended as far southwest as south eastern Iowa and southern Illinois and as far south as northern Kentucky.
The principal divisions of the drift in the North Central States are given in the following table, red zones, The tatest drift inging soils and weath op in this The latest drift sheet is named own in top in this table and earlier deposits are set down in order of age beneath. Their names are taken from
States or regions in which they are well displayed. The drift sheets east of the Alleghenies, except hose formed by the latest or Wisconsin drift, have ot yet beeni correlated to the satisfaction of al geologists win hose of the North Central States, and there is similar uncertainty as to the correlaCordilleran region. For this dra below is restricted to the country lying between the Rocky Mountains and the Alleghenies.

## Drift sheets of the Keevatin and the western part of the Lab rador ice fildds.

| eewatin. | Labratoro west of Allegheny |
| :---: | :---: |
| Wisconsin drift. | Wisconsin drift. |
| Peorian soil. | Peorian soil. |
|  | Iowan drift (?) and main loess deposition. |
| Not differentiated fron Yarmouth. | Sangamon soil |
| No Illinoian drift discovered. | Illinoian drift. |
| Yarmouth soil | Yarmouth soil. |
| Kansan drift. |  |
| Aftonian soil. | not differentiated; per haps wholly pre-Kansan. |

Lobation of ice.-At certain places and at different times the ice margin was divided into prom nent lobes and the moraines were arranged in great loops encircling the southern ends of the
large basins. (See fig. 5.) The cause of the loba-


Fig. .,-Sketch map of sonthern Michigan and portions
adjacent States, showing the distribution of the glacial moraines and the directions of iee movement. Position
Ann Arbor quadrangle is shown by the small rectangle.
ion is found in the fact that the ice mass was
necessarily thicker in the basins than on the bordering highlands so that there was more vigorous movement in the thicker ice and a corresponding extension of lobes of ice into the basins. Such obation was probably strong when the ice came nd the basins in the oncoming of the glaciation the waning stage it left moraines that show the mount of lobation.
What is true of one glacial advance and retreat is probably true of all that have occurred in the Great Lakes region. At certain times in two or more of the great stages of glaciation the Southern enes, the Michigan, the Sasinaw and the Huron Erie, each of which formed prominent moraini ystems concentric with the border of its basin The lobes that touched the Ann Arbor quadrangle are the Saginaw and the Huron-Erie. (See fig. 5.) The Saginaw lobe came into it from the north, reaching, at its greatest extension, about to the borders of the southwest-flowing portion of Huron River, while the Huron-Erie lobe entered from the east and covered the greater part of the quadrangle. Moraines.-Ridges of stony drift formed at the margin of the glacial lobes are very conspicuous in width fichigan. These morana several miles and in height from about 25 feet up to nearly 500 feet. The surface of the morainal areas of the State is ordinarily very uneven, made up of knolls and interlocking ridges among which basins are
inclosed, but the moraines also exhibit all shade inclosed, but the moraines also exhibit all shades of topography ranging from this sharp expression down to a nearly featureless smooth ridge. Most of he smooth ridges occur where the ice lobe termimoraines. The Wisconsin drift erries a comle series of moraines, most of which mark stages halting, though some represent slight readvances during the general recession and disappearance of he ice. In places these are superimposed upon or pass across morainic ridges that were formed in earlier stages of glaciation. These moraines and their included lakes give the Southern Peninsul of Michigan much of its picturesque scenery
Kames.-In Michigan the drift has been more largely modified by water than in the neighboring States of Ohio, Indiana, and Illinois. In som places it is completely assorted and lies in leveltopped deposits. In other places it is imperfectly drift are more or less intricately associated with assorted beds. Combinations of commingled and assorted drift that take the form of sharp knolls and ridges are known as kames. Some of these in the Ann Arbor quadrangle constitute its most prominent features, as will be seen by reference to the geologic map. Many, of the kames are in the between moraines. Some of them were probably formed at points where streams emerced fromaty formed at points where streams emerged from connection with moulins or glacial mills, at some distance within the limits of the ice sheet.
Eskers.-Long narrow gravel ridges,
which lead from a till plain into a moraine and of thought to be the product of drainage within or beneath the ice, are called eskers. One conspicuous example of this class of deposits in the Ann Arbor quadrangle is known as the Lima esker, which is described below in connection with the interlobate moraine of the Saginaw and Huron Erie lobes.
Glacial outwash.-In the Ann Arbor quadrangle, as well as in other parts of Michigan, there are extensive deposits of gravel and sand that head in moraines and lead outward from them. These deposits were formed by streams that flowed away
from the ice. Those that fit somewhat closely the from the ice. Those that fit somewhat closely the
edge of the moraine and do not extend far away dge of the moraine and do not extend far away that lead directly away from the moraine in long narrow strips and turn into valleys are known valley trains and gravel plains.
Some of the beds of assorte
appear underneath the uppermost till shich probably spread as outwash in front of the ice and subsequently overridden by the ice in its next interbedded with the till sheets was all deposited as
lacial outwash, for at some places it contains strips partitions and lens-shaped masses of till that ithin to have been deposited beneath the ice, ith the till is very extensive and interbedded that is largely drawn upon by wells.
Ground moraine, or till plain.-Most of the comparatively smooth areas lying between the moraines are underlain by a sheet of till, or of till containing more or less extensive inclusions of gravel and sand. This deposit was probably in arge part formed beneath the ice rather than at its xtreme edge, and has been called ground moraine on ill in these por 1 . The preponderance of ill plains to distinguish them from the plains of gravel and sand
Stricu.-At the quarri
the village of Maybee about 1 mile northeas laciation, including traces of two and heavy three distinct movements, as well as considerable sifting in each movement. One set of strix shows bearing ranging from $\mathrm{S} .19^{\circ} \mathrm{W}$. to $\mathrm{S} .30^{\circ} \mathrm{W}$., with heavy grooves bearing S. $22^{\circ} \mathrm{W}$. These grooves and the strix in them are older than cerain others that pass over them nearly at a right angle. These later strix range from N. $18^{\circ} \mathrm{W}$. to N. $40^{\circ} \mathrm{W}$., with a general bearing about $\mathrm{N} .30^{\circ} \mathrm{W}$. In a small quarry south of the main or Woolmith quarry strix were found bearing more nearly westard and presenting a range of $40^{\circ}$, from N. 51
$30^{\prime} \mathrm{W}$. to N. $91^{\circ} 30^{\prime} \mathrm{W}$. (Sherzer, W. H., Jour $30^{\prime} \mathrm{W}$. to N. $91^{\circ} 30^{\prime} \mathrm{W}$. (Sh
Geol., vol. 10,1902 , p. 213.)
As the ice movement may have shifted within single stage of glaciation, it can scarcely be sumed at the several sets represent as many ral southestward . and Wisconsin stages at the time of its greatest extension. But as it shrank and as lobation in the basins of the Great Lakes became more promnent, its movement might easily have shifted from southwestward to northwestward. The northwest-ward-bearing strix are directed toward the moraines of the Huron-Erie lobe, which traverse the central portion of the Ann Arbor quadrangle and were robably formed at or near the close of the Wis-ard-bearing glaciation. Whether the sosinest Illinoian stage can not yet be decided.

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                                    pre-wisconsin drift
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There is some uncertainty as to the number of drift sheets present in the Ann Arbor quadrangle. The Illinoian and Wisconsin sheets are well repreanted, bot the Iowan sheet has not been identified, Ider sheet than the Illinoian. In comprises an der shan the Minoian. In vew of this here The drift sheet supposed to be Illinoian consisto mainly of hard or notably compact till underneath he Wisconsin drift. This hard till is traceable the Wisconsin drift. This hard till is traceable
southward by means of well records to unquestionsoule Illinoian drift, which emerges from beneath he Wisconsin in southern Indiana and Ohio. The indurated condition of this lower part of the drift in Michigan is very similar to that of the exposed portion of the Illinoian farther south, and when taken in connection with the known occurrence of a similar sheet through the intervening territory rift sheet. presumption that it belongs to that oian drift asthermore, the occurrence of expected, because the Labrador ise field (which eposited the Illinoian drift) passed across this region to regions farther west and south, wher hat drift is exposed. The only question seems to e whether or not the pre-Wisconsin drift is wholly

The greater compactness or induration of this dift has not yet been fully explained, even for its exposed portions, but is apparently due in large time to permeate its compact and clayey as well as its looser textured portions and to bind its particles together. It is true that at some places the Wisconsin drift also has been cemented, but so far observed this cementation occurs only in material that is readily pervious to water. Ordinarily the Wisconsin drift is so soft that it may be excavated
easily with a spade, while the Illinoian usually requires a pick, and blasting is at some localities necessary to loosen it sufficiently for handling. The amount of pre-Wisconsin drift in the Ann Arbor quadrangle is much greater than was
at first supposed. This older drift not only fills at first supposed. This older drift not only fills preglacial valleys and extends over the general region, but appears to form the nucleus of the large morainic ridges within the quadrangle.
Indeed, the principal moraine traversing the Indeed, the principal moraine traversing the
quadrangle from its northeast to its southwest quadrangle from its northeast to its southwest corner seems to have been formed in pre-WisconValleys of considy veneered with Wisconsin drift. Valleys of considerable depth had been cut in this older drift before the Wisconsin was deposited, so that along the line of such interglacial valleys the low as the present stream beds
No rempants of soil beds.
consin and pre-Wisconsin junction of the Wisobserved within the limits of this quadrangle, but at a point only a few miles farther southwest, in central Hillsdale County, there is a tract, comprising several square miles, in which a black soil underlying the Wisconsin drift has been penetrated by wells. At many places in the northern counties of Indiana also soil has been found between the Wisconsin drift and that which underlies it. In view of these occurrences of buried soil in neighboring districts it may be expected that similar soil will be recognized in this quadrangle when deep borings become more numerous or when the records of the present borings are more fully worked up and interpreted. Buried soil may also be discovered in outcrops along the bluffs of streams, though such situations are generally unfavorable for its preservation. Some of the upper part the overiden drit sheet was and remnants of soil may therefore be present only in protected situations.

## A deposit of

quadrangle was noted by Aln drift within this quadrangle was noted by Alexander Winchell in which at a depth of $131 \frac{1}{2}$ feet a change occurred from an adhesive blue clay, apparently the Wisconsin drift, to a "compactly bedded shalelike material," which appears to be an older drift sheet. The record indicated the presence of $28 \frac{1}{2}$ feet of shalelike material, which was underlain by 4 feet of partly cemented sand, the bed rock being struck at a depth of 164 feet. The court-house stands on ground that is about 90 feet above
Huron River, so that the adhesive blue clay or till Huron River, so that the adhesive blue clay or till at this point extends down to a level about 40 feet
below the river, but, as indicated below, probably below the river, but, as indicated below, probably
here fills an interglacial valley. here fills an interglacial valley.
1902 about one-half mite Company sunk a well in 1902 about one-half mile west of the court-house, oft ground 25 feet lower, in which the change from 102 feet, or at nearly the same level as in the court-bouse well rial taken from this well consist of a very stony hard till for a depth of 15 feet and a more sandy till, with fewer pebbles, 21 feet farther, and beneath this a thin bed of water-bearing gravel resting on the Coldwater shale, which was found at a depth of about 140 feet. In another boring made by the water company in 1904, about one-eighth mile farther west, the hard till was found at 141 to 163 feet, its surface being a few feet lower than in the wells just mentioned. A well sunk by the Ferdon Lumber Company, in the valley of Huron River, one-half mile north of the court-house, entered very hard till at 14 feet and continued in it to bed rock, which was reached at a level 130 feet below the river. In this well the surface of the hard till is 40 feet or more higher than at the court-house and water company wells, and its base is considWells recently sunt
Wells recently sunk around Ann Arbor and in of hard till, and quadrangle have struck the sheet hard till, and its outcrop has been lately observed at a few places in the valley of Huron River. A has been struck in these wells shows that its surface rises toward the west at an inclination corresponding rudely to the rise in the present surface until it reaches the crest of the main moraine of the Huron-Erie lobe in this quadrangle. Farther west it has not yet been definitely recognized. Its alti-
tude at Denton, on the eastern border of the quad-
rangle, is about 630 feet, at $Y$ psilanti 675 to 700 rangle, is about 630 feet, at $\mathrm{Y}_{\text {psilanti }} 675$ to 700 feet or more, at Pittsfield about 825 feet, and the moraine crossed by Huron River just above Ann Arbor it may be present up to 900 feet o more. Renliteng moraine indicate that reaches of Amul west of Ann Arbor. Its greatest thickness probably occurs along this high moraine, for the rock
surface beneath the moraine is in places less than 700 feet above tide. East of the ridge and 2 mile north of Ypsilanti, on the Bennett estate a single well shows great thickness of the hard till, reaching it at a depth of 106 feet and penetrating it to bed rock at a depth of 300 feet.
Some of the best exposures of the hard till are in the bed and banks of Huron River below the city of Ypsilanti. Just below the Ypsilanti water works station it forms a reef-like shelf along the west bank of the river, and about a mile farther lown, in a point that projects sharply into the
valley from the north side, it rises to a height valley from the north side, it rises to a height of
25 feet above river level. The preservation of this sharp projecting point seems to be due to the great resistance offered by the hard till to the stream. A good exposure of what may prove to be preisconsin drift is found above Ann Arbor, at point where the Whiley there Lake road nises from he valley to the bluff. A tin sheet somewhe blue and brown probably by irrogur ont motted blue and brown, probably by irregular oxidation, Drift struck in cuts along the Ann Arbor Railroad borth of Northfield station, at altitudes of 960 to 970 feet, is so indurated that the laborers working on the railroad found great difficulty in excavating it. In general appearance, however, it is freshe than most of the pre-Wisconsin drift.
Wells along the high moraine leading southwest from Ann Arbor have penetrated 100 to 130 feet of soft drift of Wisconsin age and then entered th hard till. For example, a well in sec. 2, Lodi Township, reached the hard till at a depth of 130 feet and was continued in it to a depth of 230 fee without reaching rock. The hard till here has an altitude of about 930 feet above sea level. Another well, in sec. 36, Scio Township, penetrated about 100 feet of soft Wisconsin drift and then entered the hard till at an altitude of about 920 feet above sea level. Between these wells and Ann Arbo in sec. 5, Pittsfield Township, a boring penetrated ltitude 822 fet po tide
The data so far collected seem, therefore, to ind ate that a very uneven surface, due in part to irregularities of drift aggregation and in part to eadvance of the ice in the Wisconsin sta the glaciation; and the Wisconsin drift has simply eneered the surface and only partly concealed it features.
section of the interlobate moraine and the attend ant gravel plains developed between the Huron-
Erie and Saginaw ice lobes during the Wisconsi Erie and Saginaw ice lobes during the Wisconsin
tage of glaciation, when the remainder of the quadrangle was occupied by the Huron-Erie ice lobe. The interlobate tract was the fist to emerg rom the ice sheet and the quadrangle becam ith the recession of the Huron-Erie lobe
The interlobate tract embraces the portion of the quadrangle that lies north of a line leading from ourmile Lake past Whitmore Lake to the hamlet f Greenoak. This tract, however, was not formed om end to end at one particular time, as were some nd extended along the line of retreat of the junction of the two ice lobes, and, as indicated by the geologic map, is very broken. The part north of Fourmile Lake was formed earlier than parts along the westward-flowing stretch of Huron River and rangle that first become free from ice
The features built up along the line of retreat of the junction of the ice lobes are complicated and heir study in detail will probably help to show he mode of development of interlobate moraines, Indeed, the portion of the interlobate tract that alls within the limits of this quadrangle not only well illustrates in its variety of topographic feafrms a pat but $f$. orms a part, but serves as a fair sample of th In northwe on Dexter and southor Puce ownchips the surfaee is remarkably ruged, shap ridges and knolls inclosing deep basins. In cast ern Dexter and northwestern Webster townships there are prominent gravelly hills or kames. A high kame stands immediately north of Pinckney and there are others near Winans Lake, northeas of Hamburg, and north of Whitmore Lake. These kames are conspicuous landmarks of the region, for hey may be seen at a distance of several miles. he moraine are more conspicuous than the ridge and knolls, though the surface among the basins ar from level.
The Sayinaw component.--In northwestern Ham burg and northeastern Putnam townships is th portion of the interlobate moraine developed by he Saginaw lobe. Its northwest or iceward border extends beyond the limits of the quadrangl atres a drainage which was formed between gecia bes Aide from the bames the morine is prominent In this area as in the tracts south vest of Hamburg the basins are more noticeable than the hills and ridges. An inconspicuous group of drift knolls 1 mile to 2 miles east of Pinckney, in the Huron River gravel plain, may be referable to the Saginaw lobe, though it stands somewha part from the remainder of the Saginaw compo ent. At the time the two ice lobes completel coalesced in the area now covered by Hambur Township and the eastern part of Putnam and Dexter the Saginaw lobe extended about to Portage River, in Putnam Township.
Huron-Erie component.-The Huron-Erie component embraces the portion of the moraine on the south side of Huron River from the border of th quadrangle at Greenoak to the bend at Portage Lake, and probably includes also the interlobate Lact It interrupted by gavel pla which mark the frmer course of anage to the gravel plain or crine in
 the midst of the interlobate moraine is shown the geologic map.
Basins.-In the morainic part of the interlobate ract, as well as in the gravel plains, there ar numerous basins, some of which are occupied by akes. Other similar basins stand somewhat back from Huron River, along tributary lines of glacial drainage that led into the main line from the north passing along the later border of the Saginaw lobe and from the south, through gaps in the morainic idges along the border of the Huron-Erie lobe The basins, however, become inconspicuous beyon the limits of the interlobate moraine either north o

