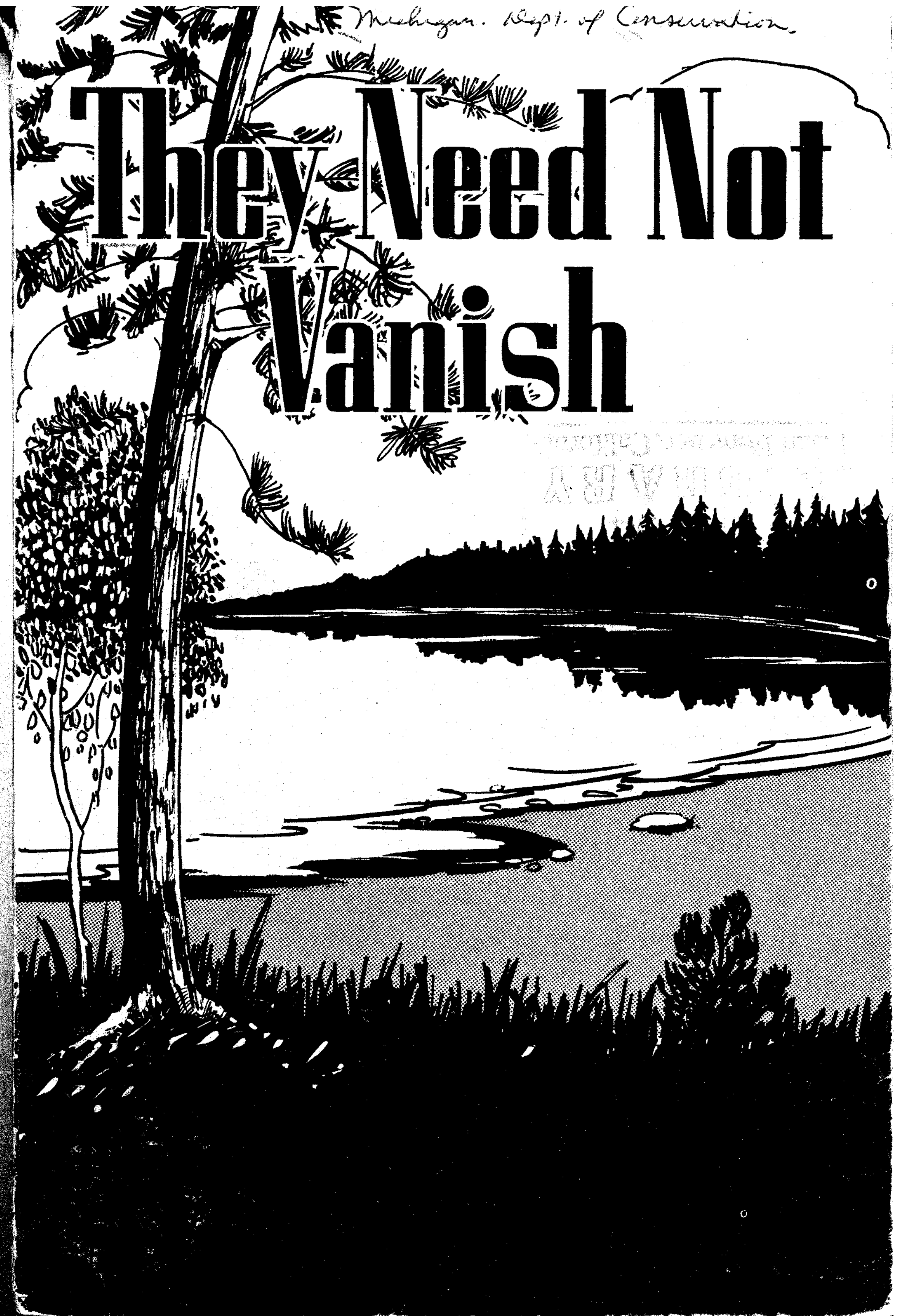
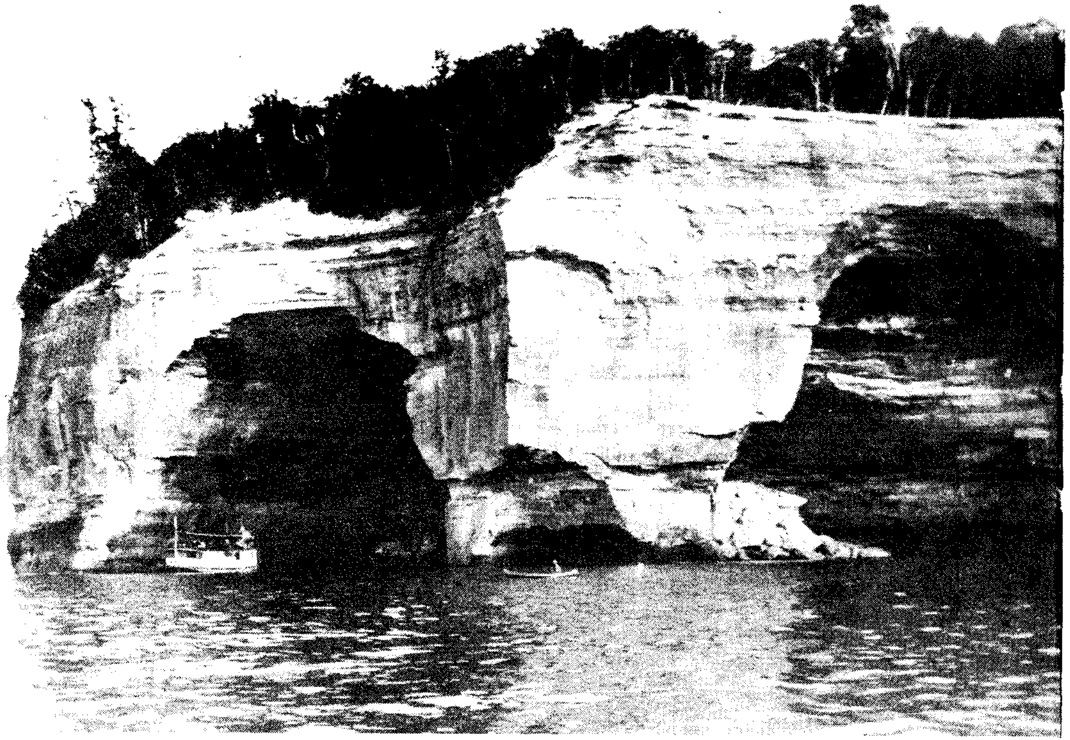
They Need Not Vanish

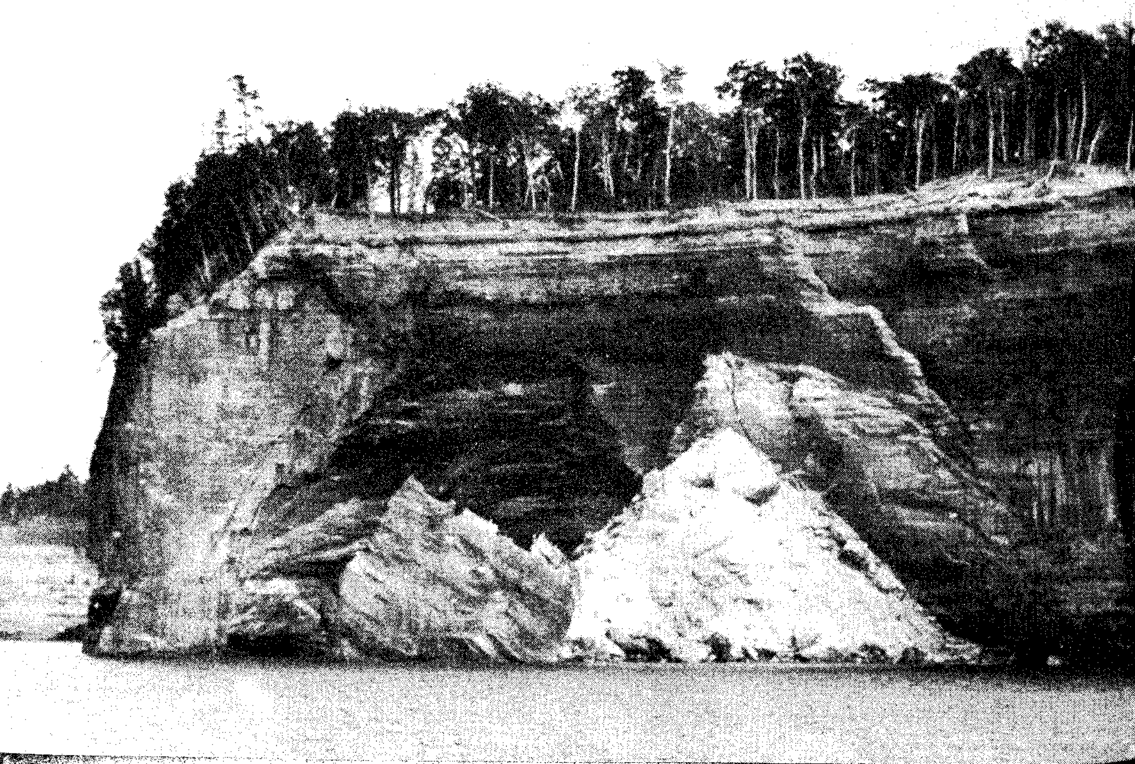




▲ GRAND PORTAL. TEN THOUSAND YEARS IN CARVING.

Photo by J. M. Longyear, 1898. Courtesy Mrs. Carroll Paul, Marquette.

DESTROYED BY THE FURY OF A WINTER'S STORM. ▼



STATE OF MICHIGAN
DEPARTMENT OF CONSERVATION
P. J. Hoffmaster, Director

THEY NEED NOT VANISH

A DISCUSSION OF THE NATURAL RESOURCES OF MICHIGAN

Edited by
HELEN M. MARTIN

from contributions by

Shirley W. Allen, Geo. C. S. Benson, *University of Michigan*

Stannard B. Bergquist, L. R. Schoenmann, H. C. Beeskaw, J. H. Kraemer, W. F. Morofsky, J. A. Porter, E. C. Sackrider, *Michigan State College*

G. S. McIntire, H. M. Martin, O. F. Poindexter, C. F. Welch, *Department of Conservation*

M. G. Adams, *Stream Control Commission*

Frank DuMond, *Public Museum,* Grand Rapids

Lynn Heatley, *High School,* Midland.

FOREWORD

THEY NEED NOT VANISH is Michigan's first attempt to offer the teachers of the State a coordinated and substantial basis for the teaching of the conservation of our natural resources. This volume, with its companion book LEARNING TO CONSERVE OUR NATURAL RESOURCES, published by the Department of Public Instruction, is intended to provide for the teacher and the general reader, not only a background of the history of this state's natural resources and what has been done to prevent waste and to promote better uses, but also to furnish practical aid in passing this information and such principles on to the student.

No conservation program can succeed without the active interest, cooperation and participation of the public. It is believed one of the most effective ways of securing this cooperation is by engendering into the younger generation a sense of the social and economic necessities for using cautiously, and if possible, wisely, those resources with which Michigan has been so generously endowed.

This book is not the result of the work of one person, but rather of a group which has been working for several years with the Department of Conservation and the Department of Public Instruction to produce what we believe to be the first such cooperative effort to give the schools of Michigan something which has long been needed. We sincerely hope this book will satisfy a goodly part of that need.

P. J. Hoffmaster
Director
Michigan Department of Conservation.

Photographs from Department of Conservation; Department of Geology and Geography, Michigan State College; U. S. Soils Conservation Service and contributors.

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Part I

WHY . . . . . ?

For well over two billion years the earth was in preparation for man's coming. Rock after rock was built, burying within its mass minerals and metals later to be used by man. Slowly, grain by grain, rock masses were taken from the land and in the sea they were built into other rocks, which in turn were slowly lifted above the sea or buckled high into mountains. But always, even during the building, the warring forces of nature were at work, slowly, relentlessly wearing down high land, low land, carrying it back into the sea.

