MICHIGAN ACADEMY OF SCIENCE, ARTS AND LETTERS

VOLUME X

CONTAINING PAPERS SUBMITTED AT THE ANNUAL MEETING IN 1928

(*The papers in Botany and Forestry of the 1928 meeting appear in Volume IX.)*

The annual volume of Papers of the Michigan Academy of Science, Arts and Letters is issued under the joint direction of the Council of the Academy and of the Executive Board of the Graduate School of the University of Michigan. The editor for the Academy is Peter Okkelberg; for the University, Eugene S. McCartney.

Previous publications of The Michigan Academy of Science now known as The Michigan Academy of Science, Arts and Letters, were issued under the title, Annual Report of the Michigan Academy of Science. Twenty-two volumes were published, of which those numbered 1, 21 and 22 are out of print. Copies of the other volumes are still available for distribution and will be sent on exchange so long as the editions last. Applications for copies should be addressed to the Librarian of the University of Michigan.

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PAPERS OF THE MICHIGAN ACADEMY OF SCIENCE ARTS AND LETTERS

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UNIVERSITY OF MICHIGAN
1929

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Set up and printed,
March, 1929
Published, April, 1929

PRINTED IN THE UNITED STATES OF AMERICA.

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ANCIENT POTTERY REMAINS IN THE SAGINAW DISTRICT, MICHIGAN

FRED DUSTIN

IT MAY be said in general that the pottery of the Saginaw District is of a somewhat crude type as to quality, form and material, but in the matter of ornamentation, we are at once struck by the infinite variety of design and pattern, and wonder at the ingenuity of the primitive workman and artist.

The culture of a people is indicated by the utensils and implements made by them, so that the various shades, from the most refined civilization to the rudest savagery, are depicted to a great extent, in the ceramic wares fashioned by their hands. Be it remembered, however, that this must not be taken as a sole guide, but should be considered in connection with all the other arts and practices of the various nations and stocks, and we may state that this is especially true of primitive peoples.

The Indians of the Saginaw District were of a medium culture, and we find that they practiced all the rude arts of their neighbors, and owing to their environment, were especially proficient in some and lacking in others. In the matter of transportation, their canoes were models of perfection; in regard to dwellings, their wigwams were miserable constructions, while in the ceramic art we find them fairly proficient. It would be interesting to discuss the reasons for these conditions, but in this paper we must confine ourselves largely to description and comment, leaving the philosophical questions to a possible future paper.

There is not an aboriginal village site in Saginaw County that will not yield fragments of pottery. When I use the term "village site" it must be understood as referring to permanent dwelling places and not to the casual camping site which was temporarily occupied, and which is distinguished by its lack of pottery remains, although it yields the weapons of the hunter and animal remains in plenty.

These fragments are turned up by the plow year after year, and lie unnoted by the husbandman, although he often stops to pick up the casual arrow-point, or pauses to note a bed of fire-crackled stones that marks the site of an ancient wigwam. It is, therefore, the collector, who, with the keen eye of interest and experience, makes available the hidden information concealed in these seemingly uninteresting potsherds, and again remodels the bowl, the urn or the kettle, and places them before us as most interesting relics of men and women who have gone before us, and whose dust mingles with the dust of their own rude utensils.

From some half-hundred village sites I have gathered pieces of pottery, but in no case have I found a perfect vessel or even the entire pieces of one. In fact, I know of but one complete article of this class, a small urn in the possession of Mr. Henry Bornhoff of Saginaw, which was dug up in Saginaw County within the last three years. It is about six inches in diameter in its greatest dimension, and is a fair specimen. The great Andross mortuary urn figured and described by Harlan I. Smith is only a fragment, having been badly broken, and not all the pieces have been recovered. Mr. Smith in describing it says: "While a pioneer was ploughing on the site, the foot of one of his oxen suddenly sank into a hole. On investigation, the farmer found that the ox had broken through the bottom of an urn which had been turned mouth downward over the head of a human skeleton. This urn is three feet nine inches in circumference and one foot eight inches in height, but before it was broken it must have been at least two feet high."

This huge vessel was found in the Andross Mound which was located in the village of Bridgeport and close to the Saginaw and Flint Interurban Railroad, and just east of the Pere Marquette Railroad. On April 24, 1912, I examined this mound. The knoll had been excavated to the depth of nine or ten feet leaving a nearly perpendicular bank of the yellow "core sand" used in moulding. Near the highest point and some fifteen inches below the surface, a piece of pottery protruded slightly. I dug under it carefully, and was surprised to find that it was nearly fifteen inches wide and from twenty to twenty-four inches long. The sand in which it was embedded was very soft and wet from the spring rains, and the piece was so fragile that it was possible to remove it in fragments only, filling two cigar boxes of ordinary size. I noted that it was much cracked before I had disturbed it, tiny rootlets having grown between the pieces. It at once occurred to me that perhaps this was a missing portion of the Andross urn, but a later study shows conclusively that it was a different vessel, for the Andross urn was distinctly marked about the middle of its long dimension with cord impressions, and its rim with incised or punched patterns, while the one found by the writer bore on its whole outer surface the impression of a woven fabric. I presume it was a part of a mortuary urn, although not accompanied by skeletal remains, and it was lying on its side, rounding side down.

This urn did not appear to be nearly so substantial in its construction as those smaller vessels that were so evidently used in cooking, and are of comparatively small size. Most of the specimens I have measured are six and nine inches in diameter across the top. By selecting a good fragment it is quite easy to measure the arc of the circle it represents and thus arrive at the true diameter of the top, but to measure the diameter of the swell of the bowl is a difficult matter.

Nearly all of my collection shows that the circular figure predominated, there being but a very few specimens indicating an angular top. In fact, we may say that practically all are of the distinctive Algonquian type, and this also applies to the decorations, for I do not now remember more than half a dozen out of the perhaps thousand pieces in my collection that indicate another type of culture.

The writer's collection numbers about four hundred or more pieces from the tops of vessels, representing about that number of pots, urns or other receptacles. It is safe to say that no two of these, except those from the same vessel, are alike, for nearly all are ornamented and the variety of decoration is as individualistic as was the black-haired artist who formed it.

In the museum room of the Butman-Fish Library the writer has on exhibit a case of pottery including the great fragment from the Andross Mound, about two hundred fragments from the tops of vessels, as well as other characteristic pottery remains showing delicacy of ornament and beauty of design, also the materials from which it was manufactured. In another case are shown pipes, both perfect or damaged, as well as broken portions such as stems and bowls. There is also to be seen in this case a portion of a pottery tube or cylinder of problematic use, for it does not seem to be a part of a tubular pipe, a specimen of which is occasionally found.

One broken pipe-bowl has a kind of geometrical embellishment upon it that is like delicate tracery, while a fine perfect "mound pipe," which I removed from a grave along with a skeleton, is entirely without ornament. Other pipe-bowls show an average amount and grade of decoration.

To come now to materials and manufacture, all the pottery-ware proper (omitting pipes) appears to have been made by mixing in suitable proportions clay and some tempering material, which as far as my observation goes, was made by pulverizing a disintegrating rock composed largely of feldspar. I have collected several specimens of this stone and have sometimes thought that a part of it, at least, was prepared for reduction by heat. Other pieces merely show the gradual breaking down incident to weathering. Our Indian artisan was well aware that some clay was not suitable, for under heat it would crumble if it contained lime. He also knew that even the right kind of clay untempered cracked in burning. We can imagine that it took many long generations for these essential facts to become fully known, but the pottery before us shows that the makers had well learned the lesson, although they never arrived at the glazed stage of manufacture.

A fresh pottery fracture usually shows a brown-gray color, but sometimes is a brick-red tinge, indicating a percentage of iron, and under a glass of moderate magnifying power, the tempering material seems to form nearly one half of the substance. Some pieces appear to have been given a thin coat of clay of different color from the body of the vessel, thus forming an ornamental surface, usually a fairly bright red, while after use, most of the fragments show blackening from the effects of fire.

Most of the articles appear to have been built up in much the same manner as the modern potter shapes round objects, for, although the use of the potter's wheel was unknown, the principle was easily followed and two or three simple implements were all that were necessary to the primitive potter. The inside of the object was smoothed by the hand, and it is not so rare to find a slight impression of thumb or finger. It would seem that the larger urns presented some difficulties, for occasionally we note that around the swell of the bowl appear the marks of many cord impressions or those of fine strands of bark, which may indicate that the vessel began to sink down of its own weight or that such a sinking was anticipated and prevented by a judicious wrapping at the right point. Not infrequently we see that a whole vessel bears the impression on its outer surface of woven fabric, probably a light basket which was lined inside with a proper mixture of clay and tempering, and which, after the preparatory drying, was either peeled off or burnt off in the baking process. Some of the fragments in my collection would indicate the latter alternative, for charred substance is seen in the moulded impressions that under the glass appear to have been vegetable fiber.

A most interesting subject is the ornamenting of this primitive pottery; I have tried to show that figures or impressions on the body of the vessel may be merely utilitarian, and incidental to manufacture. As a rule the decoration is on or near the upper part of the object, that is, the rim. Here we find our pottery-maker exercising her art, and I have been much impressed by the variety of the designs. There does not appear to be any of that symbolism which is so strikingly shown by the Pueblo tribes of the Southwest; no pictorial art; no striking geometrical figures, but a ready and skilful use of the means at hand and best adapted to the crude material upon which it is placed.

We find, therefore, cord impressions, small indentations either in groups or running around the vessel, other impressions which look as if made by a small wheel with a notched edge, round recesses made by punching the surface with a properly formed tool, diagonal or perpendicular bars made either with a pointed tool or by impressing a bit of twig or bone into the plastic surface and not infrequently we find that the upper edge of the rim bears impressions of like character. The rim is often

rounded and made heavier, thus strengthened, and will sometimes bear ornamental figures on the inner side.