The presence of so many basins in an interlobate ract is generally supposed to be due to the burial the drift, in the course of its deposition, of masses of ice which, on melting, left the surface indentel by basins. The deposition is thought to have been rapid, for the lobes of ice were converging and were onosited at this time is indican aun of drif deposited at this time is indicated by the difference ad the wfe of the bodering 1 d pssibly may be meared by the beigh of the idges and knolls above these basins height of the basins along the border of Huron River reach depth of nearly 150 feet below the adjacent grave lains, their bottoms standing 750 feet above see evel. The highest knobs in this interlobate belt aceed 1050 feet in height, thus rising more than 00 feet above the bottoms of the deepest basins. The depth and extent of the basins in this interbate belt, together with the fact that they remained unfilled while the ice was retreating to a distance of everal miles and discharging a large amount o utwash into this westward-flowing part of the Huron, seems to indicate that the outlying ice bocks persisted in the drift for a period to be With in centuries if not in thousands of years. With a view to determining the probable or possile length of time that such masses of ice might arsist in deeper basins, an estimate has been oo feet thick buried to a depthears 0 a vould persist about 450 years, while if the tem-年rature were but $1^{\circ} \mathrm{C}$, which is not unlikely he time required for melting would be doubled Should the cover have been thicker than 2 meters s seems probable in some places, the ice would have been preserved longer. The estimate therefore indicates that the larger masses of ice may have persisted more than a thousand years. In this connection attention is directed to the fact that mall masses of ice derived from Alaskan glaciers ave been preserved in a lateral moraine for a time during which the glacier has shrunk to a level 300 eet lower and to a distance a mile farther up its valley than it occupied at the time these masses became detached from the glacier. (G. K. Gilbert, . 56.$)$
A moderate settling of material appears also to ave occurred in portions of bordering gravel plains. For example, the general level of the avel plain near Portage Lake and Pinckney is 15 miles farther west, is fully 20 feet higher. Yet he clacial waters were discharged westward, acros he divide. The character of the bedding in the deposits near Portage Lake indicates a vigorous current of water, the material being largely oravel It can not therefore be assumed that the low area was occupied by a pool, and it seems necessary to infer that the amount of settling here has been reater than at the divide. It may be supposed hat a thin sheet of ice was buried here, which, on melting, let the material down, as in the basins, But the settling may have been brought about in other ways. The greater amount of settling may due in part to the greater thickness of loose material deposited in this lower region, east of the livide, for it was here apparently fully twice as hick as on the divide. The water apparently percolated more rapidly through this lower porthon, bividg in riting than that on divide, and the resulting greater solution of limestone to settling.
Closely connected with the southern part of the interlobate moraine is an esker which will be condered before the inner border district is described The Lima esker.-The Lima esker is the only presentative of this class of glacial ridges noted in the Ann Arbor quadrangle. In its length of early 5 miles it lies entirely within the limits of ima Township, its head being in the eastern and hip. It in the thain of kames west of Fourmile Lake with a large kame mass on the ner border of the interlobate moraine northwest of the lake. It lies along the borders of a swampy depression that is traversed by the outlet of Four-
mile Lake, though the stream that formed the esker, as shown by its bedding, flowed in a direc
tion the reverse of that taken by the lake outlet. The esker stretches westward from Mill Creek valley to Lima, but its trend there changes abruptly from west to about north-north west, a course which it maintains to its terminus. Along its course it exhibits also minor curvings and meanders. From Lima northward it is a nearly continuous ridge, aps. mile in A sur joins the main esk mile north of Lima
In height the Lima esker ranges from 5 feet or less to about 20 feet, and in breadth from 50 feet to about 500 feet. Its slopes are generally rather gradual, for it is steep sided at only a few points. altitude of nearly sheet shows that this is due to its position-that is to the altitude of its base-rather than to variations in its own height. Where it stands in the bottom of the marshy depression its altitude is not far from 880 feet, but on the edge of the bordering till tracts it reaches 940 feet, while in its usual position on the slope it stands between 00 and 920 feet above sea level.
The esker is composed of a rather sandy gravel ${ }^{n}$ which the pebbles are not conspicuously rounded or waterworn. Among the pebbles are fragile pieces of black Devonian shale, which seem to betering subjected to remarkably little stream the mas. Theses that the material of the esker was very little transplease fin and release from the ice. Very few of the pebbles brought from distant sources. Most of them were derived from rocks that outcrop in southeastern Michigan between the esker and the western end of Lake Erie, and apparently less than one-tenth of the coarse material is from Canadian crystalline rocks. It is of interest to note that much of the material in the esker stands 300 to 350 feet higher thàn the ledges from which it was derived. This lifting of the material was probably accomplished by the ice, and not by the esker stream, for the ice heet passed from the lower into the higher country. The Lima esker and its attendant features may throw some light on the question of the horizon of esker development in the ice sheet, though the conditions that prevailed at the time the esker was formed are not yet fully understood. The currence of so large a percentage of local mateaeems best explained on the hypothesis that iee shet, for is sto a dian have sional formity to the lin of lawest altude in the depresed tract which it follows appear to indicate that the esker stren wa in pear 10 indicate that the and was therefore slightly above the ground surface beneath the ice sheet. Another feature surgesting that the horizon may not have been so low as the bottom of the ice sheet is the accumulation of gravelly material in kames at the terminus of the esker up to an altitude notably higher than the surface of the ground moraine along its course-a places higher even than its crest. The kame southwest of Fourmile Lake reaches an altitude of more than 960 feet, and the group northwest of the lake has points that stand more than 1000 feet above dide, or nearly 100 feet above the general level of the esker. The beaping of this gravel at the terens of the esker seems to point either to the esker-forming stream as a contributor, or to an earlier stream or streams, following essentially the the rob or $y$ ared by the presumption that the water may have gushed up at the margin of the ice A stream might thus reach a higher altitude in building the kames at the maroin than it had when building the esker the margin than it had when building the esker made by Russell at the border of the Malaspina Glacier show the presence there of strong gushing streams such as are here suggested. While, therefore, the esker stream may have been floored by ice, it is not certain that its horizon was so far above the level of the base of the ice sheet as to give a continuous descent to the kames that were apparently formed by it at the ice margin.
The low tract which the esker follows is a charcteristic feature of this and many other eskers. It
angle embraces in its northwest corner a small south of the Huron Valley
Area and character.-The Ann Arbor quad
angle embraces in its northwest corner a smal
is a strip one-fourth to one-half mile wide, which stands 20 to 40 feet lower than the bordering land. made certain not only by the presence of the esker on its bed and slope but by its general freedo from erosion features. The inequalities of its sur face are such as result from glacial deposition rather than from stream erosion. It seems to mark a belt in which the ice sheet supplied insufficient material to build up the surface to the general level, while the mass of kames at the northwest end of the tract suggests the place to which the glacial material was carried and deposited. This lack material, it is thought, may have resulted from th fact that streams (such as that which formed the esker) carried much of the material within the ice sheet out to its margin and there built up the form an esker probably depends on the adjustment of the stream to the size of its channel or tunnel. If the tunnel were large and only partly occupied by the stream an esker might be tunnel constricted and the head of ice kept the tream was it would be vigorou stream was great, as in woul be after vigorous may have been sufficiently strong to carry all the material through the tunnel and build it into kames at the ice margin. The streams carrying this material to the margin would deplete the por tion of the ice sheet traversed by them of such material as was within their reach, so that on the complete melting of the ice the depleted portions would be marked by belts of land standing lower than bordering portions that were not thus depleted. The esker-building stage apparently followed the stage in which the material in the tunnels was more completely swept to the ice margin. Indeed, the position of the esker on the surface of the ground moraine seems to indicate that it was formed as the ice was disappearing after all ice movement had virtually ceased, when conditions in which it was deposited.
the ice from the tateri
In melting back from the interlobate moraine the Saginaw lobe withdrew northward and disappeared from the Ann Arbor quadrangle, leaving of the Huron-Erie lobe
The interpretation of the first steps in the shrinking of the Huron-Erie lobe within this quadrangle is not easy, it being questionable whether the shrinking went on at a somewhat regular rate all along the border, or whether the ice held its position at certain parts of the border while shrinking in other parts. The withdrawal of the ice from the interlobate moraine in the western part of the quadrangle may have preceded its withdrawal in the northern part, just as the development of the interlobate moraine appears to have begun earlier in the western part.
The western part of the district between the interlobate moraine and the large morainic system farther southeast is generally free from welldefined ice-border phenomena, but a bowldery in extending along the north side of the swas the Lima esker to Dexter may show the trend of the ice border at a brief halt in its retreat. This the ice border at a brief halt in its retreat. This in southern Lima Township, but elsewhere it is no more undulating or moraine-like than the border districts. This bowldery strip runs nearly parallel with the moraines on each side of it and its position apparently supports the view that the ice border made a general regular retreat.

The northern part of this intermorainic strip, from Dexter northeastward, is much more varied in expression than its western part. For several miles east of the bend of Huron River, in Webster and northern Scio townships, the surface is of morainic type but comprises numerous kames.
This area nearly connects at the northwest with This area nearly connects at the northwest with
the interlobate moraine and thus suggests a somewhat close relation to it, comparable to that of the Lima esker to the moraine. East of Webster townships, much of the surface is flat and the trift is of much of the surace is flat and the it is interrupted by strips of the gravel plain that
stretch from the southeast to the great gravel plain
in the valley of Huron River. The first indicain the valley of Huron River. The first indicasoutheast of the interlobate moraine is found in bowldery strip, accompanied by low hummock and shallow basins, which runs eastward through the central part of Northfield Township and connects in western Salem Township with a moraine of greater strength. At the west it connects with the rolling tract of Webster Township just noted Few of the knolls in this strip are more than 10 feet high, but these knolls and the basins that accompany them give the surface a wavy appearance which is in striking contrast to the very flat sur ace of the gravel plains and is also more varied than that of the till plains of the northern part of Northfield Township. The gravel plains heading in this bowldery strip give added plausibility t he opinion that it marks an ice border.
One of these gravel plains heads in secs. 28 an 29 , Northfield Township, and takes a course slightly west of north past Horseshoe Lake to Whitmor wide. Its surface is indented by shallow baid ne of which is ceupied by Horsello The waters that cormed this Horseshoe Lake to have been unable to carry gravel or san beyond Whitmore Lake, but may have found ascape either northeastward, along a sandy strip or northwestward to Huron River along the line of the outlet of Horseshoe Lake. A series of knolls and marshy depressions south of Horseshoe Lak have the appearance of ice-border phenomena and suggest that this gravel plain was started when the ice stood as far north as Horseshoe Lake and was extended southeastward with
of the ice border in that direction.
Another gravel plain heads in the north part of secs. 13 and 14 and covers much of secs. 11, 12, 1 and 2 of Northfield Township. This plain also may have been extended southward with the with drawal The ict ship. The outwash matial is coarse, and in very far from the immediate border of the ic very Thus the extent of a gravel plain m
means indicate the vigor of the outwash.
Another gravel plain, which is well developed in northwestern Salem and southwestern Lyon townships, extends southward beyond the bowlder belt noted above and connects with a later morain but the northern end of it may have been formed before the ice retreated from this bowldery area. In line with the suggestion just made-that in some places along lines of glacial drainage considerable deposition occurred as the ice was melting back from the interlobate moraine toward its nex prolonged halting place (at the outer moraine the Huron-Erie system)-it may be observed tha the coarser deposits are perhaps due in larger degre to strong currents forced out at the ice border or from under the ice by great water pressure within the ice. An inspection of the gravel seems to sustain this view, for much of it is not so well ronded as it should be if thansported for several miles down the drainage lines. Other items of evidence a sophar the sheet. For example a gravel strip that beads in sheet. For example, a gravel strip that headse slightly higher than portions of the bordering till plain. This upbuilding could hardly have occurred unless the ice still occupied this till plain while the gravel was being deposited. A gravel strip that heads in central Scio Township and leads westward is loaded with surface bowlders for a mile or more west of its head, as if the deposition had taken place while the ice still covered it, before it had shrunk to the position marked by the head of the gravel plain. Of course the ice border may hav oscillated a little and at times extended slightly beyond a moraine while forming it.
morainic system of the huron-krie ick lobe.
Moraines of the system.-The morainic system of the Huron-Erie ice-lobe occupies a belt from 6 to 10 miles wide extending from the northeast to the the areal coor (See also , 5hown ine areal geology map. (Nee also fig. 5, p. 4.) It outermost or western one is a probable continu-
tion of the Fort Wayne moraine of the Maume while the eastern one is a continuation of the Defi nce moraine. The middle moraine is weaker an less continuous than the others. From the south ern part of the quadrangle southward into Ohio merged with the Defiance moraine.
Fort Wayne moraine.-The outer or Fort Wayne moraine is by far the strongest of the system, though, as indicated above, it seems to have a preWisconsin basement ridge. Throughout much of its course across the quadrangle it constitutes a divide between drainage systems. In the area of Hest of Ann Arbor it separates the drainage Huron from that of haisin River, while in he drainage of Huron from that of Rouge River Huron River, it will be observed, passes through the moraine just above Ann Arbor. In this norainic system basins do not form so conspicuou part feture as in the interlobate moraine, a larg well of topography. Busins are however, not rare and few of them contain lakes. The sharpest hills or knolls of gravelly constitution are generally kames Lake, which carvìs the highest point in the quad rangle ( 1107 feet) there is a prominent kame abou 2 miles west of Ann Arbor, which rises above the 1080-foot contour. Other kames lie north and eas of Ann Arbor, on the north side of Huron River nd a conspicuous group occurs east of Emery.
ade mone and associated till plains.-Fron le moraine northeast ward nearly to salem he mid Fort Wayne moraine, but from Salem eastward to and beyond the edge of the quadrangle is distinct from it. In the region south of Ann Arbor it distinct from both the others as far as Saline, bu is combined with the Defiance moraine in the area between Saline and Tecumseh. Immediately east of Ann Arbor there is a prominent drift mass on fore are lise main body of drift being in all probability refer ble to alder or Wisconsin age About a mile south of pre boundary line between Ann Arbor and Pittsfield townships this middle moraine leaves the high ract and becomes relatively inconspicuous an before reaching Saline River it takes on a comple form, being composed of three parallel, very fain ridges. On the south side of Saline River there is rather prominent moraine, formed by the combination of this moraine with the Defiance morain
The topography of this middle moraine is of the nob-and-basin type near the northeast corner of the quadrangle, but elsewhere is predominantly of the swell-and-sag type, and most of its prominent nolls are kames.
In Pittsfield Township a till plain having a area of 12 to 15 square miles lies between the middle moraine and the Defiance moraine. This is the largest till plain in this morainic system within the Ann Arbor quadrangle. The next in
size, covering an area of 2 to 3 square miles, li ize, covering an area of 2 to 3 square miles, lie and outer members of the system.
Defiance moraine.-The Defiance moraine enter he quadrangle about 5 miles south of its northeast f Fleming ald ang the east sid Geddes. From that point it takes a curving cours southward and westward to Saline River below the village of Saline, and thence to Tecumseh it follow the eastern edge of the combined belt. At some places its eastern slope extends down below the hore of the glacial Lake Maumee. Many irreguharities of surface in the lake bed are due to not effaced by which have been toned down but portion of the moraine that stands above the leve of this old lake exhibits swell-and-sag topography ontaining but few basins and laken
No definite morainic ridge younger than th Defiance moraine appears within this quadrangle At the east border of the sandy tract in the south ast corner of the quadrangle, however, a some he Defiance morine probably marks the outlin of the ice lobe at a brief halt in its retreat. This
rip may therefore indicate an iceward limit of Lake Maumee. The abrupt border of the sand a his line is also consistent with this view, for the material have prevented the transportation of after ward developed in the plain where the ice had tood have carried the sand down their valley and thus broken at some places the continuity of his line, which otherwise appears to mark an ice border.

## local glacial drainage.

From the outer or northwestern moraine of this system there were several lines of discharge withi he limits of this quadrangle, as indicated on th eologic map. All of these drainage lines conerge toward an outlet, westward past Pinckney, discussed under the heading "Drainage developent." Two of them, in Novi and Salem town hips, were also lines of discharge from the middle oraine, but the others, except that coincident with Huron River, became inoperative when the ice hrank away from the outer moraine. The head most of these lines of glacial dranage, as the con$0 \mathrm{fet}, \mathrm{b}$ litle 1 hannel near Pincloy. Higher trect of out ecur in Fredom Townchip enst of Plesant Lake in sec. 25 of Scio Township, south of Sister Lakes nd near Emery, in the southeastern part of North feld Township. The surface of some portions of the outwash near Huron River in the western part of the quadrangle stand below the 900 -foot conour, or lower than the portions at the outlet. It eems probable, as has already been suggested, hat, since the deposition of the gravel, these low portions have settled more than those at the outlet nd that the original gradient of the outwash tract has thus been altered. In some places, however here appear to have been pools in these lines of rainage. It seems hardly probable, for instance, hat the lines that head in northwestern Lodi and in astern Scio townships had well-graded beds fron heir junction in western Scio Township northward arel floor of the northem ort of the rave for hich $d$ southand inted of nothwerd, wough it may have been begun by strems flowing westward through the outlet at Pinckney.
The line of glacial drainage that heads 2 mile orth of Ann Arbor leads northwestward through well-defined valley standing 20 to 40 feet below the border districts and having a width of about one-half mile until it approaches the northwest corner of Ann Arbor Township, where it become nuch narrower. It continues narrow for a few miles and then opens into a gravel plain nearly mile broad, standing about at the level of a til plain east of it. The eroded part of the valley, may be said, terminates at this point. This valley ppears to be due to ordinary erosion, and not be a partly masked interglacial valley. This being the case, its erosion and subsequent filling may b used to estimate the time taken by the ice to for he moraine in which the gravel bed heads. The glacial draingen the midale moraine is
 he ice bor ${ }^{\circ}$. lower than its top. The drainage from the noth os or the castern pased thi qarange, hover, appears long two lines toward the outlet at Pinckney, and may have passed through that outlet. One line headed about 2 miles southwest of Salem, the othe 3 miles northeast of the same village, and they came together near South Lyon. Whether the drainage continued northwestward through the Pinckney outlet may have depended on conditions for discharge farther south, and those have not yet been fully investigated. At this time there was apparently an open channel not only down Huron River to the edge of the ice at Ann
Arbor but also from Ann Arbor southwestward Arbor but also from Ann Arbor southwestward long the ice front to the valley of Raisin Rive near Clinton. The ice border there may have extended across to the west side of Raisin River, but need not have obstructed drainage along the tan 1 immediately outside is scarcely 850 feet.