Strange animals have lived upon the sea floor and in the waters above. They died and left their hard skeletons to petrify. Later, amazing animals lived upon the land and left their records in the soft mud and sands, about waterholes, or they were buried in asphalt lakes, or mired in marshes. Some of their bones became petrified. Strange forests covered some lands many times. Forests grew, sheltered strange insects, were set on fire by lightning, were blown down by storms, died, and were buried.

Layers upon layers of rock were laid down, pushed up, tilted, filled with minerals—and that process never ceases. Slowly, surely, grain by grain, down came the highlands, back to the sea. Over and over, plant life thrived, died, was buried, until finally the highest form of plant life came upon the land, the hardwoods and the flowers. Over and over, the seas became populated with animal life, but each group was more highly developed than the one that came before, until finally the vertebrates, and at last man, came upon the land.

And there was the earth spread out for man to enjoy. At first he enjoyed the simple pleasures of the lands, streams, forests—food, simple clothing, rude shelter. He did not materially disturb nature's processes, nor was he disturbed by them. Nature remained in balance. But life became complex. Man learned to increase and store his food supply, to use raiment for adornment as well as for protection. He learned to plant and cultivate a crop and therefore established permanent dwelling places. He learned to use the forest materials to protect his rude fields from wild animals and from his neighbors, and with the skins of wild beasts to construct shelters for himself. He tamed wild creatures for his own use; harnessed the currents of the streams to turn his wheels. He made tools of the minerals he found about him. He became civilized.

As he became more and more civilized he used more of nature's gifts, upset more of nature's processes, upset the balance of the endless experiments in taking from the sea and returning to the sea. Nature destroyed but replaced; man destroyed but did not replace. He rudely tilled the fields and in a few short years took from them all the land could give, all that nature had stored through millions of years, then he moved to another region. He accumulated flocks of animals and birds, let them graze as they would, and did not replace the grasses. Nature held back the rains, let the streams run dry. The grasslands grew bare and man and his flocks started the long trek to another land of plenty. He cut the forests, burned them to clear land to till; used their wood to build towns. Later he cut the forests to build ships to carry him ever onward from the regions he had depleted to new regions he could exploit. Over and over man repeated these processes until he had spread over the earth, always depleting faster than nature could repair or could restore. He came to need millions of things he once knew nothing of. Then he came to realize he must repair some of the damage he had wrought. He learned he could halt some of the inexorable onslaughts of nature's forces—weather, winds, water,—that he could restore some of the areas he had devastated. He learned that he need not hasten but could delay changes of the earth's surface that were not beneficial to him. He became aware that he could control the good and bad nature does, could use yet preserve for his descendants—as his ancestors had not used nor preserved for him—many of those resources nature had been storing up for him through more than two billion years. He called this conservation.

True, nature had set the scene, spread her gifts prodigally, hidden many of them, lured man on to find others. About a million years ago a great glacier moved southward over the lands. In Europe, mountain ranges lay across its path and the vegetation could escape only up the mountains and there perished of cold, so that only a few of thousands of species of trees remained when the ice left Europe. Animals could flee southward through mountain passes, but all the animals did not come back. In North America

no mountains barred the southward retreat of the trees and animals before the invading, killing ice. The trees did not die, all but the peach returned on the heels of the invader when the ice melted. The Indian came. He took of the forest only what he needed for his immediate use and he scarcely disturbed the soil. Came the white man from Europe and marvelled at the wealth and variety of the forest. The Vikings cut a little timber, the early English explorers took a little more. These haphazard depredations were quickly healed. But the English took back samples of wood to the island kingdom that then, as now, needed ships for the navy which maintained her food lifelines, and they saw the wood was good and came to the land that could supply their forest needs. The age of iron had not come completely into its own. The French coming through the valley of the St. Lawrence marvelled at the forests but they were intent on the quicker riches of the furs. Westward the settlers came and to the ring of the axe, the scrape of the plough, the frenzied scream of the trapped furbearer, the cheep of the dying nestling, the country was settled. Lavishly they used the resources nature gave, and the use was justified on the frontier. But the frontier passed and use was just as lavish. It was not justified. No shortage of men or tools made necessary squandering of lavishly given resources.

On January 26, 1837, Michigan was admitted to the Union; a state with a vast wealth in soils, waters, minerals, forests, and their products. So sparse was the population, concentrated in the southern tier of counties, that few people dreamed the day would come when the somber, trackless forest would be reduced to pine barrens; when the grayling would no longer leap in the rivers. They little thought that cities would grow up concerned about an adequate water supply. They would not have believed that winds and waters following man's activities would ever reduce the marvelous fertility of the clearings, and the prairie fields. President Andrew Jackson's Thanksgiving proclamation of 1835 expressed thanks for the bountiful supply of wild life—turkeys, geese, ducks, "clouds of carrier pigeons," vast herds of deer, antelope and buffalo*,—an inexhaustible wealth of virgin timber, millions of acres of virgin soil. But within seventy-five years the inexhaustible wealth of 1835 had become the need of 1910. During all these years thinking men, much in the minority, were increasingly alarmed at the waste of our wealth, the depletion of our re-

*500 buffalo robes passed the Post at Sault Ste. Marie in 1787.

sources, the ill-use of our possessions. The first Legislature was concerned about the need for salt purchased at great price from New York, and directed the newly formed Geological Survey to find salt within the State boundaries, to determine which, if any, of the 72 sections set aside by the Federal Government for producing salt were productive. That was the first act of conservation in Michigan—to search for, develop, and properly use, without waste, a resource of the State. The State Geologist was authorized to determine if the bog iron ore on certain school lands in Branch County should be mined or schools built thereon—our first experiment in land use planning.

The fur trade had declined before statehood and a few thoughtful persons realized that the forests also could be destroyed and warned the legislature that unless the State protected its forests north of the well-settled districts the best timber would be taken by lumber thieves, the young growth destroyed, "stumps be left to fungus diseases which would infest the whole forest"—but nothing was done about that—"our forests are limitless and inexhaustible."

That alarm, even in those days, was felt about depletion of game birds is shown by placing Act 109 of the Public Acts of 1840 on the statute books. The act prohibited the killing of woodcock, grouse, "quail, partridge and pheasant," during certain seasons in Wayne County, and assessed fines for the illegal killing or possession of such birds. That was the State's first game protection law. These two acts show that some citizens of Michigan have always been conservation conscious, have realized the value of our resources and that they should be and could be used wisely without waste and exhaustion. But they realized also that if left to the individual, our reserves would diminish, and that the State itself should regulate for all or become the custodian of the resources of the public domain. But no laws were made to protect the passenger pigeon, no laws saved the forests that kept the streams cool and clear, no laws saved the grayling. Laws were made later to protect the whitefish, but the trackless, "inexhaustible" forests were hewn and burned to barrens of hot, sandy plains, which the jackpine sought to restore, but from which most wild life had fled before the State awoke to the fact that trees could have been properly lumbered, protected from fire and the forests saved. In January of 1865 Alexander Winchell, addressing the Michigan Agricultural Society, said, "It should at least be required that all abandoned soils subject to work should be planted to trees, which will eventually restore the surface to its primitive conditions and compensate to some extent for the fearful devastation of the mature forest which our citizens are now waging." But the State learned that the individual could not be relied on to do it, the State must assume control. And today we travel miles to the Hartwick Pines to see what the original white pine forest looked like.

The very process of clearing the land for agriculture by burning actually depleted its value by burning the top soil and humus as well as the unwanted timber. Unplanned drainage removed much of the ground water that carried plant food in solution, and in some areas rich top soil dried out and was blown away.

Mineral wealth was also exploited, not so rapidly nor so greedily, because, excepting for salt of which we really have quantities to last several million years, the immediate need of man is for other resources. But the rich ore bodies were depleted and leaner ores and lesser minerals came to be used, although as late as 1881 the Commissioner of Mineral Statistics reported of the Northern Peninsula, "Its mining resources are permanent." Late in the history of the development of the mineral wealth, petroleum was discovered in quantities profitable to produce. It also was wasted by unwise and inexperienced operators. But the State came to the rescue of this resource in time and passed laws based upon the experience of operators in mid-continent states who by continuous research of private enterprise had found that the best way to conserve natural gas and petroleum is to leave it in nature's storage place—the rock in which it is found—and take it out of storage only as the public needs it. Private industry and government frequently work together to the advantage of each and the future happiness of the public. Private enterprise can, and does, use its monies in patient research to learn new methods of developing and using our resources with a minimum of waste. New uses are evolved for the wastes that are found. Industrial laboratory workers find in the test tube replacements for dwindling natural resources. Probably the best conservationist of the irreplaceable resource is the large industrial user guarding his investment and making profits from the by-products.

Surface waters were impounded as water power operations and drainage projects increased and some streams with their fish population dwindled; cities drained water from underground resources and must seek new supplies. . . .

Many books have been written, many more will be written, about our original natural wealth, those gifts of nature which have enabled men to reach the civilization we now enjoy. But as our resources were exploited and destroyed with little thought of the future, as they dwindled, the cry to conserve them for the future became louder, stronger, clearer, and through the years we have learned that it is possible to use our natural wealth wisely—use but not destroy. We have learned to plan so that the resources will not diminish and will be put to the best possible use for the greatest good. This is conservation.

Given time, nature will repair the damage done by man as well as repair the damage done by her own forces, but nature's mistakes and experiments in repair cover thousands of years, man's mistakes made in a day cannot be repaired in a lifetime. Man is only one of the destructive forces of nature—but he can repair the damage he does, and delay or restrain the activities of nature's older agents.

Natural resources are many, but all are interlocked, all depend on rocks, air, water, and the sun. It is difficult to separate them, and any discussion of one overlaps discussion of another. Man's first needs—wild life, animal and plant, and water resources—were first depleted, and therefore first thought of in conservation. Thus the seeds of conservation were sown in colonial times, as naval stores diminished, and germinated in the early part of this century. When exploitation of our wealth reached the Pacific shores—then something had to be done about it and conservation of the forests and the water supplies was debated over the land. The public became conscious of what it owned. Agricultural lands became less productive. Wind and water warred against formation of soils when man in his greed had removed the grassy protective covering of the plains. Then the farmer and the grazer cried for help. Cities developed and must depend on the agricultural area for foods and upon those natural resources from which could be fashioned the artificial resources upon which city (urban) wealth depends. Thus conserving natural resources became more and more a social problem, and when a social problem becomes acute something is done about it. As city life became complex the simple pleasures of life became remote and more attractive—"The country"—green fields, rippling brooks, hunting, camping, fishing, picnicking, golfing, "living in the open, under the stars" became alluring. A tourist industry was born and grew great, and need came for the conservation of places of beauty, pleasure, and recreation, and restoration of the exploited waste lands.

Individuals, communities, associations, clubs, schools, and colleges, enlisted in conservation; some thought only of fish or game, others only of forests, others of the trillium and arbutus, others of our mineral wealth. But true conservation considers all the resources and the relation of all the resources to all the people—city dweller and ruralite alike, industrialist, farmer, tourist, stay-at-home.

Since 1921 Michigan has had a Department of Conservation, a union of all those agencies of government established after 1837, whose aims were to search for and use and preserve our natural wealth, to replace if possible lost resources, to find means of proper usage without waste of the resources that remain. Departments of Conservation have been established in college and university to help with the problem, but real conservation needs the help of everyone who wishes to use wisely and to enjoy the wealth of our possessions, to aid in the establishment of a permanent program of conservation of our wild life, forests, waters, soils, minerals, our places of recreation, our scenery, and our historic landmarks.

And you in the cities who cannot get out to hunt and fish, who have no time for the beaches, or wildflowers, or copper mines. No place for you in conservation? Your very livelihood depends upon it. Your food and clothing come from the soil—soil erosion increases your cost of living. Depletion of water supplies may destroy, not only your drinking water, but also the air conditioning systems for your shops and theatres; depletion of forests, quarries, mines, destroys your building materials and the raw products upon which your industries are based. Maybe you can't get out in the field and save an orchid—but you can know it is there; maybe you can't stop a forest fire—but you need not start one; maybe gas is just something that comes from the filling station—but you can learn to run your car without wasting it; and you can become informed of the thousand and one ways each one of our natural resources enter your daily life. Have you a city park, a place of recreation for everyone? Are the vacant lots weedy eyesores or filled with queen anne's lace and blue chicory? Both are baneful pests to the farmer but a source of beauty in a vacant city lot. Is slum clearance conservation? Removal of billboards and ugly shacks that hide beautiful views? Maybe you can't physically work for conservation—but what about the power of public opinion, and what good is public opinion unless it is well informed? You need not live "near nature" to be a conservationist, because nature lives in your lives, and it is up to you and all of us to see that she is not betrayed by our misuse of the wealth she has stored for us.