The form of these vessels showed not only ingenuity in manufacture but a keen appreciation of the most desirable shapes and dimensions. We find them of globular form, bottoms rounded and tops drawn toward the center, and we also note that the bottoms were thick, the material tapering from one half to five eighths of an inch at the center of the bottom, to about one fourth to three eighths of an inch near the top of the rim. They presented no angles where contact with other articles was likely; they were rounded on the bottom the better to set them upon three or four stones in the fireplace; also, to present as large a surface to the heat as possible; they were thick at the bottom for strength to resist fire and contact with supports; they were drawn in at the top to avoid as far as possible the spilling of their contents, which also applies to the bulbous form. A measurement of many pieces indicates that nine inches approximate diameter across the rim was a favorite size and undoubtedly was to this extent partially standardized.

I have mentioned pottery pipes and objects other than those used for culinary purposes. As far as my observation goes, the tempering material for these articles appears to have been a coarse sand, the pounded rock being unsuitable on account of the size of the grains which interfered with making the hole through the stem.

Some of these pipes were of neat design and good proportions while others were more crude. The stems were usually lozenge-shaped or oval in cross-section and were short and tapering sharply from mouthpiece to bowl.

It remains to describe some of the more notable village sites where pottery remains are especially plentiful. On the archaeological map of Saginaw County which the writer prepared a few years ago for Dr. W. B. Hinsdale (of the University of Michigan) will be noted village and camp sites, cemeteries, mounds, trails, fords, caches and other data, and references in this paper can be looked up accordingly.

At the center of Section 2, Township 11 North, Range 4 East, the Tittabawassee and Shiawassee rivers unite to form the Saginaw. The extreme south end of the city of Saginaw embraces a little more than the north half of the section, the city line coming to the point where the rivers unite. Green Point proper is outside the city, but common usage makes that portion of the section lying north of the Tittabawassee and west of the Saginaw known to the general public as "Green Point." A little west of the section-line between Sections 2 and 3, and about five hundred feet from the Tittabawassee River are two large mounds — at least they were large before being levelled by plow and flood—known as the Green Point Mounds, and surrounding these mounds and extending up and down the river were perhaps the most extensive village remains in the County.

This interesting locality has been a favorite collecting ground for the writer, and a large proportion of his best pottery specimens has been collected here.

Since the land was cleared up some thirty years ago or more, it has been under the plow nearly every season, and the occasional spring floods, which come high enough to flood these flats, rush across certain portions in swift currents which sweep the loosened soil away and have disclosed hundreds of relics, among them the pottery fragments.

There is a spot a few hundred feet southeast of the mounds, another immediately west and adjoining the westerly mound, and still another a hundred rods or more west and northwest where, under favorable conditions, I presume a half-bushel of potsherds might be collected. Unfortunately, the owner of the land has become possessed with the idea that the traditional "pot of silver" is somewhere hidden on his three hundred acres, and no longer permits collecting, and the tractor, plow and harrow are doing their work in pulverizing the remains of aboriginal culture.

In the Northwest Quarter of Section 31, Township 12 North, Range 4 East, is another notable locality quite different in character and aspect from Green Point. From the archaeological standpoint, it is known as the Frazer Village Site and Frazer Mound. It is a sand bluff some twenty feet above the ordinary stage of the Tittabawassee River, which was the scene of a fierce and sanguinary traditional battle between the Sauks and invading Chippewas and Ottowas, and there is plenty of evidence corroborating the tradition. The light sand after working has often been windblown, and I have found this beautiful spot overlooking the river at a wide bend in its course a fine collecting ground for all kinds of Indian remains. Owing to the dryness of the place, the potsherds are not so liable to destruction from cultivation as at Green Point, and I have collected perhaps two thirds or more of the rim of a vessel, picking up the pieces at odd times running over a period of five or six years. They had been scattered by the plow, but from time to time were exposed. I had hoped to secure the entire rim and reconstruct it, but owing to the run-out condition of the land it has not been worked for several years and is too weedy to reward any search, although a few hundred feet southeast I have made some fair collections in an old orchard. These two sites are typical, and while the writer has collected many potsherds at other points, the bulk of his collection has been made at these places, and many fine articles besides pottery have enriched his accumulations.

On the other hand, while localities like the Satchell Village Site in Section 30, Township 11, Range 6 East (Frankenmuth Tp.), the Stroebel Village Site in Section 5, Township 11 North, Range 4 East (James Tp.), are prolific in weapons, utensils, ornaments, and other objects, pottery remains are not plentiful although by no means absent. I have collected potsherds in at least eight townships in Saginaw County as well as in the city of Saginaw and miscellaneous relics in two or three

more townships. There were probably at least a hundred permanent Indian villages, large and small, in Saginaw County when the Revolutionary War occurred, and it is not improbable that as many existed in 1800. This implies a large aboriginal population, but it must not be understood that these Indian villages were populous in the same sense that our present communities are populous, for the natural resources of a hunting and fishing people whose food was largely flesh supplemented by a little corn, wild rice, berries and nuts, would not support more than a few hundred persons in a county even as productive as Saginaw.

I have collected potsherds from forty-five or fifty of these villages, and have often pictured to myself the method of manufacture and the scenes attending its production. In the National Museum at Washington there may be seen a number of life-sized groups of Indian men and women engaged in the simple arts and industries of the aboriginal period.

I have not had the privilege of seeing these life-like representations, but have studied them on the printed page, and many times I have conjured up in my mental storehouse of day dreams, not waxen figures but living men and women, black-haired, dark of skin, and with eyes of jetty depths, weaving their baskets, grinding their corn, building the birch-bark canoe or painfully and slowly hollowing the dug-out, chipping the arrow-point, pecking the stone axe and among them, the patient Indian woman forming her water-jar or kettle from the plastic clay.

Perhaps as she works, her baby in its quaint nest swings from a bough before her and other brown children are in cautious play, for danger is always nigh. We see her beating the crumbling rock for tempering and kneading the clay to its proper consistency. We see her mixing the two and soon an urn begins to take shape. How deftly she manipulates it, smoothing inside and out as the work progresses. She moulds the rim, pinching and smoothing it into the desired angle and height. It is now completed as a purely utilitarian product, but we note that it does not satisfy her, and as we watch, she impresses a cord around the top leaving its figure in the clay: also produces a sharp-pointed bit of bone and makes incised diagonal marks around the rim, or perhaps with another implement she impresses different figures or with a short piece of twisted cord indents a series of casts in regular order.

At last the work is finished, and is carefully set aside to season. Tomorrow it will be baked and thus enter upon its usefulness. There is one thing that has especially impressed us and that is the individuality of the potter. The form of the vessel may be conventional, but it is the convention of service and use. It is the artistry of ornamentation that strikes us, each potter impressing herself, as it were, on her product.

SAGINAW, MICHIGAN

INDIAN MOUNDS, WEST TWIN LAKE, MONTMORENCY COUNTY, MICHIGAN

WILBERT B. HINSDALE

IN ALBERT TOWNSHIP, the southwest corner of Montmorency County, occupying nearly the whole of Section 29, there is a beautiful clear-water lake, called West Twin Lake. East and West Twin Lakes are separated by a strip of low land less than a quarter of a mile in width. There are said to be a few Indian mounds at different places near the east lake, but the informants were very indefinite in their descriptions and locations.

Upon the north shore of the west lake there are probably fifteen mounds, although this description appertains definitely to a group of eight, about the center, east and west, of the north bank (see Fig. 2). They are upon the SW. ¼ of the SE. ¼ of Section 20, land owned by Mr. Herman Lunden of Gaylord. The distance from the mounds, which are situated upon a level plain 30 feet above the lake at this point, to the crest of a gravelly declivity, which pitches abruptly down to the water, is 20 feet to the nearest and 80 feet to the farthest. From the first, or east mound, to the most westerly of the group the distance is 460 feet. The soil is gravelly sand. The plain upon which the mounds are situated is an open space overgrown with grasses, low shrubs and scattering jack pines. Formerly this territory was a heavily wooded pine forest.

Running along the bank of the lake, past the mounds, is a well-worn path now being trodden by fishermen and cows. Not many years ago it was followed by lumbermen. According to the statement of an old woodsman, who has lived in the vicinity from a time before the surrounding lands were lumbered, this path was as distinct as at present. It is, no doubt, the old trail of the Indians who walked the shore long ago, coming to visit the monuments of their dead and going from village to village. (See Pl. XIV, Fig.1.)

Upon the fourth day of June, 1927, accompanied by Professor C. W. Angell of the University Museum staff, the writer visited the location being described and began excavating Mound 2 at once. Four days were spent in digging, two to five men being employed at different times. Each mound will be described later in detail. The following table indicates the dimensions and relative situation of the mounds.

TABLE SHOWING SIZE AND POSITION OF MOUNDS

Mounds	Diameter in feet	Height in inches	Distance from "X"	Distance south of line* to center	Distance to lake
1	28	40	730	18	50
2	25	34	770	13	55
3	20	30	810	20	70
4	14	15	900	36	70
5	11	14	1190	50	80
6	8	13	1180	80	40
7	5	8	1185	100	20

* Line running N. 65° 15′ west from "X" in lower right-hand corner of the diagram.