An outwash apron about 875 feet above tide $\{$ at Ann Arbor to the level of Lake Maumee-a borders the middle moraine in the eastern part of the city of Ann Arbor. It extends from the south bluff of Huron River southward nearly 2
miles and underlies the university campus. This outwash apron was built apparently into a pool or lake that bordered the ice from the site of Ann Arbor sonthwestward to Raisin River in Bridgewater Township. The lake may have stood a little below 875 feet and its level was probably determined by the lowest available outlet toward the southwest. This is nearly 50 feet lower than the Pinckney outlet, which served as a line of discharge for the glacial drainage from the outer moraine. Back of the outwash apron just discussed is a depression (fosse), separating it from he moraine. This fosse, which extends only from he university campus northward to Huron River is a strining topographic feature and contains sev-解 position in this fosse while the outwash apron out ide it was built up to a height of about 40 feet.
In the northwestern part of Ann Arbor there
a somewhat older gravel outwash plain which stands at a higher altitude than the campus plain, its upper level being at about 920 feet. This gravel it is likely was deposited while the ice still occupied he low recess in the western part of the city and the valley of Huron River in the northern part. The bedding shows a westward dip from the very brow of the west bluff of the river, indicating that the discharge was westward, probably through a narrow, winding channel across a low part of the outer or Fort Wayne moraine to Sisters Lake, in ec. 25 , Scio Township, whence it may have passed o the Pinckney outlet. The Pinckney outlet was therefore probably abandoned when the ice sheet withdrew from the high tracts in the western part Ann Arbor and thus permitted the drainage to urn away from the present Huron valley at this The placil southwestward to the Raisin Valley and probably also that from the headwater part of and probably also that from the headwater part of
the Huron valley, took a southwestward course from Ann Arbor to Raisin River in Bridgewater Township, and thence down the Raisin Valley into Township, and thence down the Raisin Valley into
ake Maumee. For a time the ice probably covered he course of the present stream below Tecumseh and held the drainage in the area now occupied by the gravel tract west of the river from Tecumseh to Adrian, but before the moraine was completed the ice seems to have left this part of the valley open and permitted Lake Maumee to extend up about o Tecumseh. The drainage connected with the part of the moraine north of Huron River seems or a time to have passed from the mouth of Fleming Creek westward, or up the present valley of he Huron to Ann Arbor, traversing a gravel-filled valley that turns westward from Fleming Creek ne-half mile above its mouth. The ice margin then probably rested against the eastern face of the nn tract When the ice shrank from away this an Arbor. When the is son from away this igh tract a low This, however, seem to have been covered by a pool or slack-water body for it is not raded up to the level of the valley floor north of the river and contains very little gravel or sand uch as would have been deposited along it if it had been traversed by a strong current. Another pool probably stood on the outer face of the moraine northeast of Brookville, in the swampy tract now ributary to Rouge River. Near Northville, which stands just east of the quadrangle, the glacial outwash reached a height of 860 feet and marks the probable level of the pool just mentioned. This would carry the drainage across the present gravelly ivide south of Brookville between Rouge River and Fleming Creek. Probably the largest pool in the line of this drainage filled the sag now drained y the headwater branches of Saline River between Pittsfield and River Raisin. This pool was perhaps 16 miles long.
It may have been as early as the time when the Defiance moraine was forming that Huron River graded up its bed in the vicinity of Dexter so high would have carried it into its present course. At least the abandoned section south of Dexter was pparently not affected by the wave of erosion that passed through the valley when the river dropped

Ann Arbor.
at Ann Arbor to the level of Lake Maumee-a
drop made soon after the ice shrunk away from the Defiance moraine. This abandoned section appears to correlate well with the abandoned course that leads southwestward from Ann Arbor and with it.

## dactal lakes

First or upper beach.-The highest of the series large glacial lakes that occupied the southeastern part of the Ann Arbor quadrangle discharged past ort Wayne, Ind., to the Wabash and thence to The Ohio and Mississippi and the Gulf of Mexico, the Fort Wayne outlet being for a time the lowest one available. (See fig. 8, p. 10.) This lake, known Lake Maumee, began with the withdrawal of the ice sheet from the he eastward retreat of the ice became gradually Ohi wad the bain of Iake Erie and north Ward into Michigan. For a ensiderable northduring the development of the Defiance moraine the area of this lake was probably nearly constant and was restricted to the lowest part of the tract between the Fort Wayne and Defiance moraines in Indiana, Ohio, and southern Michigan. Its water at this stage scarcely touched the Ann Arbor quadrangle, for the low land west of the Defiance moraine in this quadrangle is nearly all above the highest level of the lake. On the withdrawal of the ice sheet from the Defiance moraine the water of Lake Maumee invaded the part of the quadrangle immediately south and east of the moraine and extended
Huron Valley to Ann Arbor. It also filled to ap Huron Valley to Ann Arbor. It also filled to ome extent the low tracts bordering the Saline
Valley inside the moraine, but the clayey tract in the southeast corner of the quadrangle may have en covered by the ice sheet nearly to the close of is highest lake stage.
The occupation of the southeastern part of the hown by such features as are commonly four on he shores and beds of extinct lakes - beaches bars and cut banks, produced by wave action, deltas where streams entered the lake, and sandy sediments on the bed of the lake. From the highest beach and the stream deltas the upper limits of the take may be easily determined. The beach shows ome variation in altitude and possibly a slight northward rise in its course across the quadrangle,
as indicated below. It seems probable, however, hat the vations are due chiefly to fluctuation in level, such as are now exhibited by the Grea Lakes. The altitude of the beach generally falls etween 795 and 805 feet above sea level, yet at places it reaches 810 or 812 feet, and at one place within this quadrangle and another in the Wayne quadrangle on the east it stands above the 820 -foot ontour. So great a variation as is required to wach the 820-foot contour is beyond what one nd doubt is therefore felt as to the accuracy of the nd touring points. The plaee in the $A$ nu rbor quangle is the extreme northwest cor er of the French Claim, about a mile west of psilanti. The delta of Huron River at Ann Arbor is 812 feet and this apparently marks a igh lake level. The lake at its ordinary level, as indicated by the usual height of the beach, stood between 800 and 805 feet, while at extreme low water it may have stood a little below 800 feet. The altitude of the beach has been determined at several points farther northeast, where it is crossed by railroad surveys, but it shows no marked rise in passing across north western Wayne nd southeastern Oakland counties, its general altitude being between 800 and 810 feet. From Clinon River, in western Macomb County, northward bout 25 miles to Imlay City the beach rises nearly 40 feet or to about 850 feet above sea level. This orthward rise in the beach is supposed to be due, in part at least, to a diferential elevation of the gro of a nord $A$ part of the no
This beach varies considerably in strength, the variation being such as is natural on the slope of moraine in an irregular region. Where the unbroken or regular for a mile or more, a good
beach was usually formed, but where the shore was $\mid$ Saginaw basin and discharged directly through the broken by morainic knolls or where the water was Grand River outlet to Lake Chicago. The portion faint or so discontinuous as to be difficult to trace. In places it is made up of two or more closely associated ridges differing very little in altitude, a conspicuous instance being found in the south western part of Ypsilanti Township. As a rule, however, there is very little overlapping or duplicating of the ridges. The lake must have stood much longer at this level in the southern portion of its area,
outside the Defiance moraine, than in the northern outside the Defance moraine, than in the northern quadrangle
Second Maumee beach.-The second beach of Lake Maumee (perhaps the third in age) stands Arbor quara or near the 780 -foot contour. At all places it or near the 780 -foot contour. At all places it to 25 feet below the first beach. This difference continues northward to the Imlay outlet where the second beach stands at about 825 feet. Its altitude where crossed by the railroad east of Almont (about 6 miles from the head of the outlet) is 821 feet, while that of the first beach is 840 feet. The second beach appears at an altitude of about 820 feet on several of the Mauhead of the outlet. The rise from 785 feet to 825 feet is nearly all made between Clinton River and the Imlay outlet, a distance of 25 miles.
The portion of the second Maumee beach within the Ann Arbor quadrangle is better defined and is more continuous and regular than the portion of the first beach. It is, however, no stronger than the best developed parts of the first beach. It is fully as strong in the Ann Arbor quadrangle as at any which formed it probably stood as long here as in which formed it $p$
areas farther south.
The Fort Wayne outlet seems to have been ope ative for a time in connection with this second each, but the Imlay or noth outlet may late have taken the entire discharge, for it appears to Third Maume
cond in age), easily traced in the southern part of the quadrangle but difficult to trace in the part north of Huron River, stands about 20 feet below the second beach, or near the 760 -foot contour. Its relations are not yet fully determined. At many places it presents a rather washed-down appearance, as if it had been submerged, and this feature suggests that after this beach was formed the ice may have encroached upon the lake's out-
let (which perhaps stood north of the Imlay outlet), let (which perhaps stood north of the Imlay outlet),
and caused its water to rise to a higher level. Posand caused its water to rise to a higher level. Pos-
sibly this may prove to be older than the second sibly this may prove to be older than the secongh
beach. It appears to have been barely high enough beach. It appears to have been barely high enough
to have opened into the Imlay outlet if its north have opened into the Imlay outlet if its north beaches. This beach has not been traced south ward into Ohio and Indiana.
At Plymouth, Mich., a short distance east of the limits of this quadrangle, this third beach is excepbrought in by Rouge River. It also exhibits unusual strength on the fan-shaped gravelly area where Huron River opened into Lake Maumee east of Ypsilanti. Moreover, this gravelly are appears to be, in part at least, a delta of the Huron and it conforms more closely with the third beach than with the higher ones. The full interpretation of this beach must be deferred until its relations are better known.

A series of weak, fragmentary ridges, three in number, apparently come next in age after the Maumee beaches and precede the Belmore beach, though the position of the latter is between them and the third Maumee beach. These beaches represent a glacial lake known as Lake Arkona
Their weakness and fragmentary character is thought by Taylor to be due to a later resubmergence during which the beaches, which were originally strong and continuous, were nearly
obliterated. (F. B. Taylor, Proc. Michigan Acad. Sci., vol. 7, 1905.) The lake that formed these beaches occupied not only much of the district covered by Lake Maumee, but extended into the
of its bed between the Saginaw basin and Lake St.
Clair was subsequently covered by a readvance of the ice, and the portion of the lake in the Maumee basin was raised to a higher level, forming a body of water known as Lake Whittlesey.
The highest Arkona beach in the Ann Arbor quadrangle stands about 705 feet with a few points as high as 710 feet, the middle about 700 feet, and the lowest about 695 feet. They are slightly higher in the northern part of the quadrangle and also in much of the Saginaw basin. The development of three beaches is supposed by Taylor to be due to reductions in the height of the Grand River outlet, which by erosion was lowered in such way as to
lower the level of the lake in two steps of a few lower each.
The beaches are at most places washed down to scarcely perceptible ridges, but the gravel which they contain marks their courses with much clearness, especially on the clayey parts of the lake bottom
Evidence that the Arkona beaches mark the shores of a lake of long duration is found in the river deltas. The Huron delta covered several square miles in the southeastern part of Ypsilanti Saline western part of Van Buren Township. in southeast formed a large delta, which appears townships. The delta of Raisin River is even larger than that of Huron River, but lies south of this quadrangle.

The beach in this region which seems to have attracted the earliest attention of geologists is the Belmore, named from a village in Ohio which stands on the beach, but known also as the Whitwas mapped for fully 60 miles by the first Miehi was gan Geological Survey prior to 1840 . It is a large the plain its la 15 fet above the plain on its lakeward side and o to 15 feet above its landward border. It is built like a dam
across valleys which had been cut down to conform with the preceding lower lake level (Lake Arkona), and in such situations its landward relief is about as prominent as the lakeward. The advancing lake, as suggested by Taylor, appears to have carried the beach farther up the slope and given it a prominence not found in lakes that made no such advance. Then, having reached its highest stage and taken its discharge through the Ubly outlet (see fig. 10), the lake seems to have fluctuated less than some of the other glacial lakes. The outlet is broad enough to have prevented heaping up of lake waters in wet seasons and is in places floored by sandstone rock, which would prevent it from being cut down. The lake was therefore probably kept at a very steady level and might in a certain time have produced a stronger beach than If we may determine the duration of a lake by If we may determine the duration of a lake by Whittlesey did not endure so long as Lake Arkona or as its successor, Lake Warren Inded, the deltas are surprisingly small, not only in the Ann Arbor quadrangle but at many points beyond its limits. On Huron River the delta deposits lie chiefly between the city of Ypsilanti and the Whittlesey beach, there being a filling or grading up of the valley to correspond with the rise of the lake from the Arkona level.
At a few places in the Ann Arbor quadrangle the Whittlesey beach rises to the 740 -foot level, but its crest stands generally between 735 and 740 feet. For a distance of 300 miles along the western and southern shores of the lake from Clinton River in Macomb County, in Michigan, southward and eastward to Ashtabula, in northeastern Ohio, the level of this beach is remarkably uniform. From Ashtabula northeastward to the terminus of the beach many miles A. Y., in the 75 miles from Clinton many miles, and in the 75 miles from Clinton 60 feet. The northward rise appears to be confined to the portion of the shores lying north of a line running from Clinton River near Rochester, Mich east-southeast to Ashtabula, Ohio. It will be observed that this line, as would be expected, runs at nearly a right angle to the line of uplift men-
tioned in the discussion of the upper Maumee beach-an uplift which appears to be still affecting
the Great Lakes region. (G. K. Gilbert, Eighthe Great Lakes region. (G. K. Gilbert, Eigh-
teenth Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 595-647.)

## Lake warren.

Upper Warren (Forest) beach.-Lake Warren, which succeeded Lake Whittlesey and embraced came to its level as the result of the withdrawal came to its level as the result of the withdrawal Bay and Lake St. Clair. (See fig. 11, p. 11.) The Bay and Lake St. Clair. (See fig. 11, p. 11.) The
highest beach, also known as the Forest, has an altitude in the Ann Arbor quadrangle of 675 to 685 altitude in the Ann Arbor quadrangle of 670 to 685
feet, and at most places in its course stands very near the 680 -foot contour. The beach rises northward to an altitude of about 780 feet, which it reaches on the point between Lake Huron and Saginaw Bay, but on passing southwestward from that point to the head of the Grand River outlet it drops to about 680 feet. Indeed, the outlet seems to be a short distance south of the line at which the northward differential uplift sets in. The beach is practically horizontal from the Ann Arbor quadrangle southward and eastward across northern Ohio, but between the Ohio-Pennsylvania line and Batavia, N. Y., it rises about 200 feet, or to 880 feet above
sea level. sea level.
The portion of this beach within the Ann Arbor quadrangle is exceptionally weak and disjointed. It is weak on the clayey part of the lake border, probably because of shallowness of water off shore
The sandy portions are difficult to interpret. If The sandy portions are difficult to interpret. If the entire sandy belt be considered a shore product
it would be very strong, but probably a considerit would be very strong, but probably a consider-
able part of the sand was deposited along the border of the ice as it melted back across this region, for a bowldery strip on the eastern border of the sandy belt, seems to mark a halt of the ice at that point. The lake waves and currents may therefore have worked upon sand previously deposited, and the waters in this region being shallow may have been able to produce only disjointed and comparatively weak ridges along the shore.
The duration of the stage marked by the upper Warren beach may perhaps be estimated from the work accomplished by Huron River, which exca-
vated a valley about $1 \frac{1}{2}$ miles wide and 15 to 20 vated a valley about $1 \frac{1}{2}$ miles wide and 15 to 20 feet deep between Rawsonville and the shore of the lake, which is near the eastern edge of the quadrangle. The valley is narrower above Rawsonville The he terrace is traceable at least up to Ypsilanci helow Ypsilanti appears to of Huron River just several feet below the level of the filling at the Lake Whittlesey stage, and this cutting probably occurred while Lake Warren stood at the level of the upper Warren beach.
Lower Warren beach.
stands about 20 feet lower than the upper Warren beach is present in disjointed sections in the southeastern part of the Ann Arbor quadrangle. As it is, however, very sandy and in places has been drifted into low dunes that obscure the old shore line it ance represented, its precise tracing is very difficult. In general, however, this shore lies near the 660 -foot contour. It is on the whole weaker han the upper Warren beach, and no marked terrace on Huron River conforms with it. The exact point of outlet of the lake that formed this each can not now be stated. Its waters are thought by Taylor to have stood too low to find an outlet through Grand River. In that case it thet, but its relations to this outlet syracuse outlet, but it
determined.

The Grassmere beach is a sandy strip that lacks the topographic expression of a shore and yet beaches it can readily be traced through clay regions because of its sandy character, and like them it maintains the horizontality of a lake shore, It is possible that, like the Arkona beaches, it has been submerged and partly effaced. The lake that formed this beach probably found outlet eastward past Syracuse, N. Y., into the Mohawk Valley, but the full relations of its beach have not yet been worked out nor has positive evidence of its submergence been discovered.