We can never forget, however, that nature is an experimenter; that nothing is permanent but change; that through all her kingdoms nature creates, builds up, only to tear down and start all over. Though the pattern is changed the methods are always the same, the agencies used do not vary through the long histories of rocks, plants, animals, man. Man can hasten or slow nature's processes, and when he does this for the benefit of himself and his fellow man now, with thoughts of the needs of the future, when he works and plans *with* nature, he is a conservationist.

Part II

THE FIRST TWO BILLION YEARS

THE FOUNDATIONS

Life and living of man, plants, and animals are complex and their many phases overlap, but all are based in the material which makes up the earth—the rocks, the soils made from the rocks, the waters which flow in or on them, the air which surrounds them. So it is well that we start our story from the beginning—a time that goes so far back we cannot comprehend it. But the story has been written by Nature herself for those of us who are willing to read. Today the agent-forces of nature—winds, water, changes of temperature, and others—are making and recording changes on the surface of the earth. Active volcanoes bring molten rock to the surface, quietly or explosively. Pent up forces within the earth cause great masses of rocks to be moved and the earth quakes. It is not too difficult to study the records being made, nor the processes by which Nature works today. Therefore, where we find similar records in the hard rocks we know that nature must have used the same processes to make them. We find that in the rocks nature has left her records of never ending change. Whether the rocks be on top of the highest mountains, at the sea shore, or those we find in the deepest quarries and mines, the records tell the same stories of building rocks, tearing them down, making new from the old—a change in pattern but not in method. Also we find in these tombs and tablets of stone a record of the life that has lived, flourished, died, and been buried, on the earth's surface during millions of years.

We really do not know how the earth was made, but the most likely theory of its origin, upon which the majority of geologists, mathematicians, astronomers, and other scientists agree, is based on what the camera discloses of the activity of the sun today. The camera reveals that the sun is a turbulent mass of hot molten material and gasses, with flaming fountains shooting bolts of sun material and sun gas miles above the sun's surface, but the pull or gravity of the sun causes the ejected material to fall back upon the sun's surface. It is believed that many billions of years ago our sun, larger then, and even more turbulent, was moving in its orderly way through space when another larger sun or star moving with incredible speed passed so near that its gravity (pull) was great enough to draw some of the ejected sun gas away from the sun—just as a swiftly moving motor bus or truck "swooshes" the air from around your car as it passes, or as a baseball makes your hair stand on end when it speeds too near your head. The separated mass of sun material started spinning like an old-fashioned Fourth of July pin wheel, but was prevented from moving off independently into space by the pull of the sun; instead it continued revolving around the sun as a satellite or planet. Several such masses were in like manner detached from the sun to make the several planets. Each mass had a pull of its own and drew to itself all the smaller planetary masses, "planetesimals", about it and thus grew larger and hotter. You know that at times enough heat is generated when a bat hits a speeding base ball to scorch the bat, so you can imagine how much more heat was generated when these little planet masses collided and crushed into each other as they ganged together and were built up into the planets. Eventually each planet drew to itself all the loose planet material about it and all settled down into what we call our solar system—the sun, its planets, and their satellites. Our moon is just another little planet that couldn't get away and wander independently about the sun, but remained attached to the earth by the pull or gravity of the larger planet. About two billion years ago our planet, the Earth, stopped growing by the accretion of in-falling planetary material and the surface of the earth began to take on the form we know now. Occasionally a bit of planet material comes near the earth, gets hot by friction with our atmosphere, and we recognize it as a "shooting star;" if it reaches the earth's surface we have a meteorite, but most of the meteorites stopped falling into the earth long ago.

As the earth mass cooled the heavier ingregients gravitated to the center and developed at hot, solid core surrounded by a less solid mass of molten rock material (the lithosphere), which in turn was surrounded by lighter gasses that, when thinned out, eventually became our atmosphere. The cooling outer surface of the molten rock material crusted over and formed a thin crust of cold but once molten rock which we term fire or *igneous* rock (granites, lavas, and their kindred rocks), and made the first solid surface of the

earth—the first terra firma, which wasn't very firm. Because igneous rocks develop mineral crystals as they cool, we call them crystalline rocks also. Continued cooling caused the crust to wrinkle and crack, and to force the lighter gasses from the rock pores to the surface into the early hot atmosphere—just as a frosting on a cake cracks as it becomes cool and dry. A part of the gas was water vapor which eventually cooled and formed the water of the earth's surface—the hydrosphere. Heaving under the strains of forces pent up in the hot interior the crust solidified with a very rough surface, high areas and deep depressions. The water gases or vapors of the thick heavy warm atmosphere condensed, fell on the surface, ran in rivulets down the high slopes to the depressions and partly filled them—thus the oceans were formed and the surface of the earth separated into lands and seas, or continents and ocean basins. And it was then—when the first drop of water condensed from the atmosphere and fell upon the land—that erosion began and has never since ceased.

The early continents were unlike those we know today, they were smaller, had surfaces of igneous rocks. No life lived upon them. Continued squeeze of the cooling shrinking crust caused the pent up forces beneath to revolt many times and push the land masses higher, or crack their edges and there pour forth molten rock in quiet or explosive volcanic activity. High mountain ranges and plateaus were built or pushed up above the level of the ocean until finally the continents settled to the forms of continental blocks our geographies show today. However, the oceans did not settle in the basins we know, but covered much of the continents with shallow seas in which the story of the next billion years was to be recorded. The continental shelves are remnants of those shallow seas and there geologic history of today is being recorded. Sometime during the later part of this first billion years conditions became favorable and life appeared on the earth, a low form of plant life capable of self sustenance, a microscopic one-celled organism living near the shores of the warm, dark oceans of fresh water. This early life form was very similar to its present day descendant which lives in bogs or mineral springs where bog iron ore is being formed—but that is a later story.

What are these records made in the shallow seas?—These tablets of time on which the story of ages is told? When the first igneous rock cracked, when the first drop of water moved, the record began. When the atmosphere cooled and frost arrived the recording became more rapid. When plant and animal life became abundant the record became complicated. Changes of temperature caused the granitic rocks to flake off at the surface, gravity and moving waters carried the loosened rocks down the slopes, rolled them together, broke them into smaller and smaller particles, carried them to the sea where they became sediments that muddied the clear fresh sea water. Some of the sediments were dissolved in the sea water, and as the process kept on through the ages the seas became salty. The sediments, sorted by waves and currents of the first oceans, settled to the bottom of the seas and were spread out on the sea floor. In the course of a long time, as layer upon layer of sediments were piled one on another, they were compressed, cemented, and consolidated into rock which we call *sedimentary.* Each layer or bed is a stratum and layered or bedded rock is said to be stratified. Various minerals in the ancient igneous rocks were made over into different sediments. The hard minerals like quartz collected together as sand, and being heavy, were not carried so far out to sea. They built up coarse and fine rocks which we call sandstones. Other minerals were broken up into fine clay and silt muds that were carried far from shore but eventually settled on the sea floor and compacted to a rock we call shale. Some of the minerals disintegrated to form lime, calcium carbonate. As the igneous rocks were eroded some minerals dissolved and were carried to the sea in solution; there certain chemical reactions caused the lime to be precipitated and in places to build up great thicknesses of lime mud that eventually solidified into a rock known as limestone. Other chemical reactions caused iron minerals to be formed which in turn settled to the bottom of shallow seas, and later in the geological history gypsum and salt crystallized out of the sea water to form great beds of gypsum and rock salt.

But even in these early warm seas another force was at work building rocks. In some way the first bacteria and one celled plants learned to take lime from the water; they collected in jelly-like masses, these ancient plants; lime collected on them, layer upon layer, and built up great masses of lime rock. Later, when animals came upon the earth they were also one celled creatures living in the sea, but as they struggled for existence they evolved to more complex creatures, and in time they also took lime from the sea water to make protecting external coverings or shells. When these creatures died their shells fell to the sea floor, accumulated in thick masses, were also broken to lime muds, but all in time became limestone rock—the cemeteries of the animals which lived

in the seas, and the museums in which the records of past life (fossils) are preserved.

So thousands of feet of sediments—clean sands, clays, silts, lime muds, and mixtures of any two or all of them—were spread on the ocean's floor and thousands of feet of stratified rocks were formed. As they became thicker their weight upset the balance between the high lands and ocean troughs. Then nature readjusted the pressures by shaking, lifting, thrusting, the hardened sediments above sea level, building mountain ranges by pushing molten rocks from beneath the crust near to the surface, in places cracking the surface rock to let the molten rock through. In other places the flat lying sediments were lifted, wrinkled, folded, crumpled, and broken into arches and troughs, making new mountains and rearranging the ocean basins. When peace came again after such a revolution were the rocks the same? No. You know that snow falls in soft flakes, and you have seen the beautiful six-sided crystals of the snow flakes—they are mineral crystals and many of them collected together could be considered rock. If you take a handful of snow, pack it into a snow ball, you rearrange and change the form of those snow crystals by the pressure of packing and actually produce another form of rock—ice. Also in the packing (pressure) some of the snow crystals melt to water. Thus, although perhaps you never thought of water as a rock, in making a snow ball you actually worked on a familiar rock—as nature does on other rocks, you changed the form from a crystal snow flake to ice. In the teakettle and refrigerator, on other water surfaces in winter and summer, you have seen water changed from a liquid to a gas or to a solid. Such a change is metamorphosis. When by one of these earth revolutions with pressures and heat nature changes rocks from one form to others, she makes *metamorphic* rocks out of the older igneous or sedimentary rocks. She changes granites to gneisses or schists, sandstones to quartzites, limestones to marbles, shales to slates. So upon the earth we have three types of rocks, igneous, sedimentary, metamorphic. The metamorphic rocks tell this tale of change but in them are many other records buried and lost.

Many times during the two billion years of recorded earth history have these changes taken place. The geologic record shows many periods of unrest within the earth—mountain building times followed by periods of quiet when erosion gnawed the mountains and highlands down to their roots. The record shows a never ending battle between the forces of the hot interior of the earth which builds up earth features, and the forces at the surface bent on their destruction—a never ending effort by one set of nature's forces to lift rock masses out of the sea only to have another set of forces break the rock down and carry it back to the sea. So long as the earth has a molten interior under pressure of a solid crust, disruptive (diastrophic) agencies will continue to construct new surface forms for erosional processes to destroy. The cycle of change will continue to the end of time.

As we divide and subdivide human history into eras and periods that cover certain related events, so we divide and subdivide geologic history into eras and periods. The first and longest era, over a billion years long, when the young earth was forming from the sun and no life existed, we call the Azoic. And we do not know a great deal about it. Following came the time, the Archaeozoic era, some 800 million years long, when the earth was very turbulent, mountain ranges and ocean basins were being built and a very primitive life was upon the earth. Then came 650 million very important years for Michigan as we shall see—the Proterozoic era. Sediments were laid down in shallow seas, bacteria and sea weeds lived and were active, and at the end, the earth, with a final turbulent upfling of mountains, settled down to quiet in the Great Lakes area, and to comparative quiet over the rest of the earth—the earth's youthful turbulence was over.

For the next 350 million years, during the Paleozoic era, the time of ancient plants and animals, nature's quiet forces of erosion were at work, gnawing away at the old mountains and carrying the sediments to the seas. Seven times the seas alternately spread over and retreated from the land causing seven new sets of conditions for the formation and deposition of sediments, each time changing the conditions under which plants and animals lived and died. Thus seven sets (or systems) of sedimentary (or stratified) rocks were laid down, one on top of the other, in the shallow seas that covered the continental blocks. These movements of the seas were world wide events, sediments were laid down in all parts of the world; therefore, although the rocks first studied in England and Wales were named for places and early peoples of the British Isles, we carry the names wherever similar rocks with similar records of life and of nature's processes are found. These periods are the Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and the Permian. Following the era of ancient life came the Mesozoic and Cenozoic, 140 and 60 million years long, in which life leveloped to the present types, the lands and ocean basins came to be as we know them, and for over 198 million years erosion was let loose to work its will on the face of our area. Man appeared upon the earth and a little later, towards the end of the Cenozoic era, the Pleistocene period of glaciation was ushered in; during that time the surface as we know it today was built and made ready for man and his activities.