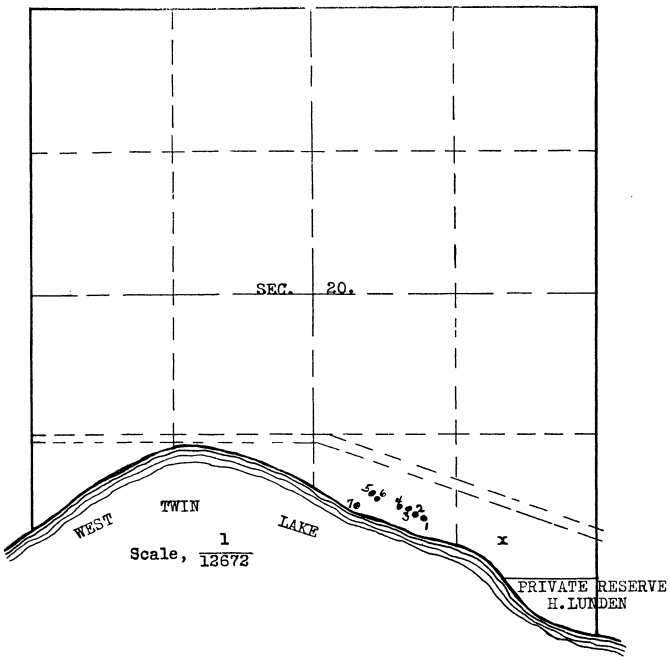

FIG. 2. Chart showing the location of seven Indian mounds on the property of Mr. Herman Lunden on the north shore of West Twin Lake, Montmorency County, Albert Township, Section 20. See table at top of p. 93.

While there are no data indicating which mound was built first, or whether they were all commenced at the same time, there was proof that the interments, above those deepest in the earth, were made at different times and that the soil was mounded up as later burials were made. In two or three mounds there had been three different times of burial; the first 2½ to 3 feet below the ground level, the second upon or a little above the ground level and above this second burial others but 12 inches from the top. One of the mounds contained six skeletons; all those examined, except a very small and low one, contained no less than three. Layers of two colors of sand and wide strata of charcoal and ashes were in every case found on top of the two lowest interments. The soil all through the mounds was interspersed with "fire stones," that is, stones that had been heated and cracked by contact with hot fires. Evidently earth had been placed upon the bodies to the thickness of several inches, and fires burned on top of this covering.

In some of the mounds, especially No. 6, the bodies had been deposited and "laid out" with great care. In others, bodies or bones had been "dumped" without any arrangement. A great many of the bones in the second stratum were evidently stripped of their flesh before being covered; sometimes the skeletons had been entombed entire and no doubt "in the flesh." The mixed-up bones indicated perhaps a communal burial. Such deposits are called ossuaries. While in half of the mounds there were evidences of fires having been kept burning for a long time, or at very numerous intervals, the thick layer of earth above the bodies had prevented any contact of the bones with heat; that is to say, there had been no cremation. It was the custom of many of the Algonquian tribes about the Great Lakes to keep fires burning for four days upon burial places.

Twenty-three skeletons, in whole or in part, were exhumed; very old persons, persons in full vigor, bones of men, women and children and one dog were taken from the six mounds excavated. Some of the lower jaws had lost all their teeth, others had full complements of perfectly sound teeth. Evidence of dental caries was frequent. In the jaws of the children the "second set" of teeth were in the stage of partial development below the primaries. Many of the bones crumbled at the slightest touch. Some had already become "mingled with the dust" except a few spiculae. Two or three skeletons were in excellent preservation. Those buried the deepest were the best preserved.

A peculiarity of the material in and of the mounds was the entire absence of any kind of artifact, except a few small perforated salt water shells and some knotted string in Mound 6 in which the skeletons of a woman, a child and a dog were found in immediate proximity. There was not so much as a flint flake or a hammer-stone discovered either in the earth shoveled and troweled over or upon the surface of the field. Probably, however, if the land upon which the mounds stand should be plowed, workshops and village sites would be found.

Mounds 1 and 2 (see Fig. 3) were the largest and were contiguous. It could be plainly discerned that the most of the earth entering into their construction was taken from neighboring depressions or wide pits. The others were surrounded by shallow but distinct trenches or moats from which the earth was taken mostly for making the bodies of the mounds. Pockets of very light-colored sand were interspersed with the "golden" sand that formed the main body of the works. This silvery sand, upon comparison with the sands of the lake, is conjectured to have been brought up the lake bank from the lake bottom. As stated, there were black bands through the mounds, of ashes, charcoal and fire stones, sometimes to the thickness of a foot.

The first question asked by the ordinary individual when constructions such as those being described are considered, is: "How old are they?" or, "When were the mounds made?" No one knows, although it is possible to approximate a time since which they were not made. Stumps of pine trees were upon the mounds. The annular rings indicate the growth of a hundred and fifty years; the trees which stood upon the stumps were cut forty years ago. The burials were made according to this computation at least two hundred years ago. If one could determine the rate of osseous degeneration or disintegration in soil of the character and situation of the mounds, he could be more definite, but chemists have no method of making such determination.

Several theories will account for the extensive fires that were kept up or frequently kindled over the lower parts of the mounds or where the mounds were later rounded up. One is that domestic activities were carried on there.

Sometimes bodies were buried under the dwelling and the place continued as a habitation. Again, as soon as a death occurred in the house, it was immediately destroyed and a domicile established elsewhere. For a statement of the behavior of Chippewas after a death, see *Kitchi-Gami* by J. G. Kohl, p. 106: "The lodge was immediately destroyed and dwellers sought refuge elsewhere after a death." It is also possible that some bodies were buried in the wigwam and that it was then set on fire. That would account for the wide ash and charcoal distribution across the entire base of the mound. If the fires were for cooking food, it would appear that there should occur such objects as pottery fragments and used and abandoned utensils. The little piles or circles of fire stones among the charcoal and ashes, would indicate, on the contrary, some purpose aside from mere bonfires.

FIG. 3. Mounds 1 and 2

It was the custom of some of the historic Indians to dispose temporarily of the bodies of their dead, so that the flesh would decay or be otherwise removed and the larger bones, at a later time, gathered and permanently buried. Mr. Bela Hubbard, *Memorials of a Half-Century*, p. 231, refers to this in his description of "The Great Mound at River Rouge." A village or community would assemble at certain places and hold a common funeral or festival of the dead, accompanied by loud and plaintive expression of sorrow and incantation. Upon such occasions feasting and dancing would continue to the limit of physical endurance. It might be that a kind of pyre was burned over the former burials before the later interments were made and covered up. That some of the fires were covered or smothered while burning is shown by the finding of large pieces of charred wood and bark under and mixed with the sand and gravel of the upper segments of the structure. The height of the mound would be increased by the thickness of the layers of charcoal, ashes and earth left and placed at these times upon the top of the old foundation.

Originally the mounds were much higher than after the winds and storms of many years had swept over them. The wear and tear of heaps of loose, sandy soil by the elements is very considerable. In many old Indian burial places bones and skeletons have been entirely exposed by the wind alone. I have noted this at Ossineke in Alpena County and at various other places near the shore of Lake Huron above Alpena.

The method of examining the mounds was, except in the case of Mound 2, to begin upon one side at the ground level and remove all the earth as progress was made toward the center. The undisturbed earth stood in a vertical face before the workers. As bones were exposed they were carefully dusted off around the edges for photographing and measurements. A trowel, a sharp-pointed stick, brushes and, in the absence of a sieve, a comb were used after the shovels were laid aside. A common "coarse comb" is an excellent tool for the raking over of earth supposed to contain small objects. After the mounds, except a narrow rim of the outside, were shoveled away, wide trenches were carefully sunk below the soil level, which in several of the examinations disclosed the most interesting interments.

Very much credit is due to Mr. Lunden, who owns the tract, for bringing to the attention of the Museum staff the existence of this group of well-preserved, undisturbed Indian antiquities which has, so far as the writer is informed, no equal within the state, except the group upon Grand River below the city of Grand Rapids. As soon as the excavations were finished, Mr. Lunden set to work to have the mounds restored to their original shape and to encourage the grasses, shrubs and "second growth," natural to the situation, to renew themselves so that the rains and winds will not do damage. It is Mr. Lunden's intention to have all the mounds upon his properties perfectly restored and reserved as parks.

DESCRIPTIONS OF MOUNDS

MOUND 1

Slightly oblong; longest diameter 28 feet; height 40 inches; distance from lake 50 feet. Large depressions near base, spaces from which earth was probably taken for construction. Depression in top of mound indicating that some time has elapsed since it had been "dug." This mound really touches Mound 2 upon west side of its base. Mounds 1 and 2 at base form a kind of figure 8 upon the ground surface. Was not excavated. See Fig. 3 and Plate XII, Fig. 1.

(A second examination of Mound 1 was made in August, 1928. A deposit of unusual artifacts was found which will be described and detailed in a subsequent report.)

MOUND 2

Slightly oblong; E. and W. diameter 34 feet; N. and S. 31 feet; height at center 42 inches. Wide shallow holes, as with Mound 2 close by, from which earth was probably taken for its construction. Depression in top, indication that some years since an attempt had been made to examine its contents. Trench 5 feet wide, 4 feet deep was dug through center. Two feet from top was uncovered a mass of bones in good preservation, placed indiscriminately. Lower, beneath a wide

mass of charcoal and ashes and a stratum of sand, were found large, long bones and fragments of skulls. One of the lower jaws was entirely devoid of teeth and the rami indicated that the teeth had been lost a long time before death; hence a jaw of an aged person. Masses of charred wood 10 inches long and 2 inches thick were found in the layer of ashes and charcoal. While this mound was "rich" in whole and fragmentary bones there was not a skeleton or skull intact. The burials had probably been communal, that is, deposits of bones and not of bodies, several persons contributing the osseous remnants of their dead after denudation of the soft parts had taken place. This condition is in striking contrast with that in Mound 5. See Fig. 6.