The Grassmere beach stands about 640 feet above sea level in the southeastern part of Michigan but
rises above 700 feet on the point between Lake rises above 700 feet on the point between Lake Huron and Saginaw Bay. It is apparently repre-
sented in the extreme southeastern part of the Ann sented in the extreme southeastern part of the Ann
Arbor quadrangle by sandy areas in the clay country around the village of Maybee. A strip of sand try around the village of Maybee. A strip of sand
leading northward from Maybee and passing about one-fourth mile west of the Woolmith quarry seems likely to belong to this beach
recent deposits.
ternace and valley alluvium
Shallow alluvial deposits are found on river erraces connected with the old lake levels. Most old lakes expand into sandy deltas of considerable extent, as is indicated in the discussion of the lake history. The narrow valleys below the level of the terraces also contain shallow beds of alluvial material, though the streams are sufficiently vigorous to carry beyond the limits of the quadrangle much of the material they are transporting. Near the headwaters of the streams, where the gradients are low, fine sediment is being deposited in marshes or lakes along the courses of the stream.
organic deposits.
The depressions and poorly drained parts of the quadrangle contain thick beds of muck and peat, which have accumulated through plant growth These dice sheet withdrew from this region. These deposits comprise not only plant remains
but numerous shells of small animals and some bones of large animals. Along the margins of some of the lakes there are also extensive deposits of bog lime or marl, which appear to be due to the growth and decay of organisms which had taken up the lime from the water. The marl deposits are discussed under the heading "Economic geology," but the deposits of muck and peat, though of some economic value, have not yet been devel-
oped commercially and will be described here will also the fossils that are found in these deposits. peat
Areas covered.-That part of the Ann Arbor quadrangle which lies above the highest glacial lake level, that of Lake Maumee, abounds in undrained flat areas, slight depressions, and relatively large basins, which are now covered by wamps or lakes. The deeper and larger basins marshes, or boos; while many of the mall and shal marshes, or bogs; while many of the small and shalthe agency of plants, and present to the eye a flat surface covered by a rank growth of vegetation. The soil below this vegetation is of dark color, or even black, is generally saturated with water from a short distance below the surface, and is nearly or quite devoid of visible mineral matter. This material is commonly called "muck," although the coarser forms of it are sometimes known as "peat," a term that may be as well applied to all its forms, since it grades from one type to another by imperceptible steps. The larger areas of these deposits are shown on the areal geology map.
Since peat has been used for centuries in various parts of the north of Europe, as an efficient and cheap fuel, and since extensive beds of this material occur in this quadrangle as well as in other parts of Michigan, it is described rather fully in is folio.
Physical properties.-Dry peat in its different forms varies greatly in physical properties. In all
its forms it is of low specific gravity, weeghing its forms it is of low specific gravity, weighing without drying, from a well-drained deposit. In color it varies from light brown to black; in texture, from a coarse, rather loosely felted mass of easily recognizable vegetable fibers to a fine-grained, compact, structureless, homogeneous substance, almost as firm and hard as soft coal. Most of the lightbrown peats are lighter in weight and coarser in texture than the dark ones, and one deposit may coarse to fine, and from light to dark, from the top of the mass toward the bottom. Physical analysis shows that vegetable matter, more or less disintegrated and partly changed in chemical composition, forms the greater part of all peat, for the remains
of plants, especially plant cells and fibers con-
stitute the bulk of dry peat. All kinds absor water readily, and deposits that lie below the surface are saturated with it and are darker in color, nuch more bulky, and less coherent than when dry. Moreover, the water it holds is given up slowly and, beyond a certain limit, can not be and tissues of the plant remains. Dry peat ignites more or less readily, according to the thor with which it has been dried, burns with a clear flame, and with little smoke (which, however, increased by the presence of water); and possesses a characteristic pungent odor. If burned in an insufficient supply of air, or with poor draft, it smoulders and remains on fire for an indefinite time, so long as the supply of the fuel is kept up. Kiln-dried peat is hygroseopic, taking up moisture from the air in considerable quantities.
Chemical composition.-From what has been said above of the structure of peat, it is evident that its chemical composition must be variable since the substance itself is so variable. It is als evident that, since it is largely made up of partly decomposed plant remains, it will have somewhat the same composition as these. Cellulose, or ordinary vegetable fiber $\left(\mathrm{C}_{6} \mathrm{H}_{10} \mathrm{O}_{5}\right)$, and lignin, or woody fiber $\left(\mathrm{C}_{12} \mathrm{H}_{18} \mathrm{O}_{9}\right)$, constitute the bulk of the vegetable matter forming peat; these, as the molecular symbols indicate, being nade up of three and oxygen, both, carbon, a solia, and hydrogen peat contains other chemical elements and peands, in very small proportion; therefore its pounds, in very small proportion; therefore ultimate analysis shows the presence mainly of carbon, hydrogen, and oxygen, with greater or less amounts of the ash-forming elements, according to the purity of the peat and the state of its decomposition
In the breaking down of its vegetable compounds the solid element, carbon, is the one that is least readily built into new compounds, so it is left more and more nearly pure as decomposition procee and as, in its ordinary forms this element is black, the peat thus gradually becomes darker in color because of the increase in its content of carbon in an uncombined or elementary form. Carbon is the chief fuel element, although hydrogen in its uncombined form as well as in combination with arbon, has high fuel value.
By averaging the extremely varying results of
numerous analyses and neglecting the numerous analyses and neglecting the ash it is seen that dry peat is composed of four elements, ven, 6 ; oxycen 33 ; nitrocen, 1 It contains more carbon and less oxygen than wood, and about 20 carbon and less oxygen than wood, and about 20
per cent less carbon, 20 per cent more oxygen, and slightly more hydrogen then bituminous coal. Its content of ash varies widely, but in the purest peats is low, running from 2 to 8 per cent. Analypeats is low, rumning from 2 to 8 per cent. Analy-
ses of the samples being taken from two holes 300 yards apart, sunk to different depths below the surface, show the following variation:

\section*{| Sample. | Locality. | $\begin{array}{c}\text { Deptat } \\ \text { infeet. }\end{array}$ | $\begin{array}{c}\text { Per cent } \\ \text { or ash. }\end{array}$ |
| :---: | :---: | :---: | :---: |
| 1 | 1 | 5 | 5.70 |
| 2 | 1 | 10 | 21.00 |
| 3 | 2 | 2 | 4.45 |
| 4 | 2 | 5 | 13.00 |}

The ash of pure peat is practically identical in composition with wood ashes, consisting of carbonates of calcium, magnesium, iron, and potassium,
with small amounts of sulphates, phosphates, and chlorides. To this, however, is frequently added foreign mineral matter that was washed or blown in from the surrounding region.
Distribution.-In this quadrang
parts of the temperate zone, peat is found in other where the ground either is or has been saturated with water. Its accumulation is due to the fact that the principal agents of decomposition of vegetable matter are plants of the lowest ordersbacteria and fungi-which require a certain amount of moisture and air. If the moisture present is sufficient to exclude the air, or a large part of it, the number and the activity of these organisms
are much reduced, and decomposition proceeds are much reduced, and decomposition proceeds
very slowly or is suspended entirely, so that excess
of water is one of the conditions necessary to conert ordinary vegetable matter into peat. Wher water stands permanently on the surface, or wher he wo 1 is normaly very near it, if vegeta notil the surfa a the de to buit until the surface of the deposit is built up so hig sufficient to check the decomposition of plant remains of which it is formed.
Development of the deposits.-Relatively fev plants that grow in water are able to live at depth reater than 10 feet below the surface, and tho ing vegetablew at such depths contain lit at depth between 3 and 10 feet are larger and have more highly developed tissues comprising greater amount of resistant material, but even these contain little of the firmer mechanical tissues. It is therefore pparent that plants which grow in shallow water and on wet land, or on land lying still higher, must chiefly be concerned in the form ion of peat, because other kinds of plants do not supply material of proper kind or in sufficien quantity to form peat deposits. Plants that grow in these habitats are well provided with tough firm tissues, and are, without doubt, the forms most oncerned in peat formation within the Ann Arbor quadrangle
In discussions of the formation of peat a genus of mosses, Sphagnum, is generally said to be the building up the deposits. Within the area under building up the deposits. Within the area unde has been formed to any considerable degree by this group of mosses, nor is it likely to be an importan peat former in this region. It is true that Sphagnum is now growing in a considerable number of peat deposits and has built them up to a slight extent since its introduction, but there is no evidence that it was ever present in a much greater number of peat bogs in which the growth of other plants is sufficient to account for all existing accir mulations. This subject is fully discussed in recent publication of the Michigan Geological Survey, and it is sufficient to say here that the peat deposits of the State exhibit a well-marked succession of plants of different types which begins in deep water and proceeds to the shore, each type
being controlled largely by depth of water or of the being controlled largely by depth of water or of the
water level in the soil. Each group of these plants, water level in the soil. Each group of these plants, including the microscopic alge, is instrumental building up the peat, but, for reasons already give that grow nearest the water level apparently contribute the greater part of the material. Sphay num is found on many of the deeper deposits of peat, appearing when the surface of the deposit tands at or slightly above the water level, and it may grow for a time, if conditions are favorab and in many deposits these grow so luxuriantly that the moss is not able to hold its place becanse of the shade, and soon disappears.
The most important peat-forming plants in this area aside from the aquatic plants growing in shal low water, seem to be the various species of the genus Carex, one of the sedges, a group of grasslike plants, differing from the grasses, however, in their manner of fruiting and in having triangular solid, unjointed stems, while those of the grass are hollow, cylindrical and have well-marked solid joints. These plants grow in wet places, and are able to form a dense, compact turf by means of roots. Growing out from the shore they form fors. Growing out fom shore they form lakes, and along the edge of and beneath this mat the peat is built up to a height of 50 feet or more This bed of peat rises until the mat may become several feet thick and no longer floats, when othe plants gain a foothold on it and build up the sur face of the deposit a few inches farther, or until it is carried so high above the water level that peat is no longer formed, because of the ordinary drying and decay of the vegetation. If the water is not deep, or if the ground is simply wet, turf-forming sedges may begin their work directly upon it and build up a shallow deposit, which, because of its porosity and the hindrance it offers to the runoff of the water, may be built up several feet, form-
ing a mound or, when it stands on the side of a ing a mound or,
valley, a terrace.

Mud Lake, in Webster Township, and Dead Lake and some others in Northfield Township, filled and are still rapidly filling with peat much of which has been formed along the margin and under a floating mat of sedge. Of the shallower peat deposits, formed on wet and poorly draine areas, the till plain between Whitmore Lake and Ann Arbor furnishes many excellent examples, and some of the peaty areas in the lake plain in the southeastern part of the quadrangle are of similar origin. An interesting series of peat deposits occurs in extensive shallow sheets that overlie the olde parts of the marl deposits about Fourmile Lak and the other marl lakes of the northern part of
the quadrangle. Peaty terraces occur in the valthe quadrangle. Peaty terraces occur
ley of Huron River above Ann Arbor.
At Ore Lake the peat was evidently at one tim more extensive than it is at present, as the shores are now being cut back, and the peat beds on top of the marl are sharply differentiated from the marr. It is easy the see, howere, that peat grew of mixed material lie between the marl and the peat. In the peat over the marl at this plae the is a heavy growth of timber. At Fourmile a similar relation of superficial peat to marl bed may be observed in artificial cuts.
Another type of pericial cut.
Concerned, is that developed on the thors origin is broad, gently sloping valleys that served as outlets for the water from the melting ice front during the retreat of the ice sheet. The most notable example of this class is the "celery swamp" south of Ann Arbor, in Pittsfield Township. In these valley the drainage of the recent past has been so poor that conditions favorable to peat formation have probably existed since the glacial waters ceased to flow through them, and the resulting accumulations have so checked the water which has sought outlet through the valleys that the water level has risen at about the same rate at which the peat was built up. If this hypothesis be correct, it is evident that the conditions here would favor a continued growt of one group of plants, provided the rainfal not change.
has been used in Europe not only directly as fuel, but in other ways and for other purposes. Gas and coke, with various by-products, and ceertain made from it; paper and other fabrics, for stock, and as the bases for a number of valuable fertilizers are produced from it. In itself, peat is an excellent fertilizer, and many of the small and impure deposits that exist on farms in the region here considered might be used in this way to the great betterment of the light and poor soils adja cent to them, for the material is pure humus, which can be obtained more readily in this way, and at less cost, than in any other. For this purpose it
should be composted before using, to insure its complete decomposition.
Peat as fuel.-To be used as fuel, peat must be dried and put into portable form. Many methods with the view of producing large quantities of the product, so that a constant supply can be maintained, and in general these methods requi elaborate and expensive drying and compressing machinery. The material may be used locall however, without such careful preparation, by however, without such careful preparation, by
adopting the simple methods of the European peasants, who cut from the deposits peat blocks of fairly uniform size, and staek them up in such a way that they dry in the summer season, after which they are stored under cover. If the material is not of the right consistency in the bog it should be taken out and thoroughly worked until it can be spread into sheets, cut into the desired forms, and left to dry. Freshly cut peat contains from 60 to 90 per cent of water and in drying shrinks from one-half to two-thirds its bulk, and while it will generally hold its form when dry, it is sometimes so friable that it crumbles at the slightest touch. The fuel value of good peat is about three-fifths that of coal, weight for weight, but as ordinarily used, it is probably a more efficient fuel than this ratio would indicate, being rejected with the ash and clinkers, whit peat is almost wholly burned. Uncompressed Ann Arbor
peat is not so efficient a fuel as that which has been compressed into blocks of uniform size and
density, since these burn more intensely and are much more easily handled
Amount of fuel in peat.-It is estimated that ingle acre of peat 1 foot in depth will furnish from 150 to 200 tons of dry fuel, and that thi amount is present for every foot in depth to which the peat extends. From the areal geology map it will be seen that the superficial area of peat in the quadrangle is large, and although careful and sysematic borings have not been extended over the entire area some of the deposits are known to reach depth of 70 feet, and many of them are at least 20 feet deep. In this quadrangle there are at present no establishments for utilizing these peat deposits, but it is reported that an establishment ready to put compressed-peat fuel on the market, nd as the sources of other kinds of fuel are mor nd more depleted it is probable that peat will b extensively utilized.

Fossils.
The older geological formations that are exposed The older geological formations that are exposed
many localities in the Southern Peninsula of at many localities in the Southern Peninsula of
Michigan contain abundant records of the life of the periods during which they were deposited, but owing to the limited knowledge of the portions these formations that lie within the Ann Arbor quadrangle it is at this time not desirable to discuss the fossils they contain. So far as known the glacial deposits, which form so large a part of the surface of the quadrangle, are without evidences of animal life. The beds of peat and marl that rest upon the glacial deposits, however, and occupy depressions in their surfaces contain, here and here, a few bones of animals and large numbers the shells of mollusks.
The bones and teeth of the mastodon have been dug from many of the swamps and peat bogs of Michigan. The most interesting discovery of this nature in the Ann Arbor quadrangle was made a few years since on the farm of Albert Darling, ers digoing a ditch across a psampy field exhume ers digging a ditch across a swampy field exhume icanus. The portions of the skeleton obtained were the lower jaw, with molar teeth in place the left tusk, teeth of the upper jaw, portions of th cranium, together with vertebre, ribs, and some of the larger bones of the limbs, all belonging to the same individual. The head, after considerabl restoration of missing parts, was mounted and how on exhibition in the geological collection of the University of Michigan.
It may be of interest to the general reader recall the fact that the mastodon is related to the elephant, but many of the parts of skeletons foun show that it was larger than any living elephant A full grown mastodon is estimated to have bee 12 to 14 feet high at the shoulder, and 24 to 25 feet long, measured from the distal end of th tusks to the base of the tail. This animal, now
extinct, roamed in large numbers over practically extinct, roamed in large numbers over practically
the whole of North America during or after the close of the glacial epoch.
As interesting as the mastodon, and contempo rary with it, is the gos the skeleton of which oha been found in the Ann Arbor quadrangle. A few years ago a nearly complete skull of this A fer was discovered beneath about 5 feet of peat by workmen digging a ditch through a celery swamp about 3 miles south of Ann Arbor. The specime is now in the museum of the University of Michigan. Three molar teeth of the same species were also discovered a few years ago in the excavatio for a tile drain in meadow land near the souther boundary of the city of Ann Arbor, between Packard street and the Ann Arbor railroad. Castoroide resembles the modern beaver in the structure of is teeth, skeleton, etc., and, as may be presumed, had essentially the same mode of life and habits, bu was much larger. The skull referred to, withou the incisors, measures 12.1 inches in length, and is 9.6 inches wide in the broadest portion, inclu-
sive of the zygomatic arches. The upper incisor, lthough broken at the distal end, measured 10 inches kull. The corresponding mesurement of the skull of a fully grown living beaver (Fiber cana-
densis) are: Length 5.1 inches; width 3.7 inches and length of upper incisor, when free from the kull, about 2.5 inches. Castoroides was mor han twice the size of a full-grown specimen he living beaver, or about as large as a domestic log. Its remains have been found at variou southward to the Carolinas and Texas. It lived at the same time as the mastodon, and is now extinct In the celery swamp south of Ann Arbor, in th me peat deposit that yielded the skull of Castor odes described above, but, at a higher horizon, por tions of the skeletons of deer, elk, and severa omestic animals have been found.
The marl that occurs in several of the lakes and eneath some of the swamps in the Ann Arbo uadrangle contains at some places numerou hells. One of the most instractive alities for obtaining these fossils is the celery swamp nea ne Armor, mentioned above. In a portion o the swamp beneath about 5 feet of peat there is ayer of white marl of approximately the same .e cllet liolity as determine by Mr. Bryant Walker, are as follows

## Vitrea hammonis (Ström.)

Euconulus chersinus var. polygyratus (Pils),
Zonites arboreus Say.
Zonites munuseculus Drap.
Pyramidula striatella An
Helicodiseas lineatus Say

Strobilops affinis Pil.
Suceine avara Say.
Succine a avara Say.
Succine retusa Lea.
Caryehium exiguum Say.
Limnnaa desidiosa var. de can
Limnnea desidiosa var. de campii Streng
Physa elliptica Lea var. (smal form)
Physa gyrina Hildrethiana Lea.
Physa ancillaria Say (immature)
Physa integra Hald.
Physa integra Hald.
Planorbis amumpanulatus
Planorbis chanpanunulatus
Planorbis exacutus Say
Planorbis exacntus Sa.
Planorbis parvus Say.
Valvata tricarinata Sa
Valvata tricarinata Say. Say.
GEOLOGICAL HISTORY.