THROUGH THE AGES

The rocks of Michigan record that the area shared profoundly in all the earth changes. Michigan began when a shield-shaped mass of igneous rock, nearly two million square miles in area and centering about Hudson's Bay, formed the original continent of North America which we refer to as the "Canadian Shield." The point of the shield extended southward across the area now the western half of the Northern Peninsula into Wisconsin, and its southern edge was a northward-bearing arc extending from the Lake Superior region to the Adirondacks. Southward was a shallow sea covering the remainder of the continental block. The granite floor of the sea had many depressions and ridges, but only the basin-shaped depression bordering the shield on the southeast need interest us. The basin shallowed scoop fashion eastward, but the deepest part was about where the Southern Peninsula is now. That was the early setting of Michigan, the basal foundation of the State.

As soon as water fell on the Canadian Shield and the first winds blew, then weathering began; the rocks started to flake off and break up, erosion was started; sediments were carried to and deposited in the seas, the first beaches were formed. Several times in these early turbulent eons the lands at the edges of the seas were lifted into high mountain ranges, only to be worn down and their sediments carried to the seas to build up new shores and to be spread on the sea floor to form stratified masses of sandstones, shales, and limestones. Each newly formed beach increased the land area, carried the strand line southward. With each uplift the sedimentary rocks were bent, folded, broken, twisted, contorted, changed; masses of hot igneous rock were forced into the broken formations, completely changing or metamorphosing them in many places so that the rocks made in the several periods of mountain building and sedimentation became a very complex mass of disturbed, broken (faulted), distorted rock—the oldest rocks that underlie the western half of the Northern Peninsula. All we can see of the

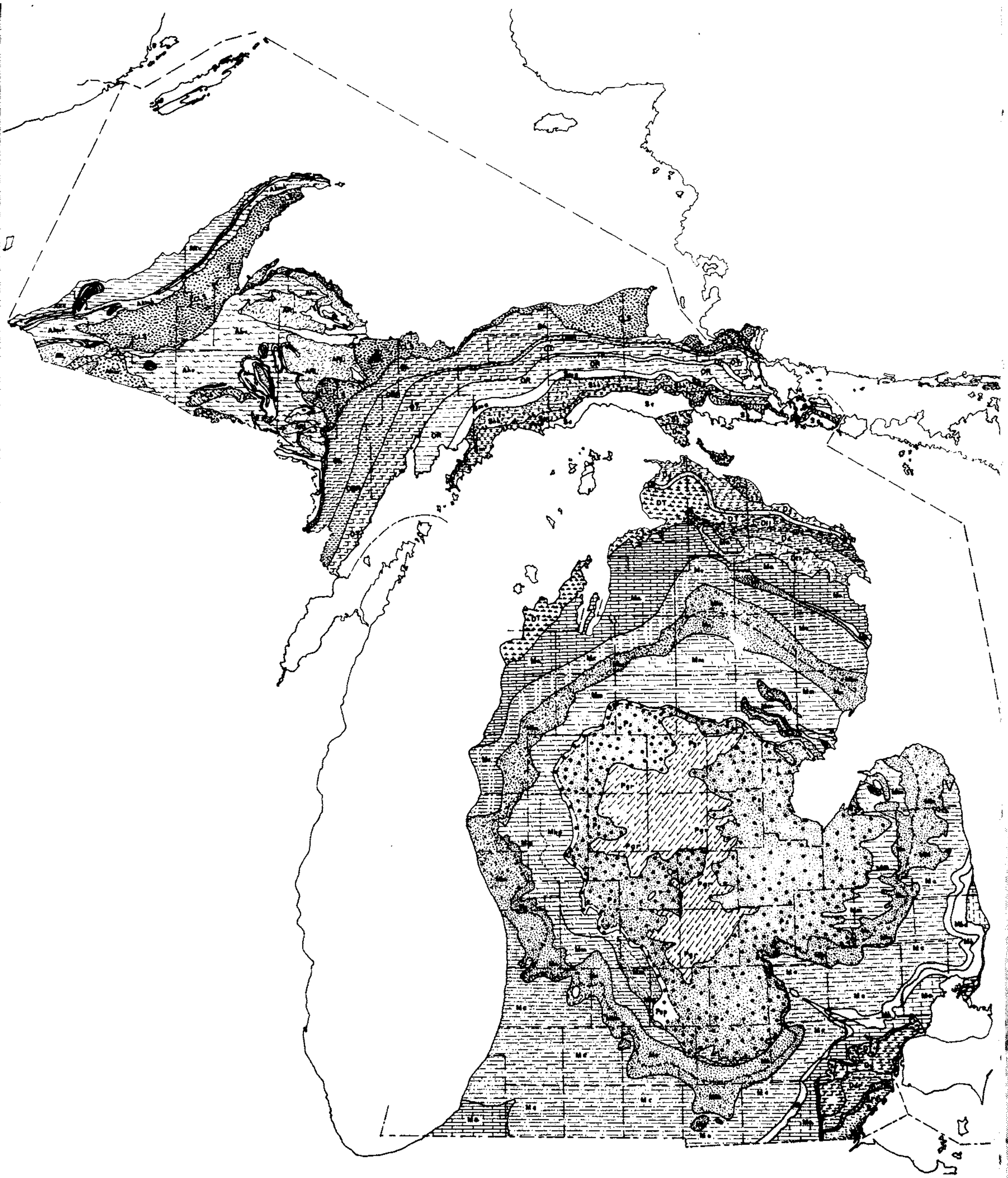


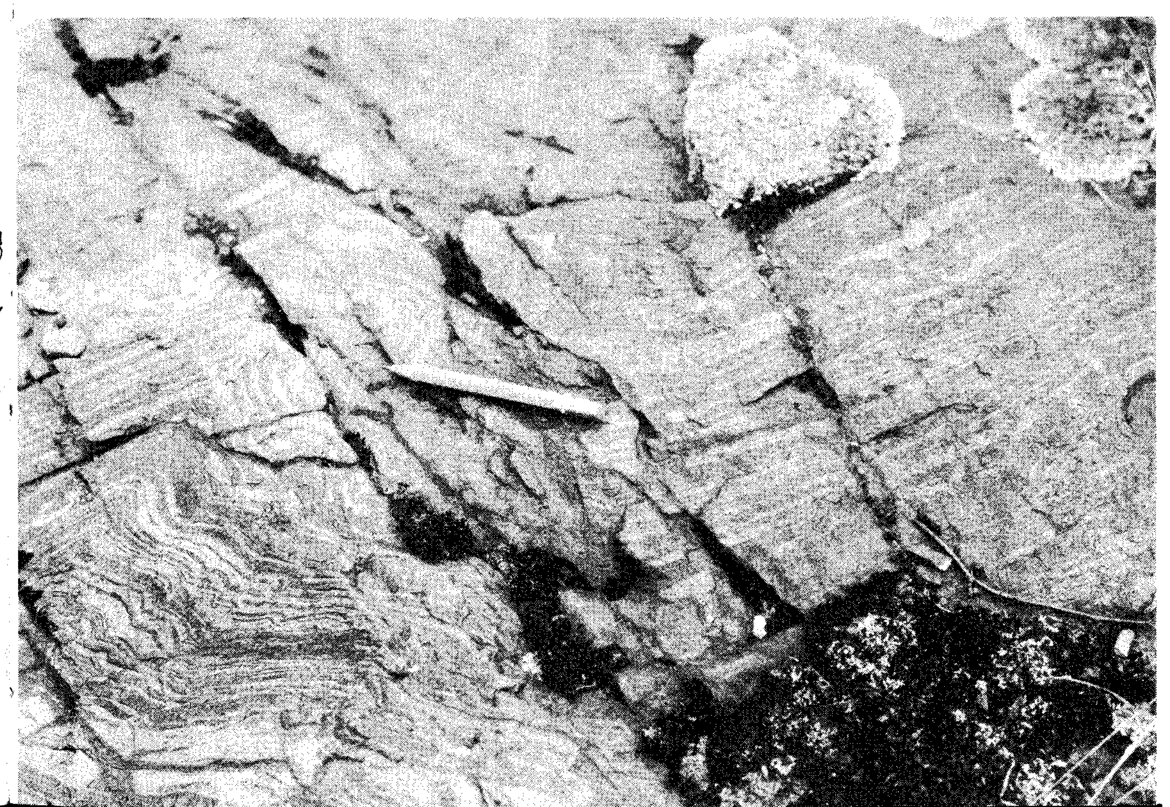
FIG. 1—ROCK FORMATIONS OF MICHIGAN

P₤r, Ps, Psp=Pennsylvanian rocks; Mm, Mn, Mlm, Mc, Ma, Mb, Mbd=Mississippian rocks; Dtb, DT, Dd, Ddr, Dm=Devonian rocks; Ss, Se, Sm, Sme=Silurian rocks; OR, OT, OBR=Ordovician rocks; ɸh=Hermansville formation; ꞒLs=Cambrian rocks; ARL=Kewatin-Laurentian granites.

oldest rocks are the Huron Mountains and the other granites and their kindred of Marquette, Baraga, and Gogebic counties. (ARL fig. 1) Once they were a mountainous sea coast, but their summits were worn in turn and all but the highest buried under later sediments.

During the first part of the Proterozoic era, a long 250 million year-period of quiet, which we name the Huronian from its record north of Lake Huron, thick sediments were laid down in a shallow sea trough that covered the Lake Superior region. In places thick sands were deposited; in others fine muds, and in other places pure lime, accumulated in the shallow but slowly deepening sea. Over the sand great masses of iron minerals accumulated, either by chemical action or by the work of iron forming bacteria, or by both and perhaps other means, until vast thicknesses of sand and iron sediments were built up, and the world's largest iron deposit was in the making in Minnesota, Wisconsin, and Michigan; and in that far ago time the foundations of Michigan's wealth and the automobile industry were laid in the old Huronian sediments we now find in the iron ranges of Marquette, Baraga, Iron, Dickinson, Menominee, and Gogebic counties (AHu fig. 1)

CRUMPLED FRACTURED JASPILLITE. LICHENS AND MOSSES ARE STARTING TO MANUFACTURE SOIL AND START A PLANT SUCCESSION ON THIS BARE IRON-BEARING ROCK. JASPER HILL NEAR ISHPEMING.



Rumblings of a new disturbance interrupted the quiet Huronian sedimentation. Again mountain building lifted the sediments, now hardened to rocks, to mountain height, crumbling, folding, contorting them. The sandstones were changed to quartzite, shales to slate, limestones to green and white marbles, and the iron sediments were folded and changed with them. The rocks were cracked and broken; they slipped and moved along the cracks—were faulted —vertically, horizontally; some blocks were shoved up onto others, some were tipped on end until a madly jumbled mass was made of the flat Huronian sediments. The writhing contortions of the red and black jaspillite of Jasper Knob near Ishpeming show something of what happened to the whole area. Into all cracks warm and hot waters, heavily mineral-laden, made their way; left deposits of minerals that are the joy of the collector, although the complex Huronian rocks in which they are found have been the lure, despair, and subject of great dispute among geologists for the last hundred years. The pink pegmatite dike in the glistening white marble of Felch Quarry tells a tale of long sedimentation, of

CHAMPION MINE PIT AT BEACON SHOWING ALMOST VERTICAL POSITION OF DISTURBED, ONCE FLAT-LYING BEDS OF THE IRON FORMATION. A VERY THIN BAND OF DARK SOIL HAS DEVELOPED FROM THIS PARENT MATERIAL.