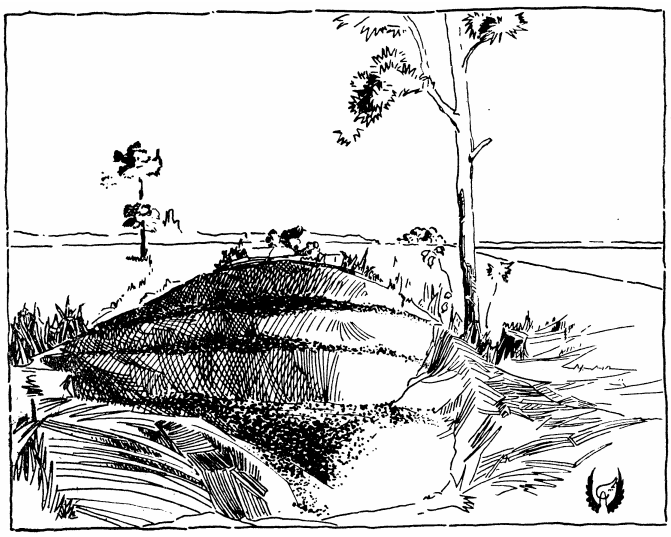

FIG. 4. Section of Mound 3, showing strata of charcoal, fire, stones and ashes

MOUND 3

Diameter 20 feet; height 30 inches; distance from lake 70 feet. Top of mound covered with humus; below, golden sand and lake wash. At different levels were strata of burned sand, mixed with ashes, charcoal and fire-cracked stones. Within 6 inches of the top there had been an intrusive burial of one person. Bones were in a disarranged emplacement. At a depth of 18 inches, and below the black band of ashes and charcoal, were two disarranged skeletons. Below these was a second black band similar to the one above. Five feet from the top of the mound and 2½ feet below the ground level were two skeletons lying side by side, N. and S. Just under these was a third with the skull towards the east and the body bent so that the legs of the three were all together, feet towards the N. The lower skull was in perfect condition with all the teeth sound and in place. Cross-section of mound shown in Figs. 4-5. See Plate XIII, Fig. 3; Plate XIV, Figs. 2-3.

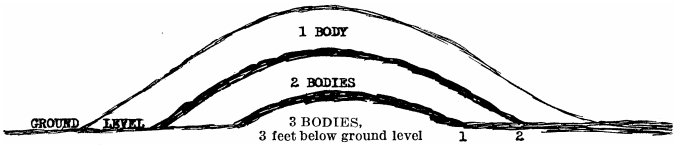

FIG. 5. Diagrammatic section of Mound 3. The lines designated by the numbers 1 and 2 represent strata of charcoal and ashes

MOUND 4

Diameter 14 feet; height 15 inches; distance from lake 70 feet. Soil in mound golden sand natural to the location. No evidences of fire or stratification. Twelve inches below the top were the broken skulls and larger bones of three individuals. No deeper burials. See Plate XII, Fig. 2.

MOUND 5

Diameter 11 feet; height 14 inches; distance from lake shore 80 feet. Mound surrounded by ditch 8 inches deep. Sixty inches from top of mound, or 47 inches from ground level, a complete skeleton was disclosed. Figure 6 shows the skeleton before a single bone was removed. All the bones of the body were recovered, even the hyoid. Teeth perfect. Length of skeleton as lying semiflexed, east and west, 54 inches. There was no evidence of fire in this mound, the mass of it being uniform in color and character.

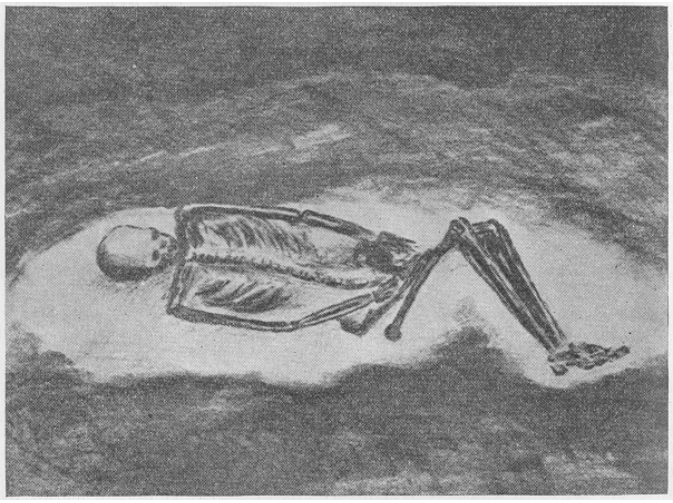

FIG. 6. Skeleton, undisturbed, in Mound 5, forty-six inches from ground level, sixty inches from crest of mound

MOUND 6

Diameter at base 8 feet; height 13 inches; distance from lake 40 feet. Forty inches below the natural level of the ground were partial skeletons of a woman, a child and a dog. Skulls were in condition to be distinctly identified. Many parts of body bones were too much disintegrated to permit skeletons to be secured entire. Woman's and child's skulls were touching, bodies lying side by side. Skeleton of dog lying diagonally across both bodies. Skull in close proximity to the child's left shoulder. Numerous cowrie shells embodied in a "hairy" mass of a probably decomposed skin bag and a piece or two of knotted string were under the child's lower jaw. Soil of mound sand, probably taken from surrounding ditch. No evidences of fire around the mound. Bodies lying east and west. Skull of dog illustrated to right in Plate XIII, Fig. 3.

MOUND 7

Diameter 5 feet; height 8 inches. Contained only very few fragments of child's skull and ribs. Rest of skeleton seemed to have disintegrated entirely. No evidences of charcoal or ashes.

MOUND 8

Location not indicated upon map. Surrounded by small clump of poplar trees. Contained thicker layers of charcoal than any other mound of the group. Under a layer of ashes and charcoal, 10 inches thick in one part, three skulls were found close together with a few leg, arm and pelvic bones, all badly disintegrated. Fifty inches from the crest and 24 inches from ground level was another similar deposit and in similar condition. Birch and jack pine bark in 8 inches of black soil was also found at about this depth. Some of the bones appeared to have been somewhat scorched but crumbled upon being examined. See Plate XII, Fig. 3; Plate XIII, Fig. 1.

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PLATE XII

FIG. 1. General view of field upon which mounds are situated. Mounds 1 and 2 and West Twin Lake in distance

FIG. 2. Workmen in Mound 4

FIG. 3. Examining Mound 8

PLATE XIII

FIG. 1. Excavating Mound 8

FIG. 2. Lower jaws of man, woman and child

FIG. 3. Human skulls (Mound 3) and skull of dog (Mound 6)

PLATE XIV

FIG. 1. Old Indian trail along Lake Bluff passing mounds in distance

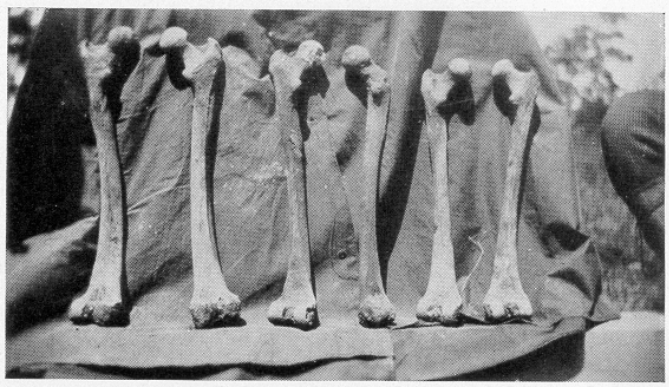


FIG. 2. Three pairs of femurs from Mound 3

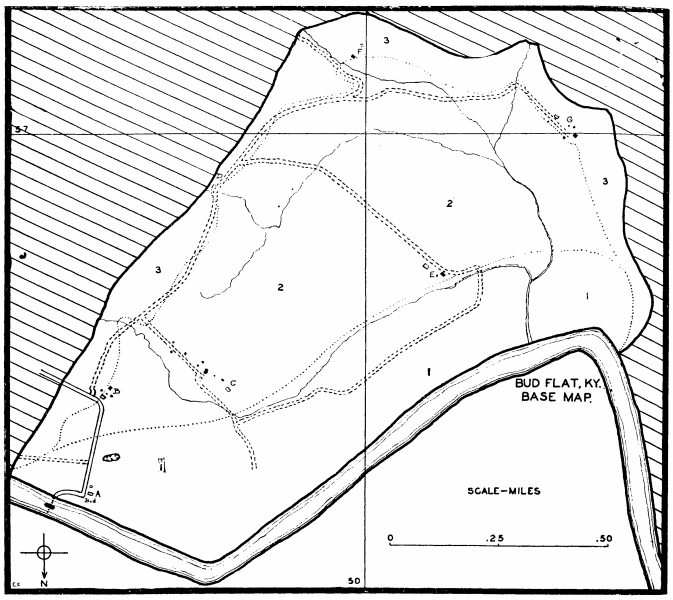
FIG. 3. Skulls from Mound 3

BUD FLAT AS A TYPE AREA OF THE RIVER FLATS ON THE CUMBERLAND

CHARLES V. V. CRITTENDEN

THE Cumberland River, the central drainage unit for this area, presents a placid picture during most of the year. Moderately large, with water opaque from brown suspended material, it gives the impression of flowing by at about the same ambling pace that the natives use in walking about. And yet on examination it proves that it has latent powers for work and fury. During late winter and early spring freshets, it rises to terrifying heights, inundating large parts of the river flats and doing much damage. The river is now in the early mature stage of incised meanders with typical features, always sharply undercutting on the outside and downstream side of its meanders and gently depositing a river flat behind it on the slip-off side of the spurs. Thus the valley through this area gives the general impression of being fairly steep-sided with a moderately wide level bottom; the river meanders from side to side, so that the bottom has the appearance of isolated scroll-shaped flats between which there is no easy land communication. There is one complication — the river at present is distinctly underfit. There are usually two fairly distinct river levels with their own features.