> Paleozolc era
silurian sedimentation.
In the Monroe formation we find the earliest hapter of the sedimentary record that can be ad in the rocks outcropping in this quadrangle The marine shells occurring in these beds indicate bottom. During Silurian time an extensive sea overed all of southern Michigan and a consider able portion of the Mississippi Valley. It extended northward to the Arctic coast and probably beyond On the northeast it was limited by the Archean highlands of Canada, while to the east and south east it extended to the coast of Appalachia, a land which lay not far from the present Atlantic borde of the United States. The prevailing sediments in his extensive but rather shallow sea formed mag nesian limestones. In Wisconsin these limestone reach a thickness of more than 500 feet, uninter rupted by other sediment. The Monroe formatio The dolomites that compose the bulk of the ormation are the result of both the gradual accumulation of organic remains and the chemical pre cipitation of calcium and magnesium carbonate i he open sea. The deposition of the shore-derive ber interrupted for the Sylvania sandstone of the ber interrupted
dolomitic series.
Gradual uplift of the sea bottom brought about the close of Silurian deposition. This elevation continued until considerable areas of the old Silurian sea became land in the regions adjacent to the Great Lakes. Land conditions continued for dif ferent periods in different portions of this area, but over much of it they were temporary. The subsidence of considerable areas of the new lands and the return of the sea marked the beginning of th Devonian period.
devonian sedimentation
The Devonian sea differed considerably from its
Silurian predecessor in its outlines. It had more ble areas of the old Silurian bem islands or peninsulas in the States adjer

Michigan during the deposition of the Dundee mestone. The new conditions resulted in the ppearance of a Devonian fauna in this region. early all of the molluscan life of the Silurian eriod had previously disappeared, and new types marme shells characterize the sediments deposfrom the fossils thus far found, fishes first appeared in this region during Dundee sedimentation. The Imost pure Dundee limestones indicate a sea nearly ree from river deposits during the early Devonian At a later period either a more rainy climate or plift of the lands surrounding the Devonian sea, both, resulted in their more vigorous erosion he soft muds which were brought down by the ivers at this time formed the shale of the Traverse rmatio
During the latter part of Devonian time there were many changes in the physical geography of he coasts around this Devonian mediterranean sea Lilino areas in north in
 The depression of the coastwise londs was doubtles xtensive, lowering the grade of streams and reduc ing their power of erosion and increasing the fine ness of the sediments which they were able to carry to the sea. Extensive marshes bordered the river near the sea and added to their fine sediments large uantities of finely comminuted vegetable matter The fine-textured fissile black Antrim shale wa eposited under these conditions. Its black color the result of the large percenage of organic mat er which was deposited with the sediments comprising it. The extreme scarcity of marine life in the sea during the deposition of these beds is in marked contrast with its abundance during th artier part of Devonian sedimentation. This hale has a wide distribution, extending southwar across Ohio and Indiana into the Southern States. is represented by the New Albany shale in din The deposition of the Antrim shale marks the clos of the Devonian in Michigan.
carbonfferous sedimentation.
The transition from the Devonian to the Carniferous period is not marked by any grea hysical changes like those which initiated th Devonian. There is no evidence in this region of ny break in sedimentation at the close of the Devonian period. The rocks show, however, that he sediments became coarser. The coarse sand on the fine argillaceous deposits that formed the ntrim. Sedimentation appears to have gone on without interruption during the period when th Coldwater formation was deposited, probably on radually subsiding sea bottom.
The deposition of the Marshall sandstone intro duced a change in the nature of the sediments, from nud that formed shales to sands and sandy clay hat formed fine-grained and in places argillaceou ndstones. The arenaceous sediments deposite this time are of very similar character over vide area. The Knobstone of Incana, a por no the Whan ral period of deposition, and by the similarity of ther physial chars indict hances to which they were due were of more tha beal extent. A moderate elevation of the lands that supplied the sediments, and the consequent rejuvenation of the streams, was probably the cause of the change from the argillaceous sedi ments of the Coldwater formation to the fine sand of the Marshall sandstone.
The Marshall sandstone is the youngest Paleo oic formation now found in the quadrangle. It is very probable, however, that sedimentation here, litttle central portion of the State, continued al shallowing into the Carboniferous. The grad reat marshes, which followed closely its retreatin hores, resulted in the contraction of the extensiv ea of Mississippian time to a series of great shal low basins, more or less closely connected. Wide at sea marshes, where grew the palmlike Lepido lendron, stal Michigan Gradual uplift of the interior -1.1 ull
above the sea. With the uplift of the region above sea level began a period of erosion and topographic development which continued until the beginning of the glacial period. This preglacial topography records indicate that it was very similar to that of southern Indiana. The Marshall sandstone forms an escarpment similar to that formed by the "Knobstone" north of New Albany.
(enozole rra.
quatervary period.
pheistocene or glaclal history
Inasmuch as this quadrangle was in the path of the Labrador ice field when it extended farthest southwestward during the Illinoian stage of glaciation, much of the pre-Wisconsin drift has bee referred to that stage. Whether the Kansan and pre-Kansan glaciations, which were operative in the upper Mississippi Valley and regions farther north, were also operative here can not be positively stated. The amount of pre-Wisconsin drift, as indicated in the description of the surficial geo ogy, probably exceeds that of the Wisconsin. On the withdrawal of the Labrador ice fiela, probably formed, and the drainge systems doubt probably formed, and he drage sstems doub vailed on the withdrawal of the ice in the late Wisconsin time. Certain deposits of gravel and sand buried beneath the Wisconsin drift are though to be products of glacial lakes of Illinoian age, but positive statements can not yet be made concerning such features.
Isconsin stage or glacition.

The earlier Wisconsin history in this district解 after its culmination in earlier $W$ isconsin time ad perm the Ann Arcopy its soutl and permitted glacial lakes to occupy its southeastern portion, as in later Wisconsin time, is not
known. There is no doubt, however, that this quadknown. There is no doubt, however, that this quadin later Wisconsin time.
The cross striation at the Woolmith quarry and at several points in southeastern Michigan outsid (this quadrangle has been 10 194-216) as ark not only of the carlier and the later Wiseonin ice movements but also of pre-Wisconsin move ments. This interpretation seems plausible but i view of complexities of clacial and interglacial conditions, there can hardly be certainty concernin striation produced in pre-Wisconsin stages.
The complex lake history and the drainage development connected with the recession of the Labrador ice sheet in later Wisconsin time are treated at length under the next heading.

## dainage development

During and after the retreat of the ice sheet the and was again exposed to rainfall, and the ordi nary processes of drainage began again, by whic the waters were collected and carried off to th Diff
Different portions of the drainage systems of this quadrangle and neighboring parts of Michigan exhibit striking contrasts, which are largely the laciation. The northwestern part of the guad angle contains fewer streams and more swampy or ill-drained land for a given area than the reqion along the great Huron-Erie morainic system, which cosses the quadrangle from its northeast to it southwest corner. The scarcity of drainage lines in the northwestern part is due to some extent to its greater proportion of gravelly or loose-textured drift, which readily absorbs rain water and carries it away underground. It appears, however, that the topography has controlled the drainage fully a much as has the texture of the deposits. The morainic hills of the northwestern part, though some of them are about as high as the principal ridge of the morainic system to the southeast, stand in broad, shallow trough whose slopes are not only very gradual, but are so interrupted by depression necessarily slow and difficult. The morainic ystem southeast of it, on the other hand, comprise
idges with slopes sufficiently steep and regular o favor the rapid development of drainage lines. As a result, numerous small lines of drainage lead lown these slopes into valley-like troughs that li idges is reneraly more abrupt than the inner iceward slopes, and the strams leading down the re radients are so steep that the run-off is rapid, and their beds may become dry soon after a rain. The streams on the inner slope maintain a much longer flow, and some are never dry. On reaching the sags between morainic ridges the streams run alon hem until they find gaps through which they may pass eastward to the lower country. The combina tion of the portions of the drainage lines alon hese sags with their small tributary feeders from the neighboring ridges give to the drainage line trellised appearance which is a marked featu hroughout this great morainic system.
In the lake plain generally a smooth slope wa offered for the development of drainage as soon he lake waters disappeared, and numerous shallo tream channels were soon formed, which took the direction of steepest slope. The Maumee beach have cansed soph fres lines into Whitlesey allel with the beaches and at a right angle with the teneral wo the that the slopes. Several of these deflected streams along he Whittlesey beach are about 2 miles long and in conjunction with the direct-flowing streams produc a trellised appearance similar to that produced by the morainic ridges. The course of the deflected portions of these streams is along the landwar side of the beaches; or where a beach presents
double ridge or where one ridge laps past another a stream may flow along the sag between the ridge Many small streams rise on the lakeward side of each of the beaches and if this fact and the deflec ions of streams on the landward side are kept in mind the probable position of a beach may be etermined from a good drainage map.
A possible effect of delta accumulations on the Arses of drainage lines may be seen along Huro River in the eastern part of the quadrangle, and
 in the sandy districts bordering the Huron east of Ypsilanti and lead directly away from the Huro ike the distributaries of a delta of which they are perhaps an inheritance. This disposition of drain aen occurs both above and below the Belmore beach and thus applies to the delta in Lake Maumee and Lake Arkona as well as to that in Lake Whittle sey. The headwaters of Swan Creek, south of the Huron, lead directly away from the river, starting from the large Arkona delta. The scattering of drainage lines in the vicinity of Milan also take place from the Arkona delta of Saline River. The drainage of the lake plain bears witness to the recency of its development, or the ster long di naintain parallel independent courses for long dis ake plain, near Detroit River and Lake Erie, show even more marked parallelism than those farther back. The tendency to gather into dendritic systems is just beginning to manifest itself in the higher and older parts of the lake plain.
The drainage development of the lake plain the character of the soil than by the topography, development being fuller where a clay soil pre vails than it is on a sandy tract. Areas of several quare miles in the sandy tracts are traversed by no drainage lines.


The drainage of this quadrangle has undergon remarkable series of shiftings in the course of it levelopment, only an outline of which can ben to 13), however, the reader may gather the lead ing elements of the history. These maps serve also to set forth the development of several lines of drainage which lie outside the limits of the quad rangle but to which no reference is here made. South Bend outlet.-When the Saginaw and Huron-Erie ice lobes were still coalescent over the headwater portion of Huron River a glacial stream
that emerged from between the ice lobes near Hamthat emerged from between the ice lobes near Ham-
burg made its way westward past Pinckney along
line indicated in fig. 6. This leads through the There it turned southward and led past Gun Lake Portage Swamp to Grand River, thence down the and through Gun River Marsh to Kalamazo river to Eaton Rapids, thence westward through a River. The relations there are not eutirely clear hannel now occupied by a swamp to Battle Creek though the stream appears for a time to have River, and thence down the river past the site of and followed Pawpaw River Kalamazo to a narrow lake thast he site wh olower paw iver down to Harthord, Dowagiac) held in front of the Lake Michigan edge and representing an early stage of Lake Chi ice lobe. This lake is one of a chain that extended cago, shown in fig. 7. This glacial lake dis from the Kalamazoo southward through a strip of chared through the Chicago outlet from the lowland now drained by Pawpaw, Dowagiac, and southwestern edge of the Lake Michigan basin,


Ira. 6.-First course of drainage from the Ann Arbor quadrangle after the
withdrawal of the ice from its western portion, and the position of the glacial lobes. D
to $1 l i n$ nois River.
St. Joseph rivers, to South Bend, Ind., where dis- to the Desplaines and thence to the Illinois, the Charge was made into the head of the Kankakee. Mississippi, and the Gulf of Mexico. The drainage then followed the course of that The Fort Wayne outlet.-When the Huron(tream to the Illinois and thence to Mississippi Erie ice lobe had shrunk to about the inner border nd the Gulf of Mexico. The headwater portion of the great morainic system that leads across the Raisin River, together with a glacial stream Ann Arbor quadrangle from its northeast to its eading in western Washtenaw County, at that southwest corner, Huron and Raisin rivers abandime took a northwestward course through eastern doned their westward lines of discharge and took a hich County to Grand River at Jackson, beyond southward course to Lake Maumee and thence past Huron voll joined the stream coming in from the Fort Wayne to Wabash River, as indicated in Howe Valley through the Portage Swamp and fol wed the course outlined above
he ice, the point of junction of a recession of

ita. 7.- Drainage from Ann Arbor quadrangle past Chicago, and the extent
of the ellacial lobes. Shaded area represents the beginning of glacial Lake
Chicago.
Chicago.
Huron-Erie lobes stood near the head of Huron at Ann Arbor marking this level of the river is a River, the drainage of Huron and Raisin rivers little more than 840 feet above sea level, or about ollowed the courses indicated in fig. 7. It coin- 80 feet higher than the present river. Much of dides with the course previously outlined only the headwater portion of Saline River was then bion hrinking of the sas ice lowe strean Lis of Grand Piver nearly to
 which it followed to the bend near Middleville. the Imlay outlet (see fig. 9), and through that a

G. 8.- Drainage from Ann Arbor quadrangle to Lake Maumee and the
Fort Wayne outlet, and the position of the glacial lobes. Shaded areas Fort Wayne outlet, an
slight lowering of the lake level. Lake Maumee From the Saginaw basin it discharged thr hen extended up to Ann Arbor, so that Huron the Grand River outlet to Lake Chicago. River formed a delta at the highest lake level in
the northern part of the city, west of Broadway. Whitlesey and the Ubly outlet.-By a
readvance of the ice border southward the passage The delta deposits now comprise horizontal top- into Saginaw Bay was closed and the lake level set beds of coarse material resting on foreset beds raised sufficiently to discharge past Ubly into the of finer material with considerable cross-bedding head of Cass River through what is termed the and a decided dip downstream. Numerous expo- Obly outlet. The lake level thus established, sures of topset and foreset beds along the bluff called Lake Whittlesey, formed a beach, which west of Broadway show that the growth of the stands at 735 to 740 feet in the Anu Arbor quad-
delta began a little farther upstream, perhaps
rangle. Its line of discharge is shown in fig. 10 delta began a little farther upstream, perhaps rangle. Its line of discharge is shown in fig. 10. one-eighth of a mile. A terrace that extends Huron River then extended 2 or 3 miles below down the river to this delta is a marked feature. Ypsilanti, and its bed was at that time at the level The terrace and top of the delta stand about 812 of the terrace on which the high school and much
feet above sea level, or 30 feet lower than the of the business portion of the city is built The feet above sea level, or 30 feet lower than the of the business portion of the city is built. The
 river led from Ann Arbor southwestward to Raisin River, as indicated above.


Fige 9.-Drainage from Ann Arbor quadrangle through Lake Maumee and
the Grand-Imlay outlet to Lake Chicago, and the position of the glacial
lobes. Shaded areas represent glacial lakes.
At the lowering of Lake Maumee to the level of Lake Warren and the Grand River outlot its second beach Huron River formed a delta at With a later recession of the ice the glacial lake in a correspondingly lower level, in the northeastern the Huron-Erie basin again became confluent with part of Ann Arbor. This delta is cut into by the one in the Saginaw basin, as at the time of Lake Michigan Central Railroad east of the overhead Arkona, and formed the largest lake of the series, bridge on Fuller street, the cut exposing topset
beds of coarse gravel and cobble. When the surace of the lake was lowered to the level of its third beach an extensive delta was formed just east of Ypsilanti.
Raisin River reached slack water at the highest tage of Lake Maumee near Tecumseh. A bed of surface clay that appears in the eastern part of Tecumseh, near the waterworks pumping station, may be a deposit in this slack water.
Saline River at that time entered a bay of Lake Maumee opposite the village of Saline, for at its all the territory traversed by the southeastward flowing portion of the stream.
The middle branch of Rouge River entered Lake Maumee at Northville, just east of the eastern edge of the quadrangle
Lake Arkona and the Grand River outlet.With the recession of the ice border northward across the point between Lake Huron and Saginaw Bay commonly known as the Thumb, a passage much lower than the Imlay outlet the lake level


FIf. 11.- Drainage from Ann Arbor quadrangle to Lake Warren and thenee westward throug
Grand River to Lake Chicago, in the southern part of the Lake Michigan basin, as indicated in fig. 11. in is description of the beaches of Lake Warren stands about 680 feet above sea level in this quad rangle and the lower Warren beach about 20 fee
y lay outside the limits of the quadrangle. The Bull. Geol. Soc. America, vol. 10, 1899, pp. 27-68) not only caused a lowering of the glacial lake in
the Huron-Erie basin but transferred its discharg


Irg. 10. - Drainage from Ann Arbor quadrangle to Lake Whittlesey and thence by Ubly out-
let to Lake Saginaw and by Grand River outlet to Lake Chicago. Also the extent of the let to Lake Saginaw and by Grand River outlet to
glacial lobes. Shaded areas represent glacial lakes.
dropped correspondingly and formed the series of $\mid$ lower, also that the fragmentary and washed-down ridges known as the Arkona beaches. In the Ann
Arbor quadrangle these beaches stand between 695
appearance of the lower beach suggests that it may
have been formed before the upper beach. If the and 710 feet above sea level. The lake or lake lower beach is the older the lake that formed it level that formed them preceded a ligher lake probably found outlet eastward past Syracuse, N.Y level, which will next be considered. The extent to the Mohawk. A closing of this eastward outlet of Lake Arkona is not known, for the ice sheet by a readvance of the ice in the Mohawk Valley subsequently encroached upon part of its bed. and a consequent rise of 20 feet in the lake, to th

Ann Arbor
level of the upper beach, would have caused the
outlet to shift to the western end of the lake. The propriety of attaching the name Lake Warren to both these lake levels is questioned, but the intro duction of another name for one stage should be deferred till after the clearing away of presen Hantis.
Huron River formed a conspicuous terrace in with eastern part of the quadrangle in harmony by it in connerection with beach. A terrace formed ot so conspicuous, a fact which may perhaps aid
readvance of the ice, by which the lake may for time have ovarflowed at the westward outlet. Its beaches are weak, apparently marking stages of short duration. Their weakness may, however, in some places at least, be due to their partial effacement by waves in a later submergence. In southastern Michigan sandy strips, between the lowe Warren beach and the shore of Lake Erie, one of which is termed the Grassmere and another the Elkton beach, were probably formed when the water found outlet near Syracuse
The discharge through the Syracuse channel


Fig. 12.-Drainage from Ann Arbor quadrangle eastward through Lakes Erie and Iroquois to Mohawk River and thence to
Hudson River and the Atlantic Ocean. Shaded area represents glacial lakes. Lake Erie was then smaller than at present Hudson River anit are
but its exact limits
in interpreting the point in question. At the ; was followed by a long-continued discharge past upper stage the mouth of Saline River was just $\left\lvert\, \begin{array}{ll}\text { Rome, N. Y., from a lake in the Ontario basin, }\end{array}\right.$ below Milan and that Macon was 2 miles known as Lake Iroquois, whose extent is shown bove Azalia, while the Raisin and South Macon, in fig. 12. Lake Erie then discharged into Lake part of the quadrangle, were lenothened in district outside the limits of this quadrangle.