FELCH QUARRY

pure lime metamorphosed to marble, perhaps by the very molten rock that cracked and forced its way through the marble, then slowly cooled, forming large crystals of pegmatite. Volcanoes became active in the western Lake Superior region and ejected volcanic cinder, ash, and bombs in explosive eruption; then, somewhat subdued, poured out lava from long vents in quiet eruption. When the eruption subsided, winds and weather broke up the lava flows into pebbles, gravel, sand, and fine muds, which became cemented together in a rock we term conglomerate. In places the sands and fine muds became sandstones and shales. Lava flows covered the conglomerates, more conglomerates were formed; they in turn were covered until several thousand feet of conglomerates and lava flows with sandstones and shales were built up. (AKU, AKMB fig. 1) In the gas bubbles (amygdules) on top of the lava flows, in the cracks of the lavas and conglomerates, nature stored pure copper and silver and many interesting and beautiful copper minerals, the treasure store of Keweenaw, Houghton, and Ontonagon counties. Time honored usage gives the name trap to the massive lavas, and amygdaloids to their porus upper parts. And the time in which they were formed is named the Keweenawan, the second part of the Proterozoic era in Michigan.

Then the Earth had another fling at mountain building in the Great Lakes district. Igneous rocks were thrust to and near the surface, lifting all the older rocks above them. As they intruded horizontal and vertical cracks, they metamorphosed the older granites, lavas, and their kind, changing the metamorphics as well as the sedimentaries and making confusion worse confounded.

This last turbulence is known as the Killarney revolution from the exposure of the granites of this time at Killarney, Ontario. The Killarney mountain range, 1,000 miles long and higher than the Alps, is now worn down to mere stubs of granite knobs. In Michigan the Killarney granites are exposed in Gogebic and Ontonagon counties; they make the mass of the Porcupine Mountains and a small patch comes to the surface near the tip of Keweenaw Point. These mountains also were worn down, they followed their predecessors into the sea. The Proterozoic era ended.

A shallow sea spread over the continent, the Paleozoic era began. It was a long, quiet era of slow earth movement and oscillations of sea level which caused twenty-four to thirty minor retreats and transgressions of the sea shared by all the Great Lakes area. In addition, in the Michigan area the rocks record at least fifty-one local changes in the conditions of sedimentation and of life in the seas that alternately filled the basin or were spilled from it in whole or in part. (And just to complicate matters further, the fifty-one formations are also subdivided by very restricted local conditions!)*

Somewhere during the long time of the Killarney revolution life had developed from the simple one-celled organisms into highly developed creatures with shells and other hard parts that could be petrified, or from which casts and molds could be made. They found life good in the Palaeozoic seas and swam in hordes. On death they were buried and their records preserved in Palaeozoic sediments so that from this time on we have a pretty complete record of the gradual evolution of plant and animal life to the high forms we know today. The fossils in the rocks play an important part in unfolding the drama of change. To the geologist, changes in assemblages of animals (faunas) means a change in the position of land

*The Legend of the Centennial Geological Map of Michigan lists and locates all of them.

and sea, and, as each succeeding assemblage is higher in the life scale, the geologist reads a time scale also. To the amateur and specialist, perfect specimens and new species, are the prize of the big game fossil hunter in the petrified graveyards of the sedimentary rocks. So that when the Palaeozoic seas began to spread over Michigan our first important wild life came with them. At times the seas were warm and clear, supporting a myriad of shelled creatures, at other times the seas were muddy, receiving great volumes of fine silts and decayed vegetation from low lying lands. At times desert conditions prevailed, and the seas became excessively salty supporting little life, or were brackish with gypsum. In other times the sea became a huge swamp. Each sea left its records in the sediments piled and spread on its floor. The sediments compacted to rock. The floor of each sea became the basin of its successor; thus each sea was smaller and within the boundaries of its predecessor. Eventually the Michigan basin was filled with a succession of bowl-shaped rock formations, one within the other. Bowls made of sandstone, limestone, shale, rock salt, gypsum in all degrees of purity—shaley-limey sandstones, sandy-shaley limestones, shaley limestones, sandy shales, and all other combinations of sediments one can describe. The formations vary in thickness, some are wedge and not bowl shaped, they do not extend across the basin—we have records which show that barriers prevented the seas making a complete submergence. On the edges of the basin wells can be drilled through thin sedimentary rock to the granite below, but the deepest well in the State, in Bay County, was drilled through over two miles of sediments and did not reach the bottom. The rocks vary in color from jetty black through gray, brown, red, blue, pink to white. They vary in mineral wealth. But all of the Paleozoic formations have a common characteristic, they all slope or dip from their rim edges to the center of the basin.

The first of the Paleozoic seas, the Cambrian, received coarse sandy sediments from swift streams flowing southward from bare highlands to the north. The shore line was somewhere in the Lake Superior trough, and to the west, somewhere near the central part of Keweenaw County. The rocks (Ꞓls. fig. 1) representing Cambrian time of 105 million years are mainly sandstones. As much of the sediment was derived from the iron formations in the west they range in color from a deep dark red to mottled red and white, buff, white, and gray. Towards the end of Cambrian time the sediments became finer, the sea shallower, and its shore farther south; the sediments were clear white sand, some of which through the millions of years have become dolomitic sands. So marked is the difference between these sediments and the earlier Cambrian that we have introduced a new period to our geological time scale, a new system in the system of rocks in North America but not found in Europe. We name it the Ozarkian (ɸh fig. 1) In Michigan the Hermansville (named for Hermansville in Menominee County) is the most important Ozarkian formation.

Ancestors of most of the invertebrate animals we know today swam in the Cambrian seas, and some invertebrates lived whose descendants disappeared from the seas forever before the Paleozoic was closed. That queer three lobed creature, the trilobite, is the usually desired possession of beginning fossil hunters—he's big and rare game.

Gradually the seas deepened, gradually almost two thirds of the North American continent was submerged. As the Ordovician period began in Michigan, the shore line probably pushed farther southward as we find traces of early Ordovician sediments in Houghton County. The rock (OBR, OT, OR, fig. 1) and fossil records show us that this time lasted for 70 million years. At first the seas were deep and clear. Lime muds were laid down on their floor which became the graveyards of millions of shelled creatures that lived in the first of the Ordovician seas—the Trenton (OT fig. 1). These brachiopods and cephalopods, ancestors of the lamp shells, the squid, and pearly nautillus of today, with trilobites, were the bosses of the living creatures of that time. But the ancestors of the corals, bryozoa—"moss animals"—starfishes, sponges, and snails were there also. And an odd creature, an ostracoderm, that wanted to be a fish but wasn't, but did have a backbone, appeared upon the scene, though not very happily as he stayed in the mud for protection from the prowling trilobites. An important creature was this ostracoderm, with his soft body and armored head, for he had a spinal cord and was the first of our vertebrate animals.

Gentle earth movements or perhaps climatic changes caused the late Ordovician seas to be alternately shallow and muddy, or deep and clear, thus the sediments became shales and limestones. The Ordovician shore came southward. How do we know? Because today the sea shells that live and die near the shore are cast up on the shore by the waves, the shells are ground and broken, and their fragments piled on the shores. In the limestones of Menominee County we find masses of fragments of shells rather than whole shells, so we believe that here also was a shore of long ago.

Where we find perfect petrified shells we know that burial was in quiet deep water, or quiet muddy water, so deep that the waves could not disturb the bottom.

Again the seas deepened, genial climates set in, the seas were warm and clear. A new period, the Silurian, set in (Sme, Sbb, Sm, Se, SE, fig. 1). Algae and bacteria precipitated lime brought to the sea in solution by clear streams, millions of shelled creatures swam about, corals built the first apartment houses in long coral reefs, and great thicknesses of lime muds were built up. Over 1600 feet of our limestones are Silurian. The thickest are the rocks we term Niagaran (Sme, Sbb, Sm, Se, fig. 1). If we would like to see what these coral reefs were like we can find beautiful fragments of them in the stone piles of Chippewa, Mackinac, Schoolcraft, and Delta counties that are chips from the Niagara limestone that comes to the surface (outcrops) from Manitoulin Island to the Garden Peninsula. We can find the so-called petrified honeycombs and chains—the remains of the walls of the homes of honeycomb and chain corals. Twisted and straight horn-shaped shells of the solitary coral that swam about with his house under him, "butterfly" and "lamp shells", and many other fossils repay a search. Many of these corals and their companions reached perfection and disappeared with the Silurian; thus wherever we find a limestone containing these fossils we know it is Silurian.

Sometime in this pleasant Silurian time one of the denizens of the sea discovered the edge of the sea, crawled out on shore, found that the plants of the land were better food than the sea supplied, found that he didn't have to fight so many other hungry creatures for his food. He learned to breathe air and became the first of the land animals. This pioneer was a scorpion with the horrible name of Paleophonus—or ancient murderer.

But the genial climates came to an end, the close of the Silurian was a long time of aridity in which the seas became so salty that living creatures swam to a more suitable home. Those that couldn't get away died, many had no descendants so their species perished from the seas. Great salt beds were deposited in our basin, and the time is named Salina. In the central part of the basin 2300 feet of alternating salt, shale, and limestone beds have been penetrated in the Salina, with 1600 feet of rock salt. The rock salt bowl becomes thinner towards its rim (Ss fig. 1).

Above the Salina salt beds in the southeastern corner of the State is a limestone named Bass Island (Srr. fig. 1). In the same position in the northern part of the State on both sides of the Straits of Mackinac is a formation we term the Mackinac limestone (Dm. fig. 1). The queer chimney rocks around St. Ignace and all of Mackinac Island are of this formation. These limestones are intriguing puzzles for the geologist—we don't know certainly to which period they belong; we do not know how they were formed, nor why they are broken up in angular blocks, full of cavities that seem to be recemented—a rock we call breccia. You can see the breccia in St. Anthony's rock and Castle Rock near St. Ignace, Arch Rock, Sugarloaf, and many other places on Mackinac Island. The Bass Island rocks are Silurian, maybe those of Mackinac Island are not. But the scenery of these rocks is remarkable, no matter what the geologists say about their age. The fossils suggest that the climate again became genial at the close of the Silurian, the seas warm, and the sea creatures returned to our region. Silurian time was 25 million years.

Then the climate changed to warm and moist as the Devonian period which was to last 35 million years was ushered in. The Michigan area was almost an enclosed pool of the Devonian sea and the northern shore of the sea was somewhere in the Lake Michigan and northern Lake Huron basins. A part of the southshore cut diagonally across Monroe County from northeastern shore cut diagonally across Monroe County from northeast to southwest. Our basin brought its eastern rim closer to Michigan. On the southeastern shore sand dunes were whipped up by the Devonian winds and are now beds of white sandstone—the Sylvania. (Ds. fig. 1). Spreading deep into the basin from the southeast, layers of sand and lime were deposited which became the formation we now term the Detroit River (Ddr. fig. 1). Once we grouped the Detroit River and Bass Island formations together under the name "Monroe"—a name geologists have rejected but the oil fraternity retains. We will refer to it later.

The Detroit River formation thins out somewhere north of Manistee as we do not find it above the Mackinac formation in the northern part of the Peninsula. Above the Detroit River is the Dundee limestone, named from its outcrop near Dundee, Monroe County (Dd. fig. 1). Above the Dundee bowl is 30 to 80 feet of Bell shale (Db. fig. 1), and above and within the shale is the Traverse limestone (DT fig. 1)—the relics of Michigan's "Coral Sea."

The Devonian has been called the "age of fishes" because so many and strange fossil fish are found elsewhere in Devonian rocks. But we had no fish problem then. The Devonian was the time of Michigan's coral seas—clear warm seas in which millions of corals and moss animals lived and built great reefs and layers of lime mud that became from 50 to 1035 feet of limestone. Swimming among the reef-building corals were many other invertebrates, —a little trilobite that could roll up like a ball—so that his fossil remains are the reported "petrified frogs' heads", the solitary "cup coral" living in the top of his house, the winged brachiopod we call the "butterfly" shell, and many others. "Sea lilies" swayed in the clear green seas, their fossilized heads are often said to be petrified nuts, their stems are the disks of stone with a central hole that the Indians used for wampum. The armored fishes lumbered about like scows in the seas, and on the land the first forests grew. But corals were dominant, and from Thunder Bay to Little Traverse Bay are the long domed and flat reefs they built. Like the Silurian these Devonian limestones are the mecca of fossil hunters.