Some notion of the general features of Bud Flat may be gained from an inspection of the U. S. G. S. map (Monticello, Kentucky, Quadrangle) and the two detail maps: the base map and the relief map (Maps 2-3). On all sides, except the river side, the Flat is surrounded by steep-sided slopes, beyond which is the surrounding upland. These slopes are concave, not graded by soil creep, and at the bottom have an outflaring skirt — the colluvial base which slopes off gently to the flat bottom. The dotted line (on the base map) which encloses the area number 3 is approximately the boundary of this feature. The soils are exactly what the name implies, a scrambled mass of fine and coarse material, the offscourings from the steep slopes above.



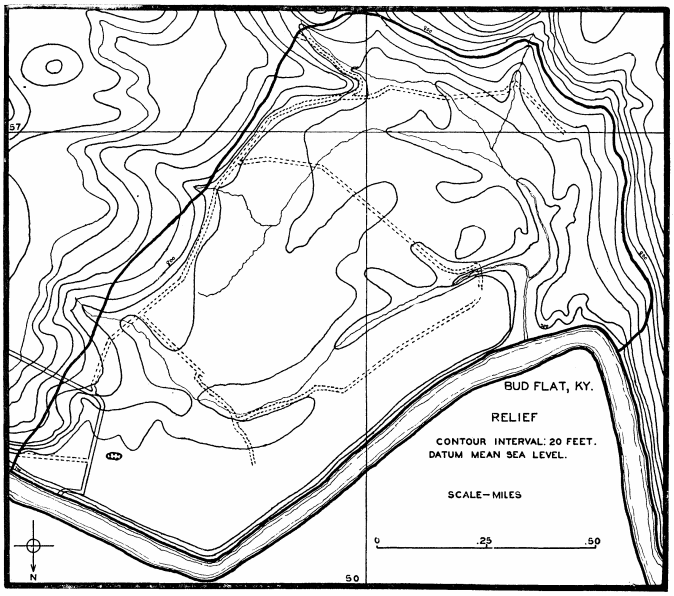
MAP 2

The Flat itself has two distinct levels, marked 1 and 2 on the base map. The upper and older (2) level was made at a time when the river was larger and more active. The soils here are sedimentary, but of quite coarse nature. Chert pebbles, the size of a man's thumb nail and larger, are mixed in with a coarse clay loam. The features of natural levee and back-marsh are only very indistinct. They have been about obliterated by surface erosion subsequently to the lowering of the river, and the back-marsh has tended to become filled in by the spreading out of the colluvial base.

It is on the more recent lower (1) level that sharper features appear. The bank of the river rises abruptly to a natural levee and slopes very gently back to the number 2 bottom. This would be back-marsh except for the rather complete drainage-system which has cut itself into the soft alluvium of both levels. The soils on this level are much finer. Fine sands are only partially held together by a small fine clay content.

There is a quite complete and rapid drainage-system for the Flat as a whole. Only in one place just south of the Bud store is the number 1 back-marsh poorly drained.

Most of the streams arise in sharp V-shaped gullies which are cutting back into the highland around the Flat. The easternmost stream flows across the upper level and then follows the lower level back-marsh, paralleling the river before joining the other stream and discharging into it over a miniature delta. This is very characteristic of tributaries in maturity. By inspection of the relief and land-use maps, some notion may be gained of the degree to which the two main streams have cut pronounced gullies in the Flat in their effort to reach down to their base level.



MAP 3

So far as can be ascertained, the natural vegetation always tended to be woods, mostly hardwood, but the land has long been cleared by man because of its relatively much higher value for agriculture than the land of surrounding areas. Of wild animal life there is consequently very little left.

Historically, Bud Flat has had a rather prosaic development. Its present name was bestowed upon it by the United States Postal authorities — a simple unmistakable name, not likely to be duplicated. But, to go back to the first real inhabitants, there is ample evidence of Indian occupation before the arrival of whites. On several low knolls on the number 2 level are remnants of what must have been Indian work-camps. Scattered flint stones, not naturally appearing in the soil, most of them worked chips, or partially finished or defective arrowheads and spearheads, are found scattered about in profusion. On a shelf in the steep slope to the south of Bud Flat was found a small mound, which, after laborious efforts on the part of an archaeologist, yielded a few specimens of broken pottery and charcoal at several levels. Undoubtedly it had been a ceremonial mound. The Indian has now almost entirely disappeared from this and surrounding areas.

After a careful effort to sift out what seemed to me to be doubtful embellishments, I offer the following as the history of the Conley family which now occupies the dominant position in the Flat. The great grandfather of the present middle-aged generation was the son of early migrants through the Appalachians. When he was still a boy, his father's place was raided by Indians, his mother was killed, his father driven away, and he himself taken captive. He lived with them until about the age of nineteen when he became dissatisfied and quit the Indian life. A year or so later he married the daughter of a white settler and acquired and began to clear up some land on Bud Flat. He prospered moderately and his sons a little better, the family gradually clearing up new land or acquiring land from less successful neighbors until the present Conleys occupy at least all of the better land of the Flat. Four of the seven families in the Flat and twenty of the twenty-nine present inhabitants are Conleys. The Conley farmsteads are marked *C*, *E*, and *G* on the base map, and the house and store marked A belong to one of the younger Conleys, who, having been injured in the World War, now manages the store and occupies quite an influential position with the people of the Flat and with the hill people from the north side of the river.

The one real intruder on the Flat occupies the farmstead marked *B*. He seems to have been a man of continual financial ups and downs who, finding himself up and one of the Conleys in financial difficulties, managed to purchase a moderate holding on the Flat. His chief occupation at present is speculation in hogs, buying them from outside, and fattening them on his corn and hillside pastures, and then selling them to the outside market. The present season seems to have cut down his profit considerably as a falling market caught him with several batches of hogs which he had purchased at a rather high price.

The house marked *D* is occupied by an elderly negro and his son and daughter-in-law. The son finds employment outside the Flat, while the old negro is a kind of tenant-retainer of the Conleys who works for meager shares in their farm produce. The farmstead marked *F* is occupied by an old man, his wife and daughter, who eke out a barely self-sufficient existence with one cow, a few chickens, and a hillside corn and vegetable patch. They really do not count as Flat dwellers, but are almost entirely characteristic of the average hill-dweller outside the flats.

The dwellings of these people, except for the one last mentioned and the negro tenant's house, are remarkably modern and well kept for this part of Kentucky. Painted on the outside and plastered on the inside, they form a sharp contrast to the hill people's homes. The furnishings, while not attractive, are complete. Around many houses there has been a definite effort to make the immediate yard somewhat attractive with grass and trees, and often the well or pump-house looks cheerful rather than ugly. During the middle part of the hot summer days the farmer and his family are often seen sitting in the shade in his dooryard, entertaining a neighbor who has strolled in. Even some of the smaller outbuildings near the houses have been cleaned up, but most of the outbuildings and all the barns are left unpainted although not unrepaired. The barns are of moderate size, with sharp, peaked roof, a small hay-mow above, and animal stalls and implement storage below. There are almost always several smaller buildings; one a combination work and junk storage shop; another a corn-crib; a small chicken coop; and farthest away, the pig shelters in which the general rule is to give only that amount of floor space which will allow the pigs to get crowded accommodations.

A word or two might be interesting concerning the store, a plain, dirty, poorly kept rectangular building set above the surface of the number 1 natural levee on piles to keep it out of the way of an ordinary spring flood. Nearly all other buildings are on the number 2 level to avoid the floods, but the store must be handy for the hill people across the river, and the owner lives next to it except in flood time. The interior of the store is a great mess: shoes and soap; groceries and sewing materials; boxes and rough counters; pop bottles and sacks of grain and flour. The completeness of the stock is astonishing if one can afford the time for observation. Business is transacted in the most leisurely manner. After the leisurely transaction, one is required by convention to stand around on the front steps and scatter any wrappings or containers that his merchandise may have been packed in, while he chats with other visitors to the store.

As the land around Bud Flat became settled and oil was discovered around Monticello, it was found that the easiest access to the river, the only good connection with outside areas, was the descent down the east slope of the Flat. Thus Bud became an important boat landing, and goods, both outgoing and incoming, were transshipped and temporarily stored here. The mails came by boat for distribution in the hinterland. But this has changed now. The Monticello-Burnside pike is passable through to the railroad at Burnside, which furnishes faster transportation. Bud Flat has very little contact with its surrounding country now, except that the mail comes down from Mill Springs. Commercially Bud still uses the river as its communication line. Young Conley at the store has a one-cylinder flatboat which takes out and brings in merchandise and supplies at the rapid rate of three or four miles an hour. Occasionally one of the puffing, stern-wheel steamers stops to take on or discharge a load of pigs from flatboats, which they always push instead of tow. It is most amusing to sit on the bank of the river in the northwest corner of the Flat, where one of the sharpest bends in the Cumberland occurs, and watch these steamers with one or two flatboats maneuver to make the bend. They back, go forward, puff and snort, ram the bank occasionally, members of the crew run about cussing, and there is a

general flurry until the trick is turned and the boat settles down to its loafing pace up or down stream.