## Later stream development -

trean development, consequent on the lowerin of the glacial lakes by outlets near syracuse, N. Y. it seems necessary to say a word, although the
in fig. 12. Lake Erie then discharged into Lake
Iroquois over Niagara Falls as it does now into Lake Ontario. At first it appears to have been much smaller than it is now, being, perhaps, confined to the deep eastern end of the basin. Under these conditions, drainage lines like Huron and Raisin rivers, which enter it from the west, were much longer than the present streams. The lake appears now to be enlarging as the result of an uplift which is raising the outlet of the lake at Buffalo. The uplift now going on may prove to be a continuation of one that was in progress while Lake Iroquois was in existence or it may be a later and independent movement. In either case it will be difficult to outline a shore for Lake Erie that is fully in harmony with Lake Iroquois, for it was the shore of an expanding body of water. For these reasons the map forming fig. 12 does rur roquois stage.
Soon after
Son after the disappearance of the ice shee ystem of drainage was established, the present sa for a time extended into the Lake Ontario basin from the Gulf of St. La wrence. The western part of the present system is shown in fig. 13.
From the sketch of drainage development jus presented it appears that the waters of this quadrangle, after traversing successively several lines leading to the Mississippi and the Gulf of Mexico, were transferred to the Atlantic, first by way of


Frat. 13 .-Present drainage of southern Michigan and portions of neighbor-
ing distriets, showing realiton to the Great Lakes, which discharge into
the Attantic by way of St. Lawrence River.
eastward, so that its waters, which had before been Hudson River and later through the Gulf of St arried to the Gulf of Mexico, were carried to the Lawrence. These remarkable shiftings, if analyzed thantic through the Mohawk and Hudson valleys. and classified in scientific terms, will illustrate by stages and, as suggested not lowered at once, but chiefly the first stage of stream developmentbeen an interruption in its lowering oce may have namely, that of consequent drainage. The several been an interruption in its lowering occasioned by
quent upon the best available slopes. The lake outlets were also the lowest ones available outside the border of the ice sheet. The entire drainage at any particular time was, therefore, consequent upon slopes and available lake outlets, whether by way of the Mississippi, Hudson, or St. Lawrence. Minor changes.-Many changes in streams within the limits of the Ann Arbor quadrangle have taken place, the most notable being where pond-
ing attended the earlier stages of drainage. For ing attended the earlier stages of drainage. For
example, Rouge River, which now flows northeastexample, Rouge River, which now flows northeast
ward from Brookville, in eastern Salem Township ward from Brookville, in eastern Salem Township, traverses a line of glacial drainage that led south-
westward past that point. This course of the river has been determined by the northeastward slope of the bed of this part of the glacial-drainage line. Similarly Saline River flows northeastward from central Bridgewater Township across Saline into Lodi Township, in consequence of a slope in that direction, though the glacial drainage was ponded sufficiently to flow in the reverse direction. Its present southeastward course past the village of Saline into the Lake plain apparently was not due to piracy, for the water seems to have taken this southeastward course because of the steeper slope in that direction, which it was free to utilize as soon as the ice sheet had melted away. Honey Creek flows past Pinckney eastward because that is the present direction of the slope, yet the glacial drainage was in the reverse direction.
It appears that under glacial conditions certain streams flowed along lines that they abandoned as soon as the ice barriers or the pools of water held by the ice disappeared, and that in certain places
the bed of a glacial stream has so settled or sunk the to cause glon in direction foilowed by the stream which formed it.
foilowed by the stream which formed it.
Somewhat different in kind is a deflection of Huron River near Dexter. The river at one time took a southward course from Dexter along Mill Creek and passed eastward through a sandy plain in central Scio Township to its present course just above Foster, thus taking a route about 4 miles longer than the present one from Dexter to Foster. Its deflection to its present course is thought to have been brought about by the deposition of sufficient gravel and sand in the portion of the Huron Valley near Dexter to cause it to flow across a
divide at the head of one of its tributaries and divide at the head of one of its tributaries and
appropriate the valley of the tributary to its own appropriate the valley of the tributary to its own
use. This is a form of piracy concerning which little has been written, but it is apparently as potent as piracy through erosion, and may find numerous illustrations in glaciated districts.
An interesting case of stream capture noted by
Bowman (Jour. Geol., vol. 12, 1904, pp. 326Bowman (Jour. Geol., vol. 12, 1904, pp. 326-
334 ), occurred on the borders of the 334), occurred on the borders of the Huron Valley
about 5 miles east of Ypsilanti, where Huron about 5 miles east of Ypsilant, where Huron middle part of the path of a small tributary runmidde part of the path of a small tributary run-
ning nearlel with the main stream. As a result the upper part of this tributary channel now discharges into the river at some distance above the former mouth, and the lower end of the original valley is abandoned.
River terraces and waves of erosion.-In connection with each of the glacial lakes the streams have adjusted their beds to the successive base-levels produced by the lowering and rising of the lake shifting of streas from indirect to direct courses, as when Huron River changed from an indirect course to Lake Maumee by way of Raisin River and Adrian to that extending eastward from Ann Arbor to the lake border. The bed of Huron River has also been deepened as a result of the shortening of the course below the Dexter deflection just noted.
In the discussion of the glacial lakes attention was called to the occurrence of a terrace on Huron River at Ann Arbor which connects with the upper
level of Lake Maumee and stands 25 or 30 feet level of Lake Maumee and stands 25 or 30 feet
below the broader valley bed occupied by the below the broader valley bed occupied by the
stream when it turned southwestward from Ann Arbor to Raisin River. Attention was also directed Arbor to Raisin River. Attention was also directed
to a lower terrace at Ann Arbor which conforms with the lower level of Lake Maumee and stands about 25 feet below, the terrace formed at the higher level of the lake. There is also a conspicuous terrace on Huron River conforming with
the upper beach of Lake Warren from Ypsilanti down to a point near Belleville. A terrace at

Ypsilanti should apparently be correlated with the Whittlesey beach, with which it connects about 2 miles below the city. Studies of the valley feature plete mapping of each terrace or its coordination with the lake level to which it corresponds, though such mapping and interpretation might be worked out. The sections of other streams falling within the quadrangle show less fully than does Huron River the relation of the drainage to the lake
level. The portion of Raisin River within this quadrangle is cut to a depth of but a few feet below the broad plain on which the river flowed when it discharged into Lake Maumee. The head water portion of Saline River, above the village of Saline, has cut but little into the bed of the pool through which Huron River flowed in its discharge to the Raisin. Below Saline it traverses the old to the Raisin. Below Saline it traverses the
lake plain in a narrow trench of slight depth. The lowering of the levels of the lakes into whis the streams of the Ann Arbor quadrangle discharged increased their gradients sufficiently to cause sucerrace deepenings of the channels, indicated by the terrace just noted. These deepenings, which have None of headward, are termed erosion waves. nouth has yet reached the head of any main stream. On the Huron the wave has reached only he outlet of Portage Lake. Above that point the stream is filling the basins along its course and eroCreek erosion has and a few short reaches. On Mill Creek erosion has beer ced en ho lis lower chiefly below Dixboro. On the Saline the wave of erosion has barely reached the southern edge of Lodi Township and on the Raisin it has reached only the Raisin basin in Bridgewater Township On the headwaters of the Rasin there are how ever, longer erosion reaches than on the Huron owing to the much greater fall the stream must make.
becent history.
The changes produced in this quadrangle since the disappearance of the ice sheet and its attendant glacial lakes consist chiefly of changes affecting the
basins of small lakes within the morainal and outwash tracts, and of erosion along the water courses, The general surface has been very little modified, and surface weathering has reached a depth of only a few inches. Some of the small morainal lakes have been converted into meadows and quaking bogs, and many have become markedly reduced in area of water surface by the accumulation of marl
and peat on their borders. The amount of such and peat on their borders. The amount of such
filling is indicated in the discussion of these deposits. The work of streams in postglacial time is surprisingly small. The slopes of the main valley with morainal knolls and basins down to low dotted with morainal knolls and basins down to low levels,
and these features serve to show that only the deeper parts of the depressions through which the streams flow have been worked upon by postolacial streams These depressions are the result of glacial rather than of fluvial agencies. The amount of postglacial stream work can be best seen in the bottoms of the old lakes Maumee, Whittlesey, and Warren. The depth of erosion there averages greater, however, than in the higher or morainal districts to the west.

ECONOMIC GEOLOGY.
The Woolmith quarry is now being worked chiefly for road material, of which several carloads are removed, crushed, and shipped by rail very day when the quarry is in full operation.
The principal source of road material is
which is found in sizes suitable for use without crushing in nearly every kame for use without crushing in nearly every kame or gravel hill, in
the Lima esker, and in the Maumee and Whitthe Lima esker, and in the Maumee and Whit-
tlesey beaches. The largest pit is that opened by thesey beaches. The largest pit is that opened by
the Ann Arbor Railroad near the northern border of the quadrangle. Gravel has been excavated from hundreds of pits at points where roads cross the line of the beaches or the eskers. Gravel has also been taken from the coarse deposits along the river valleys at a few places, such as the delta of Huron River at Ann Arbor, and the outwash apron south of Huron River. Gravel interbedded with till has been drawn upon for road material at some localities, as in the western part of the city of Ann

Arbor and at several points along the edge of the Huron Valley both above and below this city. The o supply all probable nabeds is sufficient in amoun and is so distributed that it may be obtained within convenient distances for hauling with teams, except in a few townships in the southeastern part of the quadrangle, which can be supplied by the Wool
mith quarry, so that no part of the quadrangle mith quarry, so that no
lacks good road material.

## bullding stones.

Some of the more massive layers of sandy dolomite at the Woolmith quarry were formerly sawed nto blocks for use as building stones but most of road material. The principal source of buse as stones is now found in the bowlders which wer strewn over the surface of the Wisconsin drift and which are sufficiently numerous in the northwestern half of the quadrangle to supply the needs of the residents. Most of these bowlders are composed of dense, hard rock-such as granite, gneiss, diorite quartzite-which, when sufficiently sound, may be broken into nearly rectangular blocks. Blocks of for buildins, many of them of excellent quality drift or embedded in it at slight depths. Thes were derived from formations that outcrop in the outheastern part of the State.
Within the last five or six years cement blocks made in part of sand obtained from points near by have been extensively manufactured and used in
the cities and villages of this quadrangle, and as he cities and villages of this quadrangle, and a manufacture and use will doubtless become more manufacture and is also now used for making abutments for bridges and other forms of masonry for which field stones or quarry rocks were formerly employed, and is replacing the plank and tar used for sidewalks and the quarry rocks or flagstone used for stepping stones at street crossings.
The Sylvania sandstone reached at a depth of about 50 feet at the Woolmith quarry is well adapted to glass manufacture but is difficult to quarry.

## clay.

Although clay is abundant in the glacial deposit of the Ann Arbor quadrangle, it is usually of infe rior quality for the manufacture of brick or tile ravel, and other objectionable limestone fragments, nd there a and there deposits formed by streams or lakes fur drain lay from which brick of fair quality and good are utilized for brick or tile making at Milan, Azalia, and Exeer, in the southen portion quadrangle. Brickmaking was carried on for some years at Ann Arbor, the clay of the abandoned bed of Huron River in the southern part of the city being used. The supply of good material has, however, been practically exhausted. An unsuc cessful attempt was made to use the sandy clay of the present flood plain of Huron River above Ann Arbor. A blue fluvioglacial clay on the forme ine of the Ann Arbor Railroad near Emery, about 7 miles northeast of Ann Arbor, was formerly use in the manufacture of brick, but owing to a chang in the location of the railroad the enterprise wa abandoned.
The Markham pottery, consisting largely of vase and other decorated wares, is made at Ann Arbo from ordinary till, which by screening and repeated washing and grading is reduced to clay of fine This pottery was established in 1904 and in two years manufactured about 3000 pieces. The vas are sufficiently porous to absorb seep the water within it cool and prevent the rapil withering of cut flowers.

## oll and gas

Several wells along the line of outcrop of th Antrim or black shale have yielded small quanti ties of gas, probably derived from the shale, and ficient to warrant piping it into dwelling houses for fuel and lighting, though, so far as known, no well is being put to this use at present. The
oceurrence of this gas has stimulated prospectors
drill to considerable depths with the hope of obtaining gas or oil in commercial quantities, but one of these efforts have been successful. Thei ailure is probably due to the absence of anticlina olds beneath which substances like gas and oil, which are lighter than water, can collect. While hese failures are sufficient to show that oil or gas in commercial quantities is not present at depths less than 1500 feet, they leave conditions untested s to the possibilities of their occurrence at greater
depths. There is no doubt that the Trenton limedepths. There is no doubt that the Trenton lime beneath the Ann Arbor quadrangle, but what it physical condition and form here may be whethe porous or nonporous, and whether folded or uni formly dipping, is not known.
marl, or bog lime.
general statement.
The portion of the Ann Arbor quadrangle outside the bed of Lake Maumee, as has already been noted, comprises many basins that now hold lakes or swamps. In these depressions two classes of postglacial deposits of high economic value have been formed through the agency of plants, namely peat and so-called marl. The peat deposits are described in a separate section of this folio. The principal deposits of marl are in Zukey, Bass, Portage, Ore, and Fourmile lakes and their associated marshes, and also in several other lakes, a places indicated on the areal geology sheet, and
beneath peat in certain of the marshes, as, for beneath peat in certain of the marshes, as, for xample, in the celery swamp 3 miles south of
Ann Arbor. Except in the five lakes named, the nn Arbor. Except in limes named, the marl does not occur in sufficient quantity to be ommercially valuable, athough it has been a for local consumption. Deposits of marl simila to those just mentioned are abundant throughout the Southern Peninsula of Michigan, and the following account of their character and origin is based on examinations made at many places.

When free from sand, clay, and other mechan ical impurities the marl is normally a fine, soft, plastic, mudlike material, cream, white, or gray in color, and crumbles to a fine powder on drying. The only known deposit of marl that doe not show the characteristics just mentioned occurs
bout the border of Ore Lake, where the marl about the border of Ore Lake, where the mar bove low-water level is in part cemented into an pen-textured, conglomerate-like rock, which form beds 6 to 10 or more inches thick. Two principa arieties a recon hat and principally to variations in the amount of organie matter present and is not important
The marl at most places cont
The marl at most places contains shells of fresh han 5 to 10 per cent of its volume and therefore do not justify the term "shell marl," sometime pplied to it Entire shells are present at the sur face of many of the deposits, but at a depth of a ew inches only fragments are usually discernible and at depths of 10 to 15 feet the shells are com pletely disintegrated.
The physical character of marl may be shown by washing it on sieves of various-sized mesh. Two representative samples, one of white and the othe of gray marl, sifted in this manner through sieve anging in fineness from 12 to 200 meshes to he linear inch, gave the results tabulated below which serve to show the general physical characte of the marls of Michigan. The samples chosen

Mechanical analyses of marl.

owever, were free from large shells, such as occur at or near the surfaces of some marl beds and did not contain concretionary nodules of the nature described below. Of the samples subjected to mechanical analysis, the results of which are
given below, No. 1 is white marl from Lake Wetzel, in Antrim County, and No. 2 is gray marl from Goose Lake, in Lenawee County, but ing those of the Ann Arbor quadrangle, show that they are of the same general character as those here considered.
On examining the fractional portions of the marl thus obtained with the aid of a microscope, it was found that the coarser particles consisted principally of fragments of circular tubes with striated walls, such as might have been produced by the deposition of crystalline grains about vegetable stems. Much of the finer material, down to that caught on a $200-\mathrm{mesh}$ sieve, consists of fragments of tubes,
evidently of the same character as those found in the evidently of the same character as those found in the
coarser portions. The finest particles of all, are coarser portions. The finest particles of all, are
amorphous grains, in which no organic structure amorphous grains, in which no organic structure
is apparent. Precisely similar particles, however, is apparent. Precisely similar particles, however,
were obtained by pulverizing the material caught were obtained by pulverizing the material caught on the coarser sieves. The evidence obtained by exception of from 5 to 10 per cent of shell fue ments, is essentially of the same character through out, and has a structure suggestive of vegetable origin. A more detailed account of the examination just referred to may be found in the Twentysecond Annual Report of the United States Geolocical Survey, for 1900-1901, part 3, pages 653-657.
Many of the marl deposits in Michigan such as those on the shores of Bass, Portage, and Ore lakes, consist largely of round or oval pebble-like masses, the largest about 1 inch in diameter, most of which are soft enough to be crushed in the hand. When broken they exhibit a concentric structure, and many of them contain, at the center, a fragment of a shell or other hard body about which deposition took place. These concretionary masses are
abundant in the surface portion of some marl beds, abundant in the surface portion of some marl beds, but at depths of 10 to 20 feet are more or less disintegrated. When fresh samples of these pebbles are treated with dilute acid, the calcium carbonate of which they are principally composed is dissolved, leaving a pulplike mass of vegetable fibers, fila-

## Mingled

Ningled with the concretionary pebbles just described, and also scattered over the surface of
many marl deposits are shells, particularly the many marl deposits are shells, particularly the
valves of unios or fresh-water mussels, bearing irregular incrustations of calcium carbonate, which on some shells is 1 inch or 2 inches thick. These masses are of the same character as the marl pebbles, and the association of algous growths with some of them is apparent.
hbmical composition.
Chemical analyses of a large number of samples of marl from various localities in Michigan show that when free from sand, clay, or other extraneous matter it is nearly pure calcium carbonate, but contains a small percentage of magnesium, and of sulphur. Representative samples of marl collected at localities in the Ann Arbor quadrangle, show the composition indicated in the following table:

| Chemical analyses of marl. [Samples dried at $100^{\circ} \mathrm{C}$.] |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Constituents. | 1. | 2. | ${ }^{3}$ | 4. | 5. |
| Silica ( $\mathrm{SiO}_{2}$ ) | ${ }^{6.66}$ | 0.96 | 0.48 | 2.65 | 0.53 |
| Alumina ( $\mathrm{Al}_{3} \mathrm{O}_{3}$ ) | 3.17 |  |  |  | . 14 |
| Ferric oxide ( $\mathrm{Fe}_{2} \mathrm{O}_{3}$ )- | 1.36 | 62 |  |  | . 99 |
| Calcium oxide (CaO). | 4709 | 53.60 | 1.27 | 49.17 | 51.87 |
| Magnesium oxide <br> (MgO) <br> - .-......... | .77 | 1.79 | 1.28 | 1.42 | ${ }^{1.10}$ |
| $\begin{aligned} & \text { Sulpharico } \\ & \text { dride } \\ & \text { dio } \\ & \text { anhy- } \end{aligned}$ | 1.25 |  |  | 82 | 14 |
| Loss on ignition | 40.70 | 43. 45 | 45.82 | 44. | 44.46 |
|  | 100.00 | 100. 00 | 100.34 | 100.12 |  |
| $\begin{gathered} \text { Calciam } \\ \left(\text { CaCO}_{3}\right) \end{gathered} \text { earbonate }$ | 8409 | 93. 92 | ${ }^{91.56}$ | 87.80 |  |
| Magnesium carbon- <br> ate $\left(\mathrm{MgCO}_{2}\right)$ | 3.72 | 2.76 | 2.57 | 2.96 | 2.30 |
| 1. From Fourmile Lake. Analyst, E. D. Campbell. <br> 2. From Zukey Lake. Analyst, E. D. Campbell. <br> 3. From Zukey Lake. Grade A. Analyst, H. W. Berger. Average of over one hundred analyses made by the National |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| Portland Cement Company. |  |  |  |  | 4. From Zukey Lake. Grade B. Analyst, H. W. Berge |
| ${ }^{\text {5 }}$. From Ore Lake. Analyst, E. C. Sullivan. In order to |  |  |  |  |  |
|  |  |  |  |  |  |
| make this analysis uniform with the others in the table,under "loss on ignition" is included: $\mathrm{Co}_{\mathrm{z}}=42.30$; combined |  |  |  |  |  |
| underunter $=1.22$; and and absorbed water= $=0.97$; the complete analysis |  |  |  |  |  |
|  |  |  |  |  |  |

The marls of Michigan, according to Charles A Davis, have been formed mainly through the vital
action of plants, and particularly of certain alge, which separate calcium carbonate from the water
in which they live and deposit it in their tissues and on their surfaces. The plants most active in this process are the Characeer, especially Chara fragilis, or common stonewort, and the smaller blue-green algæ Zonotrichia. These plants, but particularly Chara, grow luxuriantly in water that is from a few inches to about 25 feet deep, and when they die the calcium carbonate they have secreted remains on the bottom. In this manner and also by the drifting of dead plants by wind and currents, thick deposits of marl are accum lated near the margins of lakes while but little such deposition takes place where the water is over 25 feet deep. These facts explain the occurrence of terrace-like deposits of marl about the borders of deep lakes, as, for example, Zukey, Bass, Portage, and Ore lakes, while their bottoms, beneath deeper water, are nearly free from similar material.
An important fact to be noted in this connection is that marl is deposited only in lakes in which the percentage of rime salts in solution is far below th lakes have outlets, and their waters are of the usual purity of the streams of the region where they occur That is, they contain about 0.357 parts per thousand of total solids, and about 0.113 parts per thousand of calcium carbonate in solution. Owing to the small percentage of calcium carbonate present these waters and the absence of conditions leading to a marked degree of concentration by evaporation, no explanation can be suggested for the formation of marl by chemical precipitation. The cementation of the marl about the border of Ore Lake, referred to above, seems to be due to the evaporation of the water drawn up by capillary attraction above the level of the lake and the precipitation of the salts it contained.