At its close the Devonian seas became shallow and were bordered by low-lying lands from which sluggish rivers brought sediments black with decayed vegetation and gradually the time changed to the Mississippian—the first part of the Carboniferous or Coal Age (M fig. 1). For 35 million years the Mississippian sea alternately entered and partially retreated from the bay which covered most of the Southern Peninsula surface. The conditions of the lands about our Michigan bay varied so that a variety of sediments were deposited; nor were the sediments the same in all parts of the basin and we have incompleted bowls. Thick shales—black Antrim, green Ellsworth, blue Coldwater—underlie the Marshall sandstone, which in turn is overlain by the Michigan shales, sandstones, limestones, and the thick gysum beds which indicate an arid climate and chemical precipitation. Near the end of Mississippian time the Bayport limestone sediments were deposited. The Mississippian fossils are not so abundant as those of the great limestone building times, but we find casts of leaves near the shells and know that plant life was becoming dominant on the land. The age of seaweeds, trilobites, lampshells, corals, was past; land loving creatures with backbones were taking the important place, and plants were becoming very important indeed on land.

Then the earth began preparing for another revolution. Slow gentle movements caused the Mississippian seas in which limestones were being deposited to almost retreat from Michigan, leaving a shallow pool (Ps. Pgr. fig. 1) in the central part of the basin and cut off from the outside sea. The time was the Pennsylvanian, the last 45 million years of the Carboniferous, and the time of the great coal swamps. Deposits in the older seas were marine, but in this Pennsylvanian area sedimentation was partly marine, partly fresh or brackish water in swamps. A layer of sparkling sand was first spread over the last Mississippian limestone and above this in the shallow waters a luxuriant swamp forest flourished—but the trees were quite unlike our modern trees. They were giant fern trees, ground pines, and horsetail rushes that grew tree high. No birds or butterflies or flowers were there, but dark loathsome amphibians and the earliest known reptiles crawled in the muds; giant scorpions and dragonflies flew about. The climate was warm and moist. The swamp vegetation died and fell to the swamp floor, layer upon layer of plant remains accumulated, changed to peat, were buried under a blanket of dark muds which slow streams brought from forest covered lands. Thus protected from the destructive oxygen of the air, they have in the long time since become the coal beds and shales of the central counties.

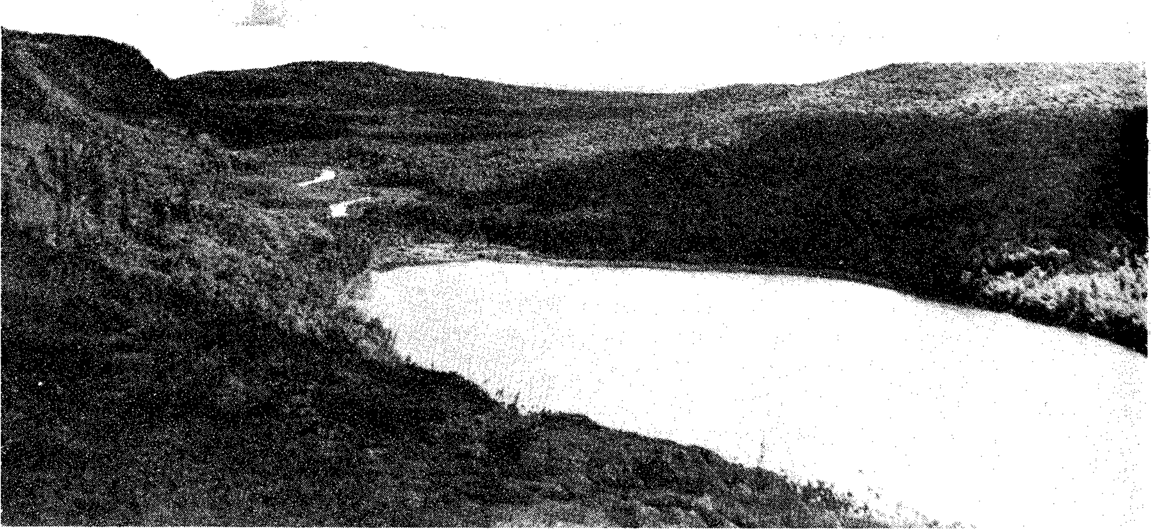
For the last time the seas rather hesitatingly invaded Michigan and a layer of thin sands and marine shales was spread over the coal swamps. Hot winds of the Permian time probably dried the last thin muds of the shallow seas and made a layer of thin red shale with streaks of gypsum in it, covering the last Pennsylvania sandstone. The Michigan basin was filled, the Paleozoic era was ended.

During 350 million years sediments on top of sediments were deposited in our basin, and its central area was gradually depressed by their accumulating weight, so that when the Gulf Oil Company drilled the deepest well in the State, near Kawkawlin in Bay County, the drill was pushed down 10,447 feet, nearly two miles, and the Cambrian sandstone was not reached.* One celled organisms had evolved to vertebrates and primitive forest trees. In those sediments and the organic remains in them were stored all the minerals plants need and many minerals man was to use for his profit and advancement, but Michigan was not quite ready for man.

*The well was started at 599 feet above sea level, about 20 feet above Saginaw Bay, in the glacial drift. 115 feet of glacial lake beds and drift were drilled through, 300 feet of Pennsylvanian rock, 1,280 feet of Mississippian, 3,115 feet of Devonian, 3,774 feet of Silurian, and 1,863 feet of Ordovician. The well was not drilled through the Ordovician.

The revolution came on in earnest, but not with violence. The continental block was uplifted in the east and Michigan shared in the general gentle uplift, but no seas ever again invaded our area, or if they did no records are left, for during the next 200 million years while the rest of the continent was being built up, erosion was let loose to work its will on the face of the Great Lakes region. Erosion, of course, had been in progress on all exposed surfaces as soon as they were above sea level, but at the close of the Permian it became greatly accelerated as our area, sharing the continental uplifts, was lifted higher above sea level when the Appalachian and later the Rocky and Sierra mountains were uplifted. Also during those 200 and more million years gentle warpings of the continent were shared by Michigan, the Lake Superior basin was warped down so that now the vents from which the Keweenaw lavas were extruded are below the lake; Keweenaw Peninsula cracked from Bete Grise Bay to Lake Gogebic, and the eastern part of the block of flat-lying conglomerates, sandstones, and lava flows (trap rock) was so tilted to the west that the cliffed eastern edges of the strata are now exposed along that great crack—the Keweenaw Fault.—But the western part of these rock flows were tilted east by the downwarp, and now the western edges rise above Lake Superior in our famous Isle Royale. Thus Isle Royale is a "mirror image" of the Keweenaw Peninsula. Upthrust of the Keweenaw block pulled up the edges of the nearly flat overlying Cambrian sandstones so that the western edges of the sandstone beds were tilted almost vertically. Erosion of the almost vertical sandstone has made the curious Rock Wall Ravine near Laurium, Houghton County. The squeeze of the warping, shrinking continent against the great bulwork of the old Canadian shield caused the sedimentary rocks of the basin to arch in wrinkles that trend northwest-southeast across the basin—and thereby hangs the tale of our oil deposits.

All the forces of erosion were at work creating much of our scenery, exposing our mineral wealth and creating some of it. The old pre-Cambrian area west of the meridian of Marquette was eroded most rapidly. The edges of the Cambrian sandstones were worn away off from the old granites and Huronian iron formations, leaving only small caps of sandstone to show where the Cambrian seas had been. The iron formations were not ores when first exposed, but during the long ages of their exposure surface waters leached out other minerals leaving the iron behind, and carried



THE FLAT SUMMITS OF THE PORCUPINE MOUNTAINS NEAR LAKE OF THE CLOUDS REPRESENT THE OLD PLAIN WHICH WAS UPLIFTED TO A PLATEAU IN WHICH THE VALLEY OF THE CARP RIVER HAS BEEN CUT. LAKE OF THE CLOUDS—A WIDE STRETCH OF THE CARP RIVER.

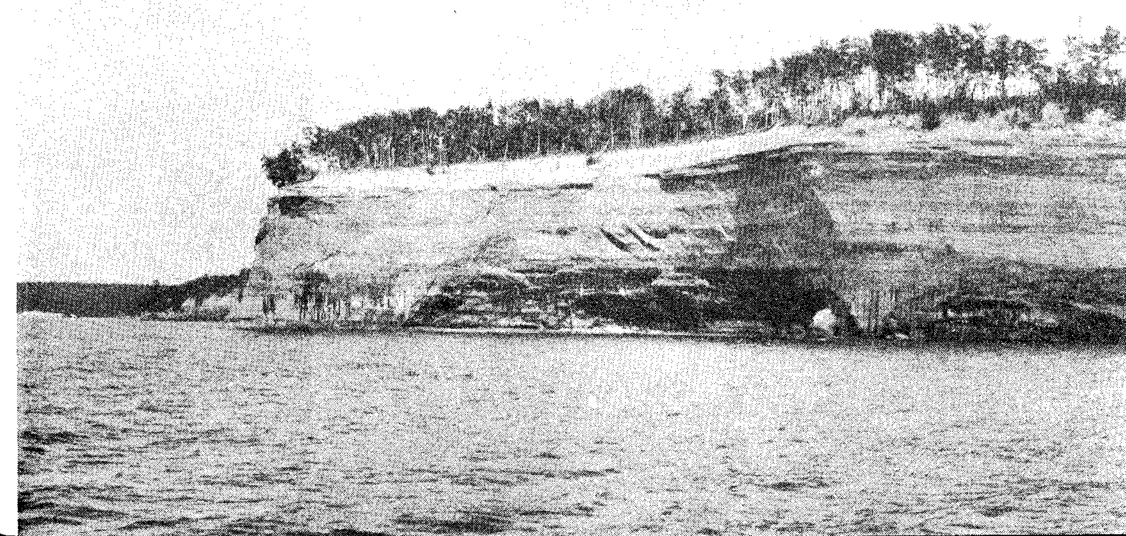
oxygen to the iron sediments, gradually changing the upper few hundred feet, metamorphosed though they were, to iron ore. That explains in part why the upper parts of the iron formations are rich and the lower levels lean in iron.

The lands of the Killarney mountains had been worn down so that the surface was brought nearer the 20,000 feet of copper-bearing lavas and conglomerates. The rugged land had been brought almost to a plain, but uplift rejuvenated the rivers, gave them swift currents, started their work all over again, and they cut deep gorges in the pre-Cambrian rocks until the whole area became a rugged imposing region of high ridges and deep gorges with many waterfalls. But rugged as the region is to the hiker, the summit levels of the ridges are fairly even and above them lift the high heads of a few individual mountains and knobs that resisted destruction by the earlier erosion—those diorite knobs of the western part of the peninsula, Mount Bohemia, Mount Houghton, and others of the Keweenaw Peninsula. Today the highest elevations are the Laurentian granites of the Huron Mountains and the Killarney granites and Keweenaw lava flows of the Porcupines in Ontonagon County. Brockway Mountain and its famous drive are on the eastern edge of the tilted Keweenaw block.

WAVE WORK ON LAKE SUPERIOR SHORE—THE TREE LINE FOLLOWS SLOPE OF THE BEDS. ROCK HARBOR, ISLE ROYALE.

In the Paleozoic area the edges of the bowls were beveled off and their rocks exposed. The thin edges of the hard resistant formations were worn away so that the outer edges are now high cliffs or escarpments. Such a structure—a short steep slope over the exposed edges of rock layers, and a long gentle slope in the opposite direction down the top of the strata, is a cuesta. The summit of a

WAVE-CUT RAMPART OF EDGES OF CAMBRIAN SANDSTONE NEAR MUNISING FACING NORTH. THE SANDSTONE BEDS SLOPE GENTLY SOUTHWARD UNDER THE SOUTHERN PENINSULA.



cuesta may be miles in length. The steep slope of the Cambrian cuesta borders Lake Superior. In the red and white sandstone of the escarpment the famous Pictured Rocks, Miner's Castle, Chapel Rock have been carved. Over the edge of the cuesta escarpment streams fall in misty beauty to the lake and the Tahquamenon drops in majestic grandeur over its ledges from quiet river reaches to rapids below. Back of the escarpment the Cambrian rocks slope gently under the Southern Peninsula.