There is only one automobile owned on the Flat and that is seldom used. The appearance of a car causes somewhat of a stir because it is only an occasional bold or reckless driver who attempts the road down from above or has any business in the Flat anyway. Buggies are seldom used. If you are going somewhere and do not care to walk, you ride a horse or perhaps take the team and family wagon.

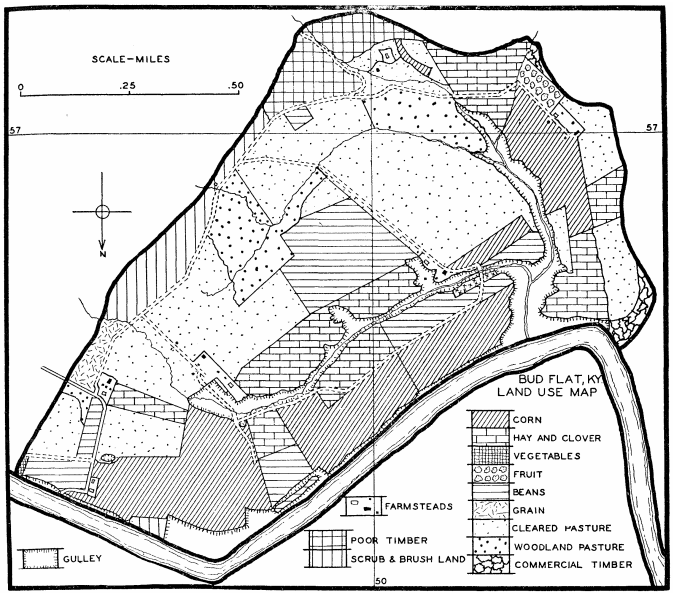
During the winter, logs are hauled down from the highland country to the top of the natural levee, to be rolled down to the river and hauled away by flatboats in the spring. This process is notoriously hard on the one road down to the Flat, as it chews up the surface of the road on the steep slopes and water erosion quickly changes the road to a gully. Very little effort seems to be made to correct this — it is hardly worth while for the small amount of traffic.

STATISTICS TAKEN FROM PLANIMETER READINGS ON LAND-USE MAP

1 square mile.....	3.626	Area Bud Flat....	3.555
Land cleared for agriculture.....			76.9%
Land directly in use for animal industry.....			73.7%
Land not directly in use for animal industry.....			6.3%
Land not cleared.....			23.1%
Commercial timber.....	.04	1.2%	
Woodland pasture.....	.21	5.9%	
Poor timber.....	.14	3.9%	23.1%
Scrub and brush land...	.13	3.6%	
Gully.....	.30	8.5%	
Fruit.....	.0175		
Grain.....	.03		1.1%
Vegetables.....	.002		
Corn.....	.70		20.0%
Beans.....	.316		8.9%
Cleared pasture.....	1.05		30.0%
Hay and clover.....	.44		12.9%
Roads, farmsteads, etc...	.14		4.0%
			100.0%

Thus we have an isolated area, isolated both from the upland and neighboring flats except by river. Conditions are such that the one occupation of the inhabitants must be agriculture. The soils are comparatively good and 76.9 per cent of the land is cleared. Practically all agricultural operations center around the animal industry because of the relative ease of transportation out to distant markets, and the greater value in the centers of population. The number 1 level is best suited for the raising of corn and beans because of ease of cultivation and they grow well here. Their dominance on this level is easily seen on the land-use map (Map 4). There is rotation of crops after a fashion, but none of that well-timed, carefully planned rotation which one finds in the corn belt. The corn and bean fields always look well cared for, and yet the farmer never exerts himself to keep them so. He works only during the cooler parts of the day, or on an occasional cloudy day. His two periods of greatest exertion come during haying time and when the spring floods wash out the fields which have already been seeded, which happens only occasionally.

Hay, usually in the form of seeded clover, is planted around the edges of the gullies or on the steeper slopes of the colluvial base where soil and surface conditions are not good for more intensive working. The yield is almost always quite heavy. It is partially stored in barn lofts, but mostly in round stacks with conical tops to shed the rain. There is almost never enough snow to keep animals from getting at it during the winter.



MAP 4

It is on the number 2 level and the colluvial base that the domestic animal industry proper appears. The number 2 level is dominantly cleared pasture with woodland pasture where the surface is rough. Here are pastured cattle primarily, with mules and horses for work purposes. The distinction between a work and a riding horse is never sharply drawn. The number 2 level then has only a few corn and bean fields on particularly flat advantageous locations and even then cannot compete with the lower level in production. The colluvial base is not much used for cultivation, but is mostly utilized for pasture, or left in poor timber with here and there a clearing used for hay or pasture. Hogs are allowed to run on the steep slopes and the surface of the ground is often littered with corn-cobs from the corn-fattening process.

What timber appears at all is second growth and never cared for as a wood lot. It is only on the upper part of the western edge of the colluvial base that there appear protrusions of the commercial timber which lies on the steep sides above.

The gullies of the two main streams and the abrupt river side slope of the number 1 natural level furnish a distinctly different landscape from the rest of the Flat. Steep slippery slopes are covered with a profusion of natural vegetation. Cane and brambles are so thick as to be almost impassable without the aid of an axe. The whole entanglement is heavily shaded by trees, usually maples, so that the ground seldom dries out and footing

is precarious. Domestic animals steer shy of such places. About the only use to which this land has ever been put has been the harvesting of sorghum cane, which, originally planted, now grows wild. In the northwest part of the Flat next to the gully may be seen a small field indicated by the symbol XXX. These are upright posts about four feet high on which are nailed horizontal crosses. Around these the harvested cane from the gullies is stacked in shock-like piles and left till winter when it is used as fodder, particularly for mules.

On the number 1 level scattered here and there in the cornfields may be found little vegetable and melon patches. They grow well and were Bud near an urban area the whole level would undoubtedly be used for vegetables — but there is no market for them. Fruit is almost entirely lacking. In addition to the few trees in the immediate yards of the farmsteads there is only one dilapidated orchard in the southwestern colluvial base. Grain is very seldom raised, for it has been found not to yield well and there is only a very meager local demand for it.

Bud Flat, one of the many flats in the Cumberland River Valley through this part of Kentucky, is an agricultural area and undoubtedly will remain so. Crops are grown mainly for food for animals, which is never an intensive type of agriculture. Because of its isolated location and slow commercial connections with outside markets, it will remain as it is until population pressure in the country as a whole demands that such areas be more intensively utilized. Life is easy-going and in comparison with that of their neighbors, quite prosperous. It would take the sudden discovery of valuable resources, such as minerals, to change the character of the life and the people and make this a land of hurry such as we find in the middle-western Great Lakes area. There are often rumors among the natives of proposed great water-power developments in the Cumberland River, but I think a thoughtful study of the country will convince one that this is destined to remain in much the same easy-going state of development that has been gradually brought about by the westward expansion of white settlers.

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THE ISLAND OF GONAVE: A STUDY IN KARST LANDSCAPE

ROBERT BURNETT HALL

THE island of Gonave, which has an area of some 300 square miles, is the largest of the outlying possessions of the Republic of Haiti. It lies midway between the two great peninsulas of the mainland in the Gulf of Gonave. Its population does not total more than 10,000, as compared with the island of Martinique, which has about the same area but supports a population which is nearly twenty times greater. Three factors are primarily responsible for the sparse settlement of Gonave. These are inaccessibility, historical background and paucity of water.

INACCESSIBILITY

The extreme inaccessibility of Gonave is due in part to its isolation and in part to the uninviting nature of its coasts. The island is not touched by the main agents of world commerce and must depend upon the irregular trips of small fishing and trading craft from the mainland. The coasts, for the most part, are fringed by an almost impenetrable mangrove barrier, which gives way to sterile saline flats and rocky hills covered with thorn forest (Pl. XV, Fig. 1). Mosquitoes, sand flies and giant chiggers occur in great numbers at different seasons. Offshore reefs and shallow waters make approach by large vessels impossible. In places, sea-cliffs, backed by steep and rocky slopes, occupy the coast.

HISTORICAL BACKGROUND

Partially as a result of its inaccessibility and partially owing to certain unfavorable aspects of the interior, the history of Gonave has differed from that of the main island.

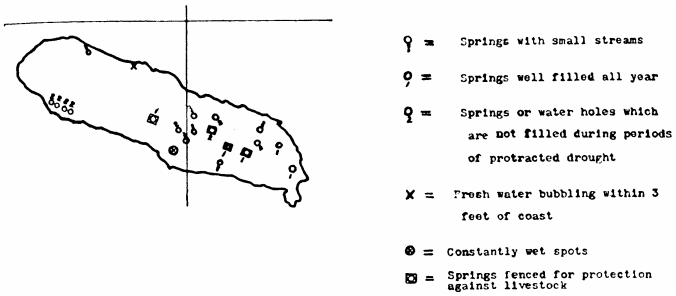
It appears that there was little if any Indian occupation of the island in pre-Columbian days. No artifacts of their culture have been found to date. Probably the island has been worked in more detail in this respect than any part of the mainland. The present military governor, Lt. F. E. Wirkus, who has located numerous sites upon the main island, has failed to find any trace upon Gonave during four years of diligent searching. However, as a result .of the murder of the Indian Queen Anacoana by the Spaniards, in 1504, many of her followers are said to have fled to Gonave from the mainland.[1] The Spaniards left the island unmolested and it would be safe to surmise, without documentary proof, that the Indians took refuge here as they did in other places the white man did not want. On the main island they hid in the high mountains and on the small island in Lake Enriquilo.