## usss.

Marl is of value as a fertilizer and if mingled with the peat that occurs in many lakes and swamps in intimate association with it might be applied but it has been used for this purpose in Michise to only a limited extent. The analyses give to only a that it is nearly pure analyses given and if calcined would yield a superior quality of lime. It has been burned for lime in a small way at several localities in Michigan; and Limekiln Lake, in the Ann Arbor quadrangle, derives its name from the fact that the marl it contains was formerly burned to lime. The difficulties in the way of manufacturing lime from marl are the large quantity of water to be evaporated and the inconvenience of handling finely divided material in the kiln. Several of the smaller marl deposits in the Ann Arbor quadrangle, it is to be hoped, will in future be utilized in ways just referred to.
When it occurs in large beds of sufficient purity marl is chiefly available for the manufacture of Portland cement. The large cement industry recently developed in the Southern Peninsula of Michigan is based on the marl deposits found there. (Russell, I. C., The Portland cement industry in
Michigan: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 629-685.)
avatlable deposits
Within the area of the Ann Arbor quadrangle there are two marl deposits of sufficient extent and Zukey and Bass lakes, and that of Fourmile Lake The marls in Portage Lake and Ore Lake and their associated marshes are also extensive and may perhaps be considered as additional deposits of commercial importance.
Zukey and Bass lakes.-The deposits of marl in Zukey and Bass lakes and their associated marshes are types of the beds in Southern Michigan, and the following facts concerning them, together with the analyses already presented, have more than local interest.
The marl in Zukey and Bass lakes occurs for the most part in terrace-like extensions from their shores, which have a depth of 8 or 9 feet of water on their outer margins and descend steeply into west of the oval in shape, measuring about 200 by 600 feet, oval in shape, measuring about 200 by 600 feet,
which contains marl that ranges in depth from 14
o 22 feet and is surrounded by water from 22 to nel representing a much smaller lake, is a chancompletely filled with marl and known as Lim Bay. The marl in these basins, which is essen tially a single and nearly continuous deposit, has been carefully surveyed by the National Portland Cement Company, which owns the deposit.
The area surveyed was divided into squares measuring 100 feet on a side, and the quantity and quality of the marl in each square was caregrades of In classifying the marl four letters $a, b, c, d$ purity were recognized, indicated by the found near the shore of the lake and in a general way the other grades are arranged in succession lakeward from it; the purest having been deposited farthest from sources of mechanical contamination. Grade $a$ and $b$ are well suited for making Portland cement, but grade $c$ is not considered ser
for that purpose, and grade $d$ is worthless.
Measurements of marl in Zukey and Bass lakes and
Lime Bay.

| Place, | Quality. | Area. | Aver. <br> ange <br> depict. | Deptit water |
| :---: | :---: | :---: | :---: | :---: |
| Zukey Lake | $a$ | Sa feet. 380,000 | $\begin{aligned} & \text { Feet. } \\ & 19.0 \end{aligned}$ | ${ }_{\substack{\text { Feet. } \\ 3.5}}$ |
| Do. | ${ }^{\text {b }}$ | 1,630,000 | 18.0 | 4.8 |
| Do. | c | 540,000 | 16.8 | 3.8 |
| Do. | ${ }^{\text {d }}$ | 120, 000 | 15.0 | 3.2 |
| Bass Lake | ${ }^{\text {a }}$ | 2,350,000 | 19.4 | 3.2 |
| Do. | ${ }^{\text {b }}$ | 770, 000 | 20.6 | 3.7 |
| Do. | c | 90,000 | 18.1 | 3.8 |
| Do |  | 70,000 | 14.3 | 2.4 |
| Lime Bay | $a$ and $b$ | 320, 000 | 17.3 | 2.0 |
|  |  | 6, 290, 000 | 18.6 | 3.7 |

The average composition of the grades of ma
designated as $a$ and $b$, as indicated by a large number of analyses, is shown by the analyses already given.
In a
In addition to the portions of the deposit sur veyed there is an extension westward in Lime Lake which, however, is comparatively small in area As shown by the measurements given above, Zukey mately $103,000,000$ cubic feet of marl. If 9 cubic feet of marl as it occurs in the bed will make barrel of Portland cement-a ressonable estime the amount available is sufficient to manufactur about $11,500,000$ barrels of cement.
Fourmile Lake.-The only place at which the marl beds of this quadrangle have been utilized White Portland Cement Company for a time made cement from the marl beds in and about Fourmile Lake. Though not so extensive as those on Zukey and Bass lakes they are yet of sufficient extent to furnish material for running the plant many years. Not many data of value could be obtained from the company concerning the mat deposits. It is worthy of mention that the clay used by this plant in cement making was obtained from a glacial deposit in the marsh bordering the lake. The clay bed is reported to have a thick clay it contains remarkably few pebbles and otherwise seems well adapted for use in cement making

## solis.

The drainage conditions attending the melting of the ice, and the presence of lakes on portions of the surface after the ice had disappeared were potent influences in determining kinds of soil. Where the are loose textured or from the melting ice the soth escape of water was impeded and was therefore slow the soils are close textured and in places almost impermeable to water. On the lake bottom the soils range from loose-textured, gravelly material at deltas and at the successive shores of the falling lake to a stiff clay that is fully as close textured as any of the glacial deposits. A sandy soil which is intermediate in texture between the gravel and the clay covers a large area in the southeast part of the quadrangle. It would be difficult to map the extent of each class of soil. Over wide areas, particularly in the interlobate moraine, the soil is subject to impracticable. There is also more or less gradation or intergradation of soils. Thus in the predominantly clay-loam areas the clay and clay loam
ranges to sandy loam; while in the sandy-loam areas there is a gradation in one direction into clay pproach to uniformity is found in the sands clays of the beds of the glacial lakes.
With the exception of the sandy
Wenerally productive. Probably tracts the soils would bring larger returns if reforested than can be obtained by farming. The steep-sided hills of the moraines are available for peach growing, for orchards planted on them generally escape damage from late spring frosts.

## water resources. <br> water power.

Degree of development.-This quadrangle includes the portion of Huron River in which water power has been best utilized as well as a section of Raisin River that affords important sources of power.
Within the limits of the qudrange, Within the limits of the quadrangle, ten dams are in operation on the Huron and several small water powers have been developed on tributaries
of the Huron and on Saline River, a tributary to of the Huron
the Raisin.
The development of water power within the Ann Arbor quadrangle is already large, but it is capable of considerable increase and improvement. A su ey made under the direction of Lyman E. Cooley, Company, for the purpose of increasing and more economically utilizing the water power on the Huron, has recently been completed, and certai of the data thus obtained have been furnished by the company for use in this folio and are here presented.
Huron River.-Huron River affords great advan ages for water-power development in the arrange ment of its tributaries, the location of lakes natural storage reservoirs in its drainage area, an the distribution of its fall. Its headwater portion, above Portage Lake, in a table-land that stand about 850 feet above sea level, includes numerou lakes and receives several important tributarie The greater part of the drainage basin of Mil Creek, which enters the Huron at Dexter, is miles eleved in the 100 squar miles fall within the limits of the bater table hand, 16 between Portage Lake and Dexter, and 143 in the Mill Creet watershed making a total f 679 square miles above Dexter. The Hur Dexter flows at an altitude 830 feet above sea level or 256.65 feet above the mean level of Lake Erie It thus appears that the stream leaves Dexter with the accession of more than 75 per cent of the drainage to furnish power in a somewhat rapid descent of more than 250 feet to Lake Erie. The stream falls 190 feet before it leaves the Ann Arbor quadrangle, being below 640 feet at its eastern limits. The following summary of gradients on Huro River in its course across the quadrangle has been obtained from a pronle included in Mr. Cooley report on the survey of the Huron River, supple mented by estimates between Ore Lake and th Hudson dam.

| Stations. | $\begin{gathered} \text { Alltadue } \\ \text { abeo.e } \\ \text { aesel } \end{gathered}$ | $\begin{array}{\|c\|c\|} \substack{\text { Distance } \\ \text { conese } \\ \text { pont. }} \end{array}$ | $\underset{\text { per mille }}{ }$ |
| :---: | :---: | :---: | :---: |
| Ore Lake | 855.6 | ${ }^{152,800}$ | 0.51 |
| Portage Lake | 850.5 | 111,560 | 6. |
| Hudson (under dam) | 838.5 | 19,200 | 1.82 |
| Dexter dam | 831.86 | , 500 | 10.42 |
| Dexter briage | 828.9 | 13,600 | 3.47 |
| Scio dam -- | 819.06 | 11, 000 | 5.117 |
| Delhi dam | 808.4 | 17,400 | 6. 76 |
| Foster bridge.- | 787. 12 | 11,20 | 5.1 |
| McMahon rapids | 776.3 | 1,300 | 19.17 |
| Foot of rapids | 771. 39 | 10,300 | 3.9 |
| Base of dam. | 763. 16 | 11,700 | 6. 8 |
| Railroad bridge | ${ }^{747.93}$ | 5,809 | 4. 63 |
| Highway bridge | 742.96 | 9,300 | 7.38 |
| Geddes (under dam). | 729.96 | 13,260 | 6.9 |
| Lowell ( (nder dam) ... | 713.39 | 22,700 | 10.88 |
| Foot of Ypsilanti rapids. | 676. | 41,500 | 4.04 |
| Rawsonville | 644.18 |  |  |

The rapid fall for 4 miles in the vicinity of Ypsilanti affords power for five dams with heads Belleville, a village about 1 mile below the point wellevile, a vila ge the poin tilized, although at one time a mill at Rawson-

Ann Arbor.
ville used water power. Dams are in operation at date of writing (April, 1905) at Geddes, Ann Arbor, Osborns Mill, Delhi Mills, and Hudson Mills, with heads of $10,8,6,10$, and 9 feet respec tively. At Dover, Dexter, Scio, and Foster the
dams are either out or are in disuse. The minimum flow of the disuse. The minimum flow of the river at Dexter is esti responds to about 61 at Hudson Mills, 92 which cor 100 at Rawsonville and 109 at Flat Rock, near the 100 at Rawsonville, and 109 at Flat Rock, near the
mouth of the river. It is further estimated that an average minimum of less than 100 feet for 30 days at Dexter will probably not occur once in generation, and this may be taken as a normal generation, and this may be taken as a normal
minimum for dry years. The ordinary low-water flow is more than double that amount. The survey by Cooley shows that it is feasible to impound the water in the table-land so as to furnish a flow which will not fall below 240 second-feet and which by good management may yield 360 secondfeet at Dexter. It also shows that it is feasible to perate 10 dams, each 21 feet high, in the sectio from Dexter to Rawsonville. The present dams will probably soon be supplanted by higher ones.
Tributaries of Huron River.-On tributaries of Tributaries of Huron River.-On tributaries of Huron River dams are in operation as follows, the data having been furnished by the mill owners:

| Location of dam. |  | $\left\lvert\, \begin{aligned} & \text { naxir } \\ & \text { name } \\ & \text { neas. } \end{aligned}\right.$ |
| :---: | :---: | :---: |
| South Fork at Rushton-. | ${ }_{19}^{40}$ | $\begin{aligned} & \text { Feat. } \\ & 14 \\ & 18 \\ & \hline \end{aligned}$ |
| School Creek at Pettysville.. |  |  |
| Hamburg Creek at Hamburg |  |  |
| Honey Creek at Pinckney... | $\begin{array}{r} 60 \\ \begin{array}{c} 60 \\ 116 \\ 20 \end{array} \\ \hline \end{array}$ | $\begin{aligned} & 14 \\ & 10.5 \\ & 8 \end{aligned}$ |
| Mill Creek at Dexter-. |  |  |
| Mill Creek in see. 29, Lima Township . |  |  |

Raisin River.-Raisin River has no great ingathering of drainage into its headwater portion, but receives several large tributaries in its middle course, angle. The above the point where it enters the quadrangle, but between that point and Tecumseh, where it leaves the quadrangle, its drainage area increases to 250 quare miles, the increase being due chiefly to two affluents, Iron Creek and Evans Creek, the latter entering within the village of Tecumseh. Thi 1100 feet at its source to R River falls from about 100 feet at its soor at the poin ional fall of 100 feet or to 744 feet in pessing to th outhern limits of the quadrangle, an Tassing to the his headwater portion, as in the headwater portion of the Huron, there are numerous lakes and porten ive gravelly plains, which receive the surface wate and to some extent the underground drainage and regulate the distribution of the water to the streams. Saline River.-Saline River, the most important ributary of Raisin River, drains an area of 130 quare miles, of which 80 square miles lie above Saline village. Its most rapid fall occurs in the vicinity of Saline, where it makes a descent of 60 feet in about 3 miles, hus affording good wate power, supplied from nearly two-thirds of the of 13 miles, from its source in Columbia Lake to he 800 -foot contour, and its descent from the 800 the 700 -foot contour covers 10 miles, leavin about 22 miles for the descent of 66 feet in it lower course. Although there are but two devel and one at Milan the the river, one near saline and one at Milan, the amount of its fall would
justify several similar powers.

Water powers on Raisin River and its tributa
the Ann Arbor quadrangle.

| Loeation of dam. | $\begin{aligned} & \text { Rated } \\ & \text { horse } \\ & \text { power } \end{aligned}$ | $\underset{\substack{\text { Maxi. } \\ \text { head. }}}{\substack{\text { ned }}}$ |
| :---: | :---: | :---: |
|  |  | Feet. |
| shten | \% |  |
| Raisin River at Manchester | 85 | 12 |
| Raisin River at Manchester | 135 | 14 |
| Raisin River in sec. 20, Bridgewater Town <br> ship, Washtenaw County. |  |  |
| Raisin River at Clinton |  |  |
| Raisin River at Teeamseh | 150 | 18 |
|  |  |  |
| Spring Brook, 1 mile south of Saline .-- | 10 | 12 |
| Saline River, $1 \ddagger$ wiles south of Saline | 45 | 9 |
| Saline River at Milan | 70 | 7 |

Drainage. Theary pumping, however, do not pass through till, porous, except in certain small areas that are cov ered by a stiff clay, that it absorbs a large part of he rainfall. It is roughly estimated that less than 20 per cent of the rainfall escapes absorption and may be reckoned as surface run-off. On many of hat gullies have not been developed, while on the lains or rently undulating tracts, while on the plains or gently undulating tracts, there are areas which scarcely any drainage lines have been devel ped, and yet the soil is so well underdrained that forms good farm land. Indeed, swamps are much more numerous and extensive on the borders of the streams and lakes than elsewhere, as may be seen by a glance at the topographic map. The divides and slopes absorb the water and supply it by slow underground drainage to the streams or kes and their bordering swamps.
Ground-water table. - The ground-water table conforms in a general way to the surface of the and, as is shown by data afforded by wells, bu tands in places considerably below the surface and yet somewhat above the neighboring swamps. Thus, n some of the high ridges in northeastern Lodi Township the permanent ground-water table is正 100 feet below the surace. Such condition where the ridges are composed of porous beds to that depth. As a rule the distance to the groud ter phe 10 than 25 fet and at $f$ paes exceeds 50 feet. On the till plains, and to some extent on the plaine of sand and gravel, and also on the moraines, the ground-water table rises and alls with the wetness or dryness of the season, so hat wells not infrequently show variations of sev ral feet in the depth of water as a rexult of the round-water fluctuations.
Water with strong hydrostatic pressure.-Wells and other excavations have shown the presence of water under two very distinct conditions, one marked by hydrostatic pressure or artesian head nder which the water rises in the pipe or well, the other showing no such pressure or rise. Waters under strong hydrostatic pressure are generally conined between beds of clayey till or other nearly
impervious material, the upper bed acting as a impervious material, the upper bed acting as a s access by direct percolation downward. The ovement of the water that is without notabl ydrostatic pressure is usually toward neighboring reams, while that in which there is strong hydro tatic pressure is as a rule largely independent of he surface drainage.
On the artesian water map the head in the well hat show strong hydrostatic pressure has been sian head from the north west toward the southeast, which indicates that the high land at the north west constitutes a catchment area from which the water passes southeastward beneath the lower dis tricts. The glacial deposits are so complex, how ver, as to preclude the assumption that a wide pread continuous water-bearing bed is presen hroughout the quadrangle. It is more probable that the water beds are distributed in strips or sections of irregular thickness and width, and that
in some places the beds have no adequate underin some places the beds have no adequate under-
round passages through which the water may find ground
escape.
In small districts where the surface is sufficiently ow, flowing wells have been obtained. The public supply of Ann Arbor and of Ypsilanti is derived
from wells of this class, but as a rule the water under hydrostatic perare fils by fow feet reach the surface. The distribution of the to and the areas where flowing wells have been obtained are shown on the artesian water map. Some of the artesian-well districts are supplied, in part at least, from catchment areas near by, which stand but little higher than the wells, and for this reason, probably, the water in these wells rises but little higher than the surface or well mouth. The Ann Arbor Water Company at one time pumped so vigorously from ne of its large wells as to drain the shallow wells in the neighboring districts out to a distance of about one-fourth mile, thus showing that these wells are supplied, in part at least, from the immediate vicinity. Yet some of the wells are 75 to 90 feet deep and pass through a bed of blue till before
finding water. The wells that were drained by the
heavy pumping, however, do not pass through till,
their entire depth being through sand and grave hat would readily absorb the surface water. These shallow wells stand on higher ground than the flownessure in the inclined beds which causes hydrostatic ess beneath the till to the fich lead down from wem flowing-well district lies south of Ans. A the line of dacial drainage already deseribed, hich led from Huron River to Raisin River. The vells here are very shallow, most of them being but 0 to 30 feet deep and the water rises only 2 to 10 feet above the surface. At the wells there is genrally a bed of clay under the surface peat or muck, but it seems to be confined to a strip only a little wider than the flowing-well district, for farther westward, at the border of the valley, a gravelly trip sets in. This gravel apparently receives the water discharged from the surface of the higher land west of the valley and conveys it to the flowng wells with hydrostatic pressure barely sufficient oo cause a flow. Confirmatory evidence of the deri-
vation of the supply from the immediate borders vation of the supply from the immediate borders of the valley is found in the fact that in dry sea-
sons the wells are weaker than in wet seasons. Wells that have remote catchment areas are not fected so promptly, if at all, by drought
Inasmuch as the flowing-well districts of this hadrangle, together with those of other parts port on flowing wells (Water-Sup and Irr Paper Tos 182 and 183, U S. Geol Survey) only brie nention will be made of them here The principal istricts are on the lake plain, one large area being at the eastern edge of the quadrangle, north of Denton, another covering 12 square miles about York, and a third comprising 2 square miles between Milan and Cone. Flowing wells in river valleys are found at the Ann Arbor waterworks, he Ypsilanti waterworks, and near Saline. Flowing wells among morainic ridges are found in and outh of Ann Arbor and northeast of Pinckney Most of the flowing wells obtain water from the basal portion of the drift, but, as already indicated, the artesian water in the area south of Ann Arbor lows at very slight depths, and some of the well the Ann Arbor Water Company are shallow.
Mineral waters.-All of the deep wells in the quadrangle have yielded mineral water, and the aters of two located at Ypsilanti have been used no at which The records as to the precise hor vells are not definite but was reached in all ppars to 0 it and it in bed by from other formations. The water at $Y$ psilanti is utilized on a small scale for baths and for drinking. The chemical composition of waters obtained from stable:



 2. Moorman well, Ypilanti Mineral Bath Co. James H.
Sheard, analyst. Water drawn September 5, 1884. Weil
cased to 550 feet; water derived from Dundee limestone.