The Ordovician Trenton limestone stands as an escarpment farther south floored on the Cambrian, but is not so pronounced as another escarpment eight to twelve miles still farther south—the edge of the massive Niagara (Silurian) limestone. The softer rocks between the Trenton and the Niagara were eroded into a deep moat between the two resistant formations so that the limestones stand like ramparts across the peninsula guarding the lands to the south. The forest fire towers are silent sentinels above the ramparts. Other soft rock rims were eroded to moat-like troughs forming the curving channels where we now find Green and Georgian bays, Lakes Michigan, Huron, Erie, and Ontario. In these channels, curving around the Michigan Basin, a river system was developed which carved the basins for four of our Great Lakes. The Devonian limestones were carved into low cuesta ramparts around the northern edge of the Southern Peninsula from Thunder Bay to Traverse Bay. But the Devonian strata of the southeastern part of the State lie flatter and were not carved to pronounced escarpments.

When the older underlying shales were eroded the resistant edges of the Mississippian formations were left as cuestas that almost encircle the Southern Peninsula. Thus the surface of the peninsula was carved to uplands, one in the north central part, the other stretching from the Thumb to Hillsdale with a lowland between, but all sloping to the river lowlands (now the Great Lakes beds) around the edge of the peninsula.

If any great beasts—dinosaurs, sabre-toothed tigers, giant pigs, or little ancestral horse or camel—roamed the Michigan uplands as we know they did elsewhere during this long time, we have found no trace of them. If they were here and died on the uplands their unburied bones were left to bleach, decay, and disappear. Or if not destroyed were carried southward by the four glacier scrapers that ploughed over the State during the long ice age. The story, if any, of the part Michigan played in the evolution of the vertebrate animals and the evolution to the modern upland forests is lost on the missing pages of time after the end of the Paleozoic and before the beginning of the latest chapter of our history.

Near the close of the Cenozoic, in geological very late yesterday afternoon, the climate changed from genial to frigid—the Great Ice Age came upon the northern hemisphere and North America became the most ice-bound of continents. Nature released a force that had been effective in other eras on other areas but had not before reached the Michigan basin—glaciation.

THE WAR OF COLD AND HEAT—THE ICE AGE

THE ADVANCE

For hundreds of millions of years Nature was busy tearing apart some newly made land and using the pieces (sediments) to build up other lands, including Michigan. For over 200 million years she was just as busy tearing Michigan down. Then, a million years ago, she sought to erase the ravages of time from the face of the State, to cover or obliterate the scars of erosion, and to write the latest chapter of the story of the face of Michigan. And strangely, for her stylus Nature used an unusual crystalline rock—glacial ice.

About a million years ago great ice sheets started to move southward from various centers of refrigeration and accumulation in Canada over the northern half of North America as far south as the Missouri and Ohio rivers. Four times the ice moved over the area and four times melted away. But in Michigan we are interested only in the last advance, in the work of the glacier which moved southward from the Labradorean center developed on the high plateau between James Bay and Labrador. This vast sheet of ice slowly, relentlessly, ploughed over the region of the Great Lakes, pushed onward by the ever thickening mass of ice on the plateau until it was brought to a standstill, 1600 miles away from its center, roughly to the position of the present Ohio River, whose course in part was established along its border.

For almost a million years Michigan lay intermittently buried under blankets of ice two to four miles thick. Changing conditions of temperature and precipitation caused the ice front to fluctuate considerably, moving outward from the centers during times when the climate was cold and moist and retreating by melting when the climate was warm and dry. At one time tropical conditions were so powerful that they drove the glacier far north and palm trees flourished near the site of Toronto, only to be killed and buried by a readvance of the ice sheet.

In its relentless, crushing advance the huge Labradorean ice sheet rasped, scraped off, and absorbed into itself the residual soil and loose rock masses which had covered the old rock surfaces; froze onto, plucked,tore huge blocks loose from bed rock, clutched them in its icy grip, imbedded them in its glacial mass, and used them as tools to erode—scrape, gouge, rasp, and scratch the surface over which it rode roughshod. It used fine sands and clays to sand, smooth, and polish not only the bed rock surface but also the boulders churned within the mill of moving ice.

High areas of hard resistant rock were smoothed off and in some localities were highly polished by the grinding, rasping, rubbing, of the debris-filled ice. In many places the smooth rock pavement is scored with scratches and grooves cut by the sharp rock tools held in the frigid vise at the bottom of the glacier and given power by the weight and movement of the ice. These markings, or striae, wherever preserved on the old rock floor tell the direction of ice movement as they always run parallel to the major directions of glacier advance. In deep valleys the advancing ice dumped some of its load and pressed the debris almost to hard firm rock by its own sheer weight.

In many places softer and less resistant rocks were deeply carved and gouged by ice erosion; thus the pre-glacial stream valleys cut in the softer rocks and the rims of our foundation rock bowls were widened and deepened. The softer rock masses picked up by the ice were usually ground between the harder stones and pulverized to fine sediment in the glacial mill.

In this manner the moving glacier became a great mass of rock-debris filled ice carrying an enormous load of coarse and fine, large and small, igneous, sedimentary, metamorphic rocks, jumbled all together, shovelled up in the north and freighted southward.

In its way the moving glacier found those gorges cut in the ancient rocks, the downwarped trough where Lake Superior now lies, and the wide valleys cut in the rims of the bowls—but they were not barriers to its progress, rather they became diversion channels or rock pathways for advance masses of the ice, where the ice could move more rapidly down a slope and became thicker than on the uplands. Thick masses of ice became keeled or footed in the depressions and moved through them as distinct tongues or lobes, acting as independent glaciers, gouging out deep depressions and widening all of them. Just as independent glaciers from the

Alpine and Alaskan snowfields and from the Greenland icecap are moving down valley today.

To these various lobes we have given the names of the Great Lakes and bays which eventually occupied the enlarged depressions after the ice had disappeared. Thus we had the Superior Lobe, with the Keweenaw lobe as an offshoot; the Lake Michigan lobe, with its Grand Traverse and Green Bay appendages; the Huron Lobe, with its subordinate Saginaw Lobe which played as important a part as its parent; and the Erie and Ontario Lobes. Slowly the lobes made their way southward out of the valleys and during the climax of the last, or Wisconsin stage of glaciation, all the lobes were welded together south of the Great Lakes region, and advanced southward as one broad sheet of ice or glacier with a slightly lobate front. Not until the ice melted back into southern Michigan did the ice front again become separated into distinct lobes. So it is that the end of the story of the ice age in Michigan is the tale of records left by several retreating glaciers.

THE RETREAT

The advance of the glacier over North America was by a southward movement of the ice, pushed forward by the weight of its own increasing mass from the Hudson Bay and Labrador centers of accumulation. The retreat was a northward recession by self-destruction; that is, the glacial ice melted and, as meltwater, flowed away from the glacier front. The ice could clutch onto and move great masses of rock, but the meltwater could move only the finer material of the glacial debris. The glacier took advantage of all the valleys along its lines of advance. Its retreat was a rout. The melt waters flowed wherever they could and the ice dumped all its booty where it stood, although here and there weak and futile re-advances were made. The thicker the ice the more rock waste it carried and the more it had to dump. In places the ice, though thick, carried little rock waste and thus left thin masses of waste when it melted. We have noted that because the glacier moved over igneous, sedimentary, metamorphic, stratified, and crystalline rock areas, it had incorporated within its body loose masses of all these rocks and churned, mixed, and ground them all together in the glacial mill, rounded off sharp edges of the harder rocks, ground the softer rocks to fine sand and clay—"boulder clay."

When the glacier melted from North America it left this mass of "heterogenous" rock debris dumped and spread over the area it

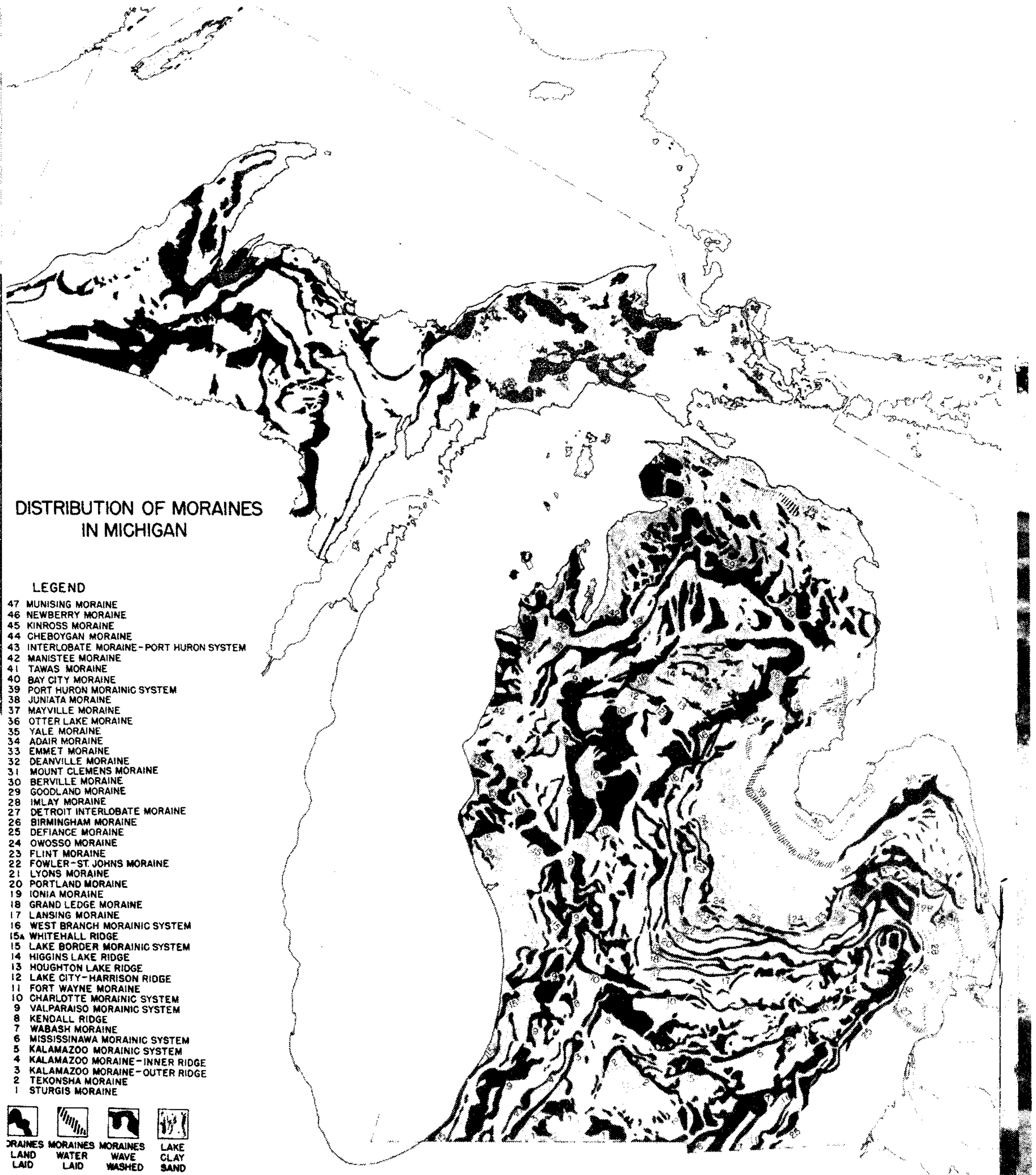


FIG. 2—DISTRIBUTION OF MORAINIC HILLS IN MICHIGAN.

had covered. Early geologists believed that all this rock rubbish had been carried by giant icebergs in a great sea that covered the area and therefore gave it the name "drift"—a name we changed to "glacial drift" when we had proof that a glacier was responsible for its location far from its place of origin. Boulders of crystalline granites and other igneous rocks are found resting on sedimentary rocks quite out of place, quite the opposite of their ordinary behavior, so that they were called "erratics." Many are hard and resistant, or have veins of harder crystals and are eroded into fantastic forms—thus being interesting rocks for the rock gardens and stone walls.