During the later Spanish and all through the French occupation, the population was increased by a second group of refugees. These were the "maroon" or runaway negro slaves. This would have included many persons who had been little affected by European contact. As we shall attempt to show, in another paper, the culture of the present-day population is even more dominantly African on the island of Gonave than it is on the mainland. How little the island was known in the days of the French Colony is shown by the fact that the otherwise well-informed Moreau de St. Mery[2] makes but one short and erroneous reference to it in his entire work on the colony.

After the establishment of the Republic, Gonave became the football of Haitian politicians. It has been let out from time to time on concession. The chief interest, at first,

was the exploitation of the timber in the interior sections. When this was gone the peasant farmers were made to furnish revenue. Taxation has been exorbitant and the agents sent by the concessionaires have made the burden still heavier by petty grafts. Partially as a result of this situation, there has grown up a group of semisecret, coöperative, agricultural societies called the Societe Congo. These organizations have found methods of combating the worst aspects of this exploitation.

Many of the present-day inhabitants have come to the island as refugees from the law of the mainland. Others came as wandering fisher folk and have settled down to a sedentary life where land is free and abundant. In recent years, there has been a steady immigration of landless peasants from the mainland. These have settled, for the most part, on that part of Gonave which lies nearest their former homes. In spite of the political situation, the people of the interior part of Gonave experience a higher standard of living than the average for rural dwellers on the main island. There, holdings are larger and there is a greater spirit of progress. The island of Gonave is Haiti's frontier.



MAP 5. Island of Gonave, showing water sources

WATER RESOURCES

The lack of water on Gonave is due to the low and erratic rainfall, rapid evaporation and the porous limestone strata which form the surface rock of the island. The average annual rainfall at the coast is estimated at about 25 inches and in the high interior at possibly 40 inches[3] (probably Koeppen's *Awi* type of climate). The departure from the average, in any one year, may equal the average figure. It is said that in the year of 1923 no rainfall occurred. In other years, the average is greatly exceeded.

The surface forms of Gonave are those of a karst country. Different portions of the island are in different stages of karst development. There are no through-flowing surface streams and there is only an occasional surface exposure of a karst stream in rainy weather. There are but two or three springs which carry water all the year. A half-dozen small springs carry water part of the year. An equal number of large water-holes have water in them during the greater part of normal years. At two points near the shore, fresh water bubbles up in the sea. These sources constitute the only supplies of water for domestic use and stock watering (Map 5).

GEOGNOSY AND LAND FORMS

The island of Gonave is an asymmetric anticline, the crest of which plunges in both directions from its apex,[4] the Morne Chein Content. A radial system of solution valleys can be identified, conforming to the main structure of the island. The surface rock is of porous limestone throughout and the land forms of the island are all of karst types, except at the sea's edge.

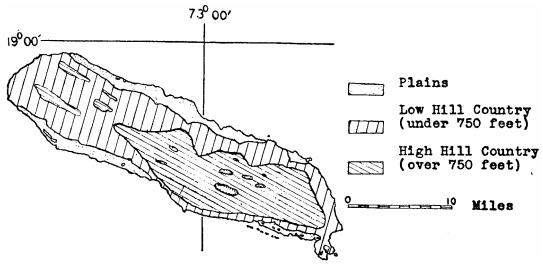
Three types of land surface can be recognized. The distribution of these types corresponds with the three landscape types of the island. The names for the divisions used here are taken from place names on the island about which the particular landscape type in question is characteristically developed.

THE PLAINE MAPOUX

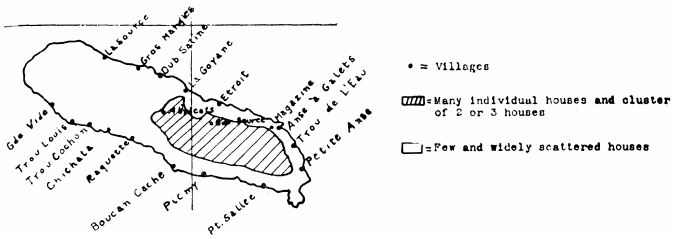
This type is confined to the vicinity about the apex of the anticlinal crest. It is the most elevated area on the island (Map 6) and, in consequence, receives the heaviest rainfall. Here the greatest amount of strain took place, resulting in more intimate and better developed fractures; also the bottom of the soluble limestones is highest above sea-level. As a result the development of land and drainage forms has been the most rapid. This area is now in the late mature stage of karst development.[5] In valley and sink bottoms the underlying insoluble metamorphic rock is but thinly covered with rubble and soil. In at least two places it is completely exposed. Solution features can no longer deepen and karst forms are in the process of decadence. A number of large uvalas are found. The Mapoux Plain is the largest feature of this type on the island and also the most elevated (1800 feet). Its encircling limestone walls rise seven to eight hundred feet above the floor. The floor slopes gradually from the sides toward the center and is covered with a thin layer of coarse, reddish soil material. The lowest or middle portion is permanently in swamp. Temporary springs occur along the edges of the uvalas and in the solution valleys and larger sinks. The two larger permanent springs of the island occur in this district, as do the more important water-holes (Pl. XV, Fig. 2).

This division is the most populated and productive on the island (Map 7). The amount of water available, everywhere on the island, determines the distribution and the density of population. In this area more ground water is available than elsewhere and also the rainfall is the greatest. The largest sinks are found here with their flat bottoms of moist, deep, soil material. Dwellings and crop lands occur in concentric circles about the supplies of water, their density becoming less with distance, finally disappearing at about the ten-mile zone. This distance seems to be the maximum of one day's travel. The crops of this area are commonly of types

demanding more moisture than the crops found elsewhere on the island. Yams, congo beans, malanga, and castor beans are among the most common crops of the valley floors and sink bottoms. Plantains are grown on the colluvial bases of the limestone cliffs, where a seepage occurs. Plantains and maize occupy the moist ground near the centers of the uvalas.



MAP 6. Island of Gonave, showing land surface



MAP 7. Island of Gonave, showing distribution of population

Habitations in this area are of the permanent type. The walls are plastered and the dwelling unit is composed of three huts. The largest one is for family occupation, a slightly smaller structure, without windows, is the store house, and the third has but three walls and serves as a kitchen.

THE PLATEAUX TYPE

This type lies just below the area discussed above. The major areas are confined to the north and northeast parts of the island. This type may be described as in the early mature stage of karst development. Here the usually dry valleys contain surface streams for a brief period following heavy rains. Uvalas are small and numerous. Many sink holes occur on the intervening uplands and are found in large numbers on the valley floors. They are of the doline type and are filled with reddish sandy and silty material. In fact, the term "mantled" karst is suggested for this kind of country, as is the term "naked" karst for areas with little or no soil cover. The limestones at these lower levels are of Miocene age and are less pure than the Eocene which constitutes the surface rock of the Mapoux Plain district. The impurities remain on the surface as soil material and tend to round off the natural karst lines. Also, the impurities from higher levels lodge here for a while on their way to the sea. Springs and water-holes are small, scattered, and temporary in nature.

The population of this area is sparse and the land which was once forested is now overgrown with tall grass and brush. Temporary settlement and milpa agriculture are the common forms of occupation. Rainfall is less, so that crops are chiefly of drought-resistant varieties. Cotton, *petit mil* (a non-saccharine grain sorghum) and cassava are the main crops.

Nearer the sea, the rainfall is very low and the porous limestone rock extends below sea-level. The discharge of subterranean streams is not possible in some places. The impure materials from upper levels have in places accumulated to considerable depths. The dolines are small and very shallow. The solution valleys are not deep and their floors are covered with sand and rubble. Small surface streams are numerous during and immediately after periods of rain.

The land is covered, for the most part, with thorn forest and is highly unproductive. A little cotton and *petit mil* are grown in the more favored areas. Goats and very thin hogs are grazed in the thorn forest. Charcoal is made and sold to more favored portions of the island. The supplies of water used are often brought by boat to the nearest point on the coast.

THE ANSE À GALETS TYPE

These are the districts where alluvial deposits have been laid upon the slightly submerged sea bottom fringing the island. A few feet beyond the land's edge a mangrove thicket presents a barrier to approach by sea. In some places, this extends unbroken. In others, where the configuration of the shore-line allows an active wave action, there are openings and small crescentic sand beaches occur. Behind the mangrove, a sterile and desolate saline flat stretches, in places, a quarter of a mile or more to the beginnings of the thorn forest. The first stunted trees of this forest occupy the highly alkaline soils of the inner alluvial plain. This portion is about equal in width to the saline flat and slopes gently seaward.

There are two sites of human occupation occurring in this landscape type. The most common is the crescentic sand beach. Here squalid fishing villages composed of unplastered wattle huts have been built to take advantage of the opening through the mangrove and the dry sand of the beach. The inhabitants of these sites depend upon the land and the sea for their sustenance. Fishing among the offshore reefs, gathering conch from the shallow sea-floor and oysters from the roots of the mangrove trees, and planting tiny gardens on the upper slopes of the rocky hills behind the village allow them a meager existence. Some few do occasional trading with the mainland and now and then a boat builder's establishment is seen. Fresh water is brought in by boat from distant points on the island and sometimes even from the mainland. The mangrove furnishes shelter for the flat-bottomed fishing boats.

The other type of coastal site occurs just behind the saline flat where conditions are more healthy and where water can be secured for part of the year from water-

holes or temporary springs. Most sites of this type are on the side of one of the radial karst valleys, down which the trade from the interior usually comes. These people combine farming with trading. The huts are more commonly plastered than those at the sea's edge, which tells of a more permanent nature of abode.

UNIVERSITY OF MICHIGAN

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[2] Moreau de St. Mery, M. L. E., *Description topographique, civile, politique et historique de la partie française de l'isle Saint-Domingue* (Philadelphia, 1787-1798), Vol. II, p. 527 f.