Reaperature alkaline.
3. Mo . Morman well, Ypsilanti Mineral Bath Co. (same well 55 No. 2). DeForest Ross, analyst. Water drawn September
3, 1897. Temperature, 16.5 C. ${ }^{\circ}$ (i)
Specific gravity, 1035s 13, 1897. Temperature, $16.5^{\circ}$. . (9) Specific gravity, 1.0358
Reaction alkaline. Before this sample was drawn the casing

The wells whose waters are included in the analyses here given were drilled in the hope of obtaining a flow, but every one of them requires pumping. Other wells, as those at Milan and
South Lyon, were put down with the hope of obtaining gas or oil, and these also have been failures so far as the primary aim is concerned. The failure of the wells to supply flowing water is due to the low altitude of the outcrops of the strata that form the gathering ground for the water. The artesian head in all the strata below the Pleistocene deposits throughout the greater part of the quadrangle is below the surface level. The rock formations as a whole are less favorably conditioned than the Pleistocene deposits to yield a flow.
Detailed conditions by townships.-In Putnam Township the drift is largely gravelly or loose textured, with abundance of water at moderate
depths, few wells being more than 40 feet deep depths, few wells being more than 40 feet deep.
However, the flowing wells in sec. 12 are about 60 feet deep, and some of the deepest wells in the village of Pinckney are of that depth. A few wells in the northwestern part of the township are sunk to a depth of about 100 feet in order to obtain water from the rock, a softer water than that derived from the glacial deposits.
In Hamburg Township wells are generally shallow, with water at 25 to 40 feet, but on the south side of the township a few have been sunk to depths of 60 to 100 feet or more, and wells east of Hamburg village are about 60 feet. Some of the deepest wells in the southern part of the township struck water at moderate depths, in sand too fine to screen, and were accordingly continued to coarser material. A well on the Winans estate, south of Winans Lake, 158 feet in depth, which enters sandstone about 8 feet, appears to be the In sunk to depths of 70 or 80 feet, but have been sunk to dephs or hor or feet, but the greater at depths of 30 to 50 feet. The drift is larely gravelly, and so far as known, no wells have struck rock.
In Lyon Township a prospect boring for oil at the village of South Lyon, 1300 feet or more in depth, is said to have struck a strong flow of water in gravel at about 350 feet, and to have reached rock at about 500 feet. However, no good record of this well was kept. Wells in the east part of South Lyon, on the till plain, are 30 to 40 feet deep, while those in the west part, on the gravel plain, are only 20 feet deep. Wells on the elevated tract in the southeastern part of the township are not deep, their usual depth being 30 to 40 feet. They enter gravel and sand that lies beneath a thin sheet of till.
In Novi Township wells generally obtain water at depths of 20 to 40 feet, but a few have been sunk to depths ranging from 60 to 100 feet. On the highest points, which stand 10 to 1020 feet above tide, wells seldom reach 75 feet. The surface of the township is very largely a clayey till, depth by most wells and an abundance of water has been found.
In Dexter Township the conditions are similar to those noted in Putnam Township, which borders it on the north. Not many of the high hills in either township are occupied by residences, and most of the wells are therefore either in the sags or near the foot of the slopes and are shallow. Between North Lake and West Lake a few wells sunk on ground that stands 990 to 1040 feet above sea level reach depths exceeding 100 feet, and some wells 60 to 100 feet deep have been dug along the west bluff of Huron River, but with these excepcons not many wells in this township exceed 40 feet in depth.

In Webster Township there are some places in $\mid$ Ann Arbor are between 75 and 150 feet in depth, which deep wells have been found necessary, hiefly on the highest hills, but few of them he wells are between 30 and A large number of still more are less than 30 feet in depth. Except long the lines of tacial drina wh. Excep utirely in cravel to the first water bed the surfae this township is generally coated with till, which this township is generally coated with till, which from the level of the ground-water table. Northfield Township comprises a larg
of plain surface, both till and gravel, the wells on which obtain water at depths ranging from 15 to 0 feet. In the southern part of the township, hich stands higher, a few deep wells have bee sunk, yet even in this higher part many wells have obtained water at depths less than 50 feet.
In Salem Township at some places deep wells seem to be a necessity, the most notable place being in its western part, within a radius of about 2 miles east, south, and west of Worden. Sev eral of the wells there are 100 to 200 feet deep and ass through a thick deposit of clayey till. Many the wells ane hownip 5 ad 40 feet depp, 4 fow Sale bre dug dep 50 fet depths of 50 feet or more. Nearly all excep of clayey till.
In T. 1 S., R. 8 E., the north half of which is called Northville and the south half Plymouth, the valleys afford boiling springs and flowing
wells, and the lake plain also is favorably situwells, and the lake plain also is favorably situboiling springs in the valley of Rouge River, in secs. 8 and 9 , furnishes the public supply for the village of Plymouth. Many of the wells on the morainic tracts on each side of the Rouge Valley each depths of 60 feet or more and enter beds of gravel or sand that lie beneath a clayey till. The till is a very thin deposit in the north western part of the township.
In Lima Township wells generally obtain water at depths of 30 to 50 feet, and so far as reported no well exceeds 100 feet in depth. The surface is generaly a lose-textured tir with occasional gravpily the wells by lirect pereolation from the apply the wells
In Scio Towns
ravel plain along Honey and except on the gravel plain along Honey and Mill creeks, is
largely a clayey till, more compact, as a rule, han that in Lima Township. As a consequence than that in Lima lownship. As a consequence, the high land southeast of Dexter, and also on the moraine in the southeastern part of the township, everal wells have been sunk to depths of 100 to 50 feet or more. There are also a few deep wells in the moraine on the north side of Huron River wo wells at Dexter have struck rock, one at the German Church, at a depth of 150 feet, the ther at the residence of John Gallagher, at a epth of 100 feet. In each the rock surface is a little less than 800 feet above sea level, or about 40 feet below Huron River. The deep wells on the bove of Huron River have a head about 850 fee ore sea leve, while the head in those in the both north and south of the valley, is higher, in me wells reaching 900 feet. It is probable that the low head along the river is due to the escap f a large part of the underground water into the ver valley through springs, some of which appear o boil up from deposits below the river level.
In Ann Arbor Township the conditions for btaining water are more diverse than in any ther township of the quadrangle, owing to the differences in the elevation of the different parts of its surface. The high portions of the township a rule require wells of considerable depth, not few being 100 feet or more. A depth of 80 to 00 feet is also found necessary on the gravel plain n and near the university campus. Most of the
flowing wells in the low land in the west part of

Ann Arbor are between 75 and 150 feet in depth,
but several have obtained water at depths of 25 to but several have obtained water at depths of
30 feet. Rock has been struck in four borings made by the Ann Arbor Water Company in and Hay \& Todd underwear factory, on the ground of the Ferdun bumer Company and on thound versity campus. The altitude of the rock surface at these borings shows a variation of but 42 feet, the lowest altitude being 630 and the highest 672 feet above tide. The head in wells in the northwestern part of the township is about 900 feet above sea level, but in Ann Arbor and in the area just east of the city it is only about 800 to 830 feet. The head appears to be slightly lower in the Huron River valley than at points a mile or more back from the river. Along the border of the valley in the vicinity of Ann Arbor there are strong springs, some of which issue from the base of the gravel deposits of the campus plain and fom river terraces. There are also numerous springs on the border of the low tract in the western part of the city. Some of these issue from the base of gravel deposits and others boil up from deeper beds. One spring just west of the city limits, on the north side of Liberty street, is estihere to thers nearly as strong within the city limits. In May, 1904, at a time when a neigh limits. In May, 1904, at a time when a neigh$45^{\circ} \mathrm{F}$., this spring had a temperature of $50.3^{\circ} \mathrm{F}$. During the summer the temperature of the spring emained at about $51^{\circ}$ while that of the well rose to $52^{\circ}$. This constancy in temperature may indicate that the spring boils up from a source so deep that it is uninfluenced by the accession of the surface waters which cause the variations in the temperature of the shallow well. In this connection it may be stated that the shallow flowing wells of the Ann Arbor Water Company also show a con-
stant temperature of about $50^{\circ}$, nearly the same as stant temperature of about $50^{\circ}$, nearly the same as
that of the boiling spring. They may, therefore, that of the boiling spring. They may, therefore, In Similar deep-seated source
In Superior Township most of the wells on the gravel plain in the vicinity of Dixboro obtain an
abundant supply of water at depths of 30 feet or bundant supply of water at depths of 30 feet or lass. The dephs of the woraine ing from 20 feet up to nearly 300 feet One the farm of feet up to nearly 300 feet. One on depth of 284 feet and entered rock only 17 feet Most wells along the moraine find water at depths of 30 to 40 feet in beds of gravel intercalated in the till, but at some places there is an unbroken deposit of till from the surface down to the bed rock. Conditions on the slope southeast of this moraine are very similar to those along the moraine, most of the wells there being about 30 feet deep, although a few have failed to dain water in the drift. A boring on the Bennett farm, in sec. 28, penetrated till 300 drift, having struck shale which seemed unlikely to furnish water. Wells on this slope and on the lake plain to the east find water that has suffin the lowest parts of the district may flow
In Canton Township the conditions are simila hip, the wells showing strong hydrostatic presur and many of them flowing. Most of the flowing wells are about 75 feet obtained flows at depths of only 20 to 40 feet. A obtained flows at depths of only 20 to 40 feet. A Ypsilanti, bored in 1873 to a depth of 28 feet, afforded at first a strong gushing well, with a head 8 feet above the surface. This well now has a head only 3 feet above the surface, and its flow is reduced to a weak stream with scarcely one-hundredth of its original volume. Neighboring wells in sec. 9 , on the farm of James Quartell, have shown similar loss of head and some reduction in volume. The deeper wells, which obtain their supply from near the base of the drift at about 75 feet, have shown but little loss of head or volume.

In Freedom Township driven wells are not so anmon as large excavated ones and water is till plain north of the moraine well. the moraine itelf i composed of loose wextured rial that is readily permeable by water and well apted to supply it rapidly to excavated wells.
In Lodi Township the greater part of the surfa morainic and the texture of the moraine is more the inner or southeast slope being especially clayey, Most of the dug wells obtain water at 40 to 60 feet though some of them reach depths of 100 or more feet. The driven wells range from about 75 feet up to 250 feet and none have reached the rock. Wells on the plain in the northwest corner of the township and those on the gravel plain in its southeastern part are shallow, being only 20 to 30 feet deep.
In 1
In Pittsfield Township deep wells are confined to the prominent moraine in its northwestern part, where several have depths of 100 to 175 feet or more, and some of these wells show the remarkably high head of nearly 900 feet. In the valley-lik flowing wells are obtained at depths of only 20 to 30 feet. It the raminder of the townh whi is a patly undulating till tract, water is easily obtained from excavated wells, though fer easive wells have been sunk in its northwestern portion, near Saline. The excavated wells, some of which reach depths of 40 to 60 feet, strike veins withou strong hydrostatic pressure, their supply being derived apparently from the immediate border Wells driven to a depth of 75 feet, such as those near Saline, strike water which has a head nearly level with the surface, or fully 20 feet higher than in neighboring excavated wells, 50 feet in depth.
In Ypsilanti Township excavated wells in the area west of Huron River obtain water at depths of 30 to 50 feet, but many of the wells in the area east of the river obtain water at depths of only 10 to 20 feet, from the base of the deposit of sand and gravel which covers that portion of the old lake sotom. In the ciy from flowing wells in the Huron River valle, 5 whid a 60 to 65 fet deep. The rock in that vicinity is struck at about 100 feet, though the Moorman well penetrated 185 feet of drift. The head in the waterworks wells is only about 685 feet above sea level, or nearly 150 feet lower than in the flowing wells of Ann Arbor In the part of Van Buren Township embraced in this quadrangle a coating of sandy gravel yields water at depths of only 10 to 20 feet. Near Denton flowing wells are obtained at depths of 70 feet or more. These pass largely through till after traversing a few feet of surface sand. In the eastern part of the township the sand coating is insufficient to yield water, and some wells are sunk to depths 100 feet or more, largely through till.
In Bridgewater Township wells along lines of glacial drainage are very shallow, few of them reaching depths greater than 25 or 30 feet. The a large amount of clayey till. Excavated wells on the morainic tracts generally obtain water at depths of 40 feet or less, but at some places it has been ecessary to drive wells to the rock to obtain sufficient supply of water. In some wells the water me theck is brackish. The gravel and sand eds incorporated in the till appear to be restricted extent, though they occur at several levels. As
result neighboring wells may differ greatly in depth.
In Saline Township wells obtain water at moderate depths on the morainic tracts, few of them having been sunk deeper than 50 feet. Wells in the village of Saline are also but 40 to 50 feet deep, but some on the lake plain in the southeastern part
of the township have been sunk to depths of 100 feet or more and some in the extreme southeas corner overflow. The sheet of clayey till appears to be more continuous beneath the lake plain in
this township than beneath the moraine, and wells must pass through this sheet in order to obtain water.
The northern part of York Township is morainic and many of the wells there obtain water at depths
of 25 to 50 feet, most of them being dug. On the of 25 to 50 feet, most of them being dug. On the hip, there are numerous tubular wells 75 to 150 feet in depth. Those in the vicinity of the Belmore beach generally overflow, but elsewhere the water lacks a few feet of reaching the surface. There are a few flowing wells in low tracts among the morainic ridges in the northwest part of the township, and it is probable that flows may be
obtained along the Saline Valley south of the vilage of Saline
The eastern half of Augusta Township is a sandy plain on which wells may obtain water at depths of only 10 to 15 feet, and the conditions are similar in Sumpter Township. The western half of Augusta Township is largely a clay plain in which the deep borings, as in York Township show strong hydrostatic pressure. Possibly flow ing wells may be obtained in the northwestern part In Clinton
In Clinton and Tecumseh townships, which together occupy T. 5 S., R. 4 E., wells obtain water at shallow depths, not only along the
broad line of glacial drainage that runs through the western part of the township but also on the bordering morainic tracts, A few tubular wells have been sunk to depths of 75 to 150 feet, and these show a head greater than that in the flowingwell district on the lake plain to the east, the head in some wells being above 800 feet
In Macon Township, which is largely occupied by the lake plain, numerous deep test borings have been made to obtain flowing wells, but flows have been obtained only in the northeast part of the from 35 feet from 720 to 755 feet above tide, there being an increase from the southeast to the northwest. The borings indicate that the head is only 700 feet in the southeast corner of the township, but reaches Milan Teetnin ior
Milan Township is a clay plain except along its The township has been tested for flowing wells in nerly every section, but they have been found only in two strips, one near the Whittlesey beach in its northwest corner and the other just below the Arkona beach in a strip leading from northeast to southwest across the central part of the township. The head in the former strip is 720 feet or more; that in the latter is 685 to 700 feet. From this lower strip the head increases very slightly toward the west, but not sufficiently to equal the rise in the altitude of the surface. Consequently the wells lack a few feet of overflowing. In the southeastern part of the township the head declines abruptly so that the water level is some distance below the surface in wells that have been sunk to the base of the drift. It is, therefore, a very In Lomising field for flowing wells. In London Township, except in its southwest and southeast corners and a few places on its north yield water to wells sulk of sulfient depth to less. In the layey poide of where deeper wells have been of the township, encountered at the moderate depths of 40 to 60 feet. If the rock struck is limestone the well ordinarily obtains water near its surface.
The northwest corner of Exeter Township is covered by sand to a sufficient depth to supply water to wells sunk 10 to 20 feet. Elsewhere in that portion of the township that lies within this quadrangle the sand is very thin and many wells have been driven into the rock, which is struck at depths of 12 to 40 feet. In the vicinity of Maybee a good supply of water is obtained at the base of he drift at depths of 12 to 22 feet.
April, 1907.




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