The advancing glacier using its rock tools gouged, grooved, scratched, polished the rock it moved over—records of defacement. It deepened and widened valleys—it was an agent of erosion. But the retreating glacier left a covering of rock waste, building up a new surface, and in large areas burying its own records of erosion in that long gap after the Paleozoic when no sediments were deposited in Michigan, or if deposited were eroded and disappeared.

Of all these glacial drift formations the moraines best tell the tale of the retreat of the ice from the surface of Michigan. They mark the lines of halt and with their accompanying till plains, the lines of retreat. They reveal the halting retreats and slight readvances of the glacier; they show us where the ice held its position for thousands of years. Each glacial lobe built up its own set of moraines which can be mapped and more or less definitely set apart one from the other, and as mappable units have been given names of localities prominent on them.

What is a moraine? A glacial dump or an entrenchment. When the ice front halted, that is, when the glacier could push forward no faster than the ice melted or backward melting equalled forward push, the melting ice dumped its load of rock waste which was added to by the oncoming glacier. Thus a ridge of hummocky hills made of all kinds and sizes of unassorted rocks and ground-up rock debris was piled high along the ice front at every halt. Thick ice with a heavy load built higher dumps, cleaner thinner ice built the low hills. Occasionally, melting ceased and the glacier again advanced over or onto its own entrenching ridge, pushed it higher, added more rock debris to its mass. The great ridge of hummocky hills extending from Illinois to Long Island marks the most southerly position of the ice sheet and is known as the Great Terminal Moraine. In Michigan we are interested in the moraines (fig. 2), left by the glacial lobes,—the ranges of hills stretching from Hills-

CUT IN A TYPICAL MORAINE DUMP OF ALL SORTS AND SIZES OF ROCKS. NEW "PARENT MATERIAL."

dale to Hastings, from Kent to Wexford County, from West Branch to Clare, or from Washtenaw and Jackson counties northeastward through Lapeer County.

The Not So-everlasting Hills

The Saginaw lobe was not so thick as the Lake Michigan and Erie lobes and therefore melted faster and was the first to retreat into Michigan. Its first halt after uncovering an area of four or five townships in St. Joseph and Cass counties was near Sturgis, where it built the first and oldest moraine in Michigan—the line of hills passing through Sturgis and bordering the triangular area first uncovered. This hilly ridge has been named the Sturgis moraine (1, fig. 2). The best authorities estimate that the Sturgis moraine was constructed not more than 35,000 years ago. From this outpost the lobe receded step by step into the Saginaw Valley, and at each halt built a moraine, so that its retreat across Michigan is marked by a succession of more or less parallel moraines forming festoons of glacial drift ridges closing in on Saginaw Bay from the

south, with their ends tied to the massive moraines of the Erie lobe in the east and the Lake Michigan lobe in the west.

Rapid melting caused the Saginaw lobe to retreat to the position of Tekonsha where it built the slender Tekonsha moraine (2, fig. 2). Further retreat brought the Saginaw ice front to the position of the Kalamazoo moraine (5, fig. 2). Here it halted long enough to build up a high, wide, massive, very hilly range. The Kalamazoo moraine extends from Hastings south and east through Marshall to Devil's Lake in Lenawee County where it connects with the Mississinawa moraine which outlines the outermost position of the Erie lobe in southern Michigan. On the west the Kalamazoo moraine of the Saginaw lobe unites with the moraine also called Kalamazoo, which the Michigan lobe was making at that time, extending from Hastings through Kalamazoo and Cassopolis. This Outer Ridge of the Kalamazoo moraine marks the most easterly extent of the Lake Michigan lobe. From this time the pattern of the morainic system is a map of the retreats and halts of all the glacial lobes—Erie, Huron, to the east, Lake Michigan in the west, and the Saginaw lobe between, and the Superior lobe in the north.

Renewed melting of the Saginaw lobe caused its front to recede to the vicinity of Charlotte where it built the less imposing Charlotte moraine. This ridge may be traced from near Milford in Oakland County westward through Brighton, Mason, and Charlotte, to the vicinity of Grand Rapids where it ties in with another morainic system of the Lake Michigan lobe—the Valparaiso, which comes north from Indiana. The Michigan lobe had retreated from the position of the Kalamazoo moraine to make a long stand in the west, during which it built up the high Valparaiso moraine which

ROLLING "KNOB AND KETTLE" TOPOGRAPHY NEAR CHELSEA, WASHTENAW COUNTY.

marks the border of the Lake Michigan lobe from Indiana to central Wexford County (9, fig. 2). This moraine is a typical "knob and kettle" formation. The highways of the region lead from valley up over knobby hill or high steep knoll, from whose summit one may look over a bumpy country of hill and kettle-like basin filled with lake or swamp or drained to rich, dark truck farm land. On the eastern side of the State near Pontiac the Charlotte moraine connects with the Fort Wayne-Wabash morainic systems which were formed at the same time by the Huron-Erie lobe after the retreat from the Mississinawa moraine.

Following the formation of the Valparaiso-Charlotte-Fort Wayne-Wabash systems, the ice began another decided retreat along all fronts. At the next long halt the Lake Michigan and Huron-Erie lobes played the dominant part in moraine building. Retreating from the Valparaiso moraine, the Lake Michigan lobe halted long enough before it retreated into the Lake Michigan basin to build the Lake Border morainic system (15, fig. 2), a complex of low ridges which closely follows the margin of Lake Michigan. The ice over the eastern part of the State was building the massive West Branch and Gladwin moraines north of the Grand River. But south of the river the rapidly retreating Saginaw lobe was building the slender moraines which fray out from the West Branch-Gladwin moraine and mark the halts of the Saginaw lobe as it backstepped into the bay.

This group of slender, deployed moraines (17-24, fig. 2) do not have the rugged topography of the moraines to which they are tied at either end as the Saginaw lobe was thinner and cleaner than the ice of the other lobes. Named in order of development from the vicinity of Lansing northward, the moraines of the deployed, slender group are: Lansing, Grand Ledge, Ionia, Portland, Lyons, Fowler-St. Johns, Flint, and Owosso. During the building of the Lake Border, West Branch, and deployed group the Huron-Erie lobe was building the Defiance moraine from near Defiance, Ohio, to a few miles east of Pontiac, Michigan (25, fig. 2) and the Birmingham, Mount Clemens and Emmit ridges (26, 31, 33, fig. 2) which lie scattered through the lake plain north of Detroit.

After the next retreat the re-enforced Lake Michigan-Saginaw-Huron lobes took the longest and most determined stand in the Lake region and constructed the most formidable entrenchments—the Port Huron moraine (39, fig. 2). The same determined stand was taken along the entire glacier front from east to west, so that this moraine has been traced more precisely than any other and stretches from the Genesee valley in New York to Lake Michigan north of Ludington, and is readily traced on the western side of the lake in Wisconsin. From Vassar in Tuscola County to the northwestern corner of Bay County the Port Huron moraine is low and gently rolling rather than high, massive and rugged as it is elsewhere. Here the ice front stood in deep water and the moraine was water laid. The reason is in the story of the Great Lakes.

The last weak stand of the ice in the Southern Peninsula before it retreated into the narrow valley of the Strait of Mackinac is marked by the slender ridges of the Cheboygan moraine which follows the lake shore from Cheboygan to Mackinac City (44, fig. 2).

The glacial features of the Northern Peninsula were formed in large part by the Superior lobe. This mass of ice was directed into the Superior Basin from the northeast, and pushing out over the rim of the basin, covered the greater portion of the Northern Peninsula. Upon its halting retreat the Superior lobe also left moraines to mark the halts, and in the western part of the peninsula complicated the pre-glacial rugged topography by filling some of the gorges with drift, diverting the courses of some streams and damming others by building morainic dams across their courses. Lake Gogebic lies in the channel of a stream that once flowed to the north but its headwaters were cut off, dammed back by a moraine, and Lake Gogebic formed. These western moraines are not yet named nor correlated with other moraines. The Munising, Newberry, Kinross moraines (47, 46, 45, fig. 2) in the eastern half mark the last stands of the glacier in Michigan. They shared in the final episode of the Ice Age which is also one of the final chapters in the story of the Great Lakes. By the time the Superior basin was completely freed of ice as the Labradorean sheet had retired to the uplands of Canada, a great lake of glacial waters spread out in front of it, covering most of the eastern half of the Northern Peninsula, and inundated or flooded all but the highest morainic ridges, and buried the story the moraines could tell.

The moraines mark the halting places of the glacier as the warming climate forced retreats. But what happened between halts? What became of the water that flowed from the melting ice? Why do we not see the bed rock in the meshes of the pattern of the moraines? And just what are these moraines like, why do some high hills seem not to fit in the pattern of moraines at all? The mass of glacial drift gives the answers and also shows us several other features that the ice left us in addition to the moraines.

In those areas where the edges of two glacial lobes came near, the moraines became complicated and mixed up. Thus at the place of near-union of the Erie and Saginaw lobes, where the Kalamazoo moraine meets the Mississinawa setting in from Indiana, readvance of the Erie lobe pushed its moraine against the also slightly advancing moraine of the Saginaw lobe. Such an area between lobes is an interlobate area and there we have some of our grandest scenery. The Irish Hills near Jackson are interlobate moraines formed at the near junction of the Erie and Saginaw lobes. The rugged morainic topography near Pontiac was formed between the Huron-Saginaw ice fronts, and the Metamora and Hadley Hills and the Highlands in northern Lapeer County were formed at the region of union and squeeze of the two lobes. The high hills north and south of Grand Rapids were developed where the Saginaw and Michigan lobes met, and the rugged hills through the region of Clare, Grayling, Gaylord, were formed by the Huron and Michigan lobes working together. How do we know the rugged interlobate regions were the work of two lobes? By the material in them.

KETTLE HOLE, CHARLOTTE MORAINIC SYSTEM NEAR BRIGHTON, LIVINGSTON COUNTY.

For example, the Erie lobe scraped the bed rock from the limestones of Monroe County and we find slabs of that rock on the southeastern slopes of the Irish Hills, but on the northern slopes we find fragments of the Pennsylvanian rocks sledded there by the Saginaw lobe from the bed rock over which it passed. On the hills east of Gun Lake, Barry County, rocks that came from north of Georgian Bay are found, but west of Gun Lake the hills carry fragments of rocks that are the bed rocks of the western Northern Peninsula.

Frequently in the construction of a moraine, blocks of ice broken from the ice front were buried in glacial debris and did not melt until long after the ice had passed. On final melting they left deep, steep-sided depressions in the moraines, some of which later became filled with water. Such depressions are named "kettles" and a moraine having many kettles is a kettle moraine. Such kettles, as well as the depressions caused by unequal bulk of deposited morainic material, account for the hundreds of lake basins we now find in the morainic areas of the State. Not all the basins have lakes in them now for thousands of them have been drained in the past ten thousand years; many kettle lakes are drying up now or their water levels lowered in times of decreased rainfall.

As the ice rapidly retreated by melting or evaporation from one moraine to the next, it left its burden of mixed rock waste just where it melted, just as a persistent winter snowdrift leaves an assortment of clay, sand, and sticks, when it melts in the spring. If the ice carried much rock waste it left a low hill; if the ice was fairly clean, the drift left was thin—like the land between Lansing and Howell, from Ionia to Stanton in Branch County, and many other places—made of the same unassorted material as the morains —cobbles, pebbles, some sand and erratics, but mainly boulder clay which was made, you remember, from the boulders which the ice ground up. These plains are ground moraines or till plains. In the main the till plains are quite stoney clay lands. Erratics are common. In some places the till plains at the present surface were deposited on the ground moraines of an earlier ice, and their undulating topography may be due to the topography of the land upon which they were deposited. They are some of the best, most easily worked farm lands in the State. On the till plains also small blocks of ice were buried for centuries and left depressions when they melted. Water remained in these and other depressions in which vegetation grew and in time filled the depressions with an