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[5] Cvijić, Jo van, " Hydrographie souterraine et évolution morphologique du Karst," *Recueil des Travaux de l'Institut de Géographic Alpine* (Grenoble, 1918), Vol. 6, pp. 375-426.

PLATE XV

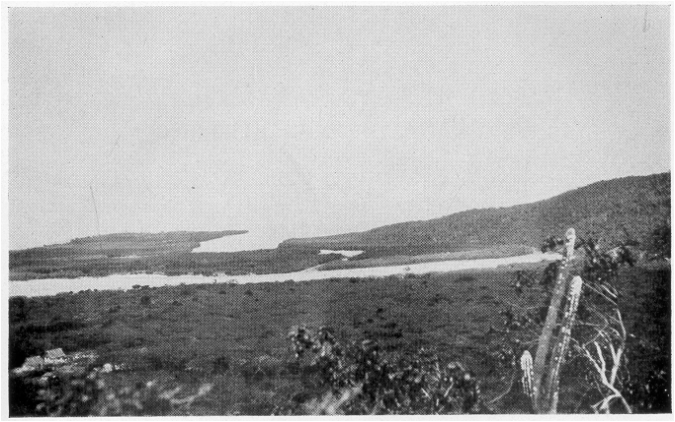

FIG. 1. The mangrove barrier, the saline flat, and the thorn forest of the upper alluvial plain at Anse à Galets

FIG. 2. The spring of Grand Source. Gourds (seen in the foreground) are the universal water-containers of Gonave. They are cut from the trees when large enough to hold approximately one gallon

SOIL TYPE AS A FACTOR IN HIGHWAY CONSTRUCTION IN MICHIGAN

CHARLES E. KELLOGG

HIGHWAY engineers have always recognized that certain soil conditions such as external drainage, land surface, and texture of the surface soil must be considered in subgrade designs. Until recently, however, none have felt the necessity of studying the fundamental characteristics of the soil and their influence upon the construction and durability of highways. Many of our highways are surfaced with gravel, macadam, and similar metals, in which the damage caused by settling, heaving and "frost boils" can be rather easily repaired. With the advent, however, of the hard-surfaced roadways, constituted to meet the demands of tremendous increases in traffic on certain of our main trunk lines and near our large commercial centers, the problem has changed. Engineers find that damaged pavements are not so easily repaired and are often a total loss. With the cost of modern paved highways ranging from $25,000 to $40,000 per mile, or even more in certain places, it is obvious that frequent replacement and repair are costly.

Because of these developments in highway construction engineers have recently begun to realize that a careful consideration of the subgrade material is essential. During the past six years, Terzaghi, workers in the Bureau of Public Roads, and others have proposed various physical "tests" for subgrade soils with the primary object of evaluating soil characteristics that appear to exert an influence on the pavement. A classification of soils has been proposed on the basis of some of these physical tests.[1] Most of these workers have completely ignored the profile character of the soil. If these physical tests are accurate, where in the soil profile should the samples be taken? Soils have several horizons of widely varying physical character and often, as in the case of Ottawa, Allendale, Ogemaw and other soil series, both extremes in texture — loose, open sand and impervious clay — are represented in the profile. In Figure 8 are illustrated typical profiles of four widely distributed Michigan soil series. It seems obvious that a soil classification based on any one or two physical characteristics is practically worthless in the study of soils as they exist in their natural condition. Physical tests are very useful in studying the different horizons in each profile and aid us in perfecting the soil classification; but in studying such problems as moisture-holding capacity, shrinkage, expansion due to freezing, and other physical phenomena, we must consider the soil as a whole.

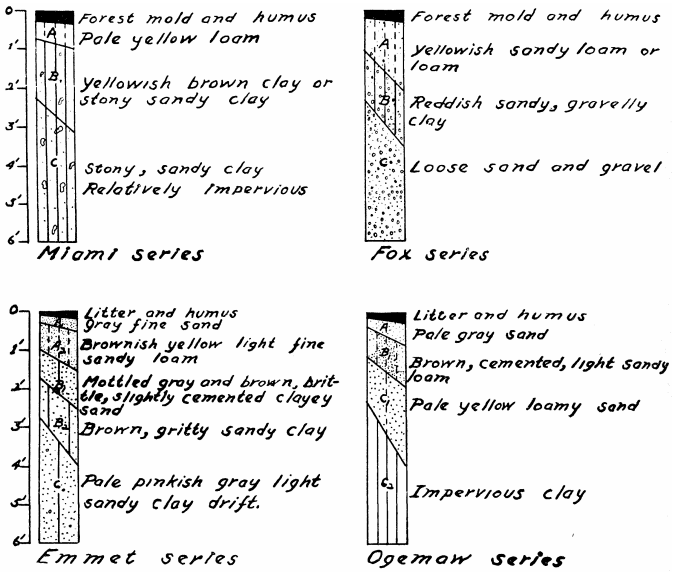

FIG. 8. Typical profiles of four Michigan soils

There are three general methods by which we may study the relation between soils and pavements: (1) by studies entirely in the laboratory, the utility of which we have already criticized; (2) by setting up a test road and observing the results, a method that is very costly and gives us data for that particular location only; (3) by a combined field and laboratory method. This last method of attack is being attempted in Michigan by the State Highway Department. It has been used to some extent in Pennsylvania and California, and Rose, of the Bureau of Public Roads, realized its possibilities.[2]

Briefly, the method used in Michigan is as follows: A chaining party of two men marks and numbers stations on the pavement at 100-foot intervals. These numbers correspond with those of the plans for construction. An engineer, familiar with pavement design and construction, maps to scale all cracks and imperfections in the pavement. Using the same station numbers for location, a soil surveyor maps the soil types on a scale of one inch to two hundred feet. The soil types recognized are in accordance with those of the U. S. Bureau of Soils and Chemistry and the Michigan Agricultural Experiment Station; but of course the scale employed allows mapping in greater detail than the regular soil survey for agricultural purposes. Further, the vertical position of the pavement in the natural soil profile is sketched, showing upon which horizon the pavement rests. Several type samples are taken by horizon and sent to the engineering laboratory for mechanical analysis and other laboratory tests. The location where the sample is taken and all observations with regard to the soil and the pavement are carefully noted. In addition, special studies are made at all places where the pavement is damaged and additional samples are collected where some special feature seems to justify it.

It is planned to place the sketch map of the engineer and the soil map on the original construction plans in order that the relationship between the soil, the type of construction, and the condition of the pavement may be studied. The soil horizons will also be sketched on the profile drawings of the plans. The number of cracks, the size of the pieces, and similar data are all tabulated for each location. The laboratory tests give us information in regard to the physical properties of the different horizons and aid in the perfection of the classification.

As a final result it would seem that from these data we shall be able to predict what type of pavement and subgrade construction will be the most satisfactory for the soil type in question. The matter is not quite so simple, however; several factors come into play which profoundly influence the effect of the soil. Some of these are: the area of the water-shed, the horizon of the profile on which the pavement rests, the character of the 'C' horizon below that depth commonly included in the soil profile, the angle of gradient, the height of the water table at different seasons, the snow covering, the depth of the soil above bed-rock, and any other factors which may have an influence on the water relations of the soil. Thus for the same reason that we cannot classify soils without considering all their characteristics, we cannot propose a logical pavement or subgrade design without taking all factors into consideration.

Frost action is by far the most outstanding problem in sub-grade studies in Michigan. So far two general types of freezing have been observed: (1) that which occurs suddenly during the freezing and thawing weather of late winter; and (2) freezing which begins in the early winter and steadily increases. It must not be assumed that these are always definite, perfectly separable phenomena, for the two types are probably more often associated than alone.

Little definite information is at hand, but from general observations and some studies of frost heaves we can present what seems to be a logical explanation of the sudden freezing which occurs during late winter and early spring. As the cold weather begins a certain amount of freezing occurs. As the pavement is a better conductor of heat than the shoulders, freezing is deeper under the slab. In late winter we find most of the snow piled up on the shoulders, leaving the pavement exposed. A little warm weather comes, and thawing begins just under the pavement. Additional water may also be supplied from melting ice and snow. On the grades the water flows under the pavement and accumulates farther down the slope. As the air temperature falls, the temperature of this pocket of water under the pavement falls quite uniformly and freezes suddenly, heaving and breaking the pavement (Fig. 9). Great damage usually results from this type of freezing. It is now hoped that by the use of lateral drainage structures and the removal of the snow from the shoulders as well as from the pavement, we may be able to correct this condition, but in some places more elaborate drainage provisions must be made than are now being used.

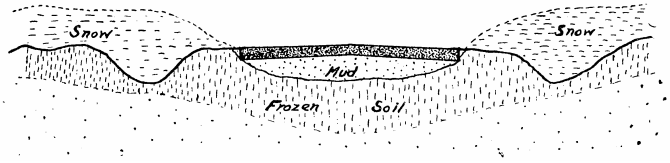

FIG. 9. Cross-section of grade in late winter as thawing begins

The freezing which occurs throughout the winter is not very well understood. The amount of heaving depends, of course, upon the amount of freezable water present, but, as we have seen already, a great many factors come into play. At first we might assume the pressure exerted to be due simply to expansion of the soil when frozen. By the use of specially constructed apparatus for measuring the volumetric expansion of moist soil upon freezing, the writer has studied the expansion of various soils at different contents of moisture. The results indicate that only a small fraction of the heaving during freezing weather can be accounted for in this way, even with soils completely saturated with water. We know that, no matter how dry the surface soil may be when it freezes, it is invariably wet when it thaws. Furthermore, when weights are placed on the ground before freezing and removed after the ground has frozen we observe crystals of pure ice between the weights and the ground surface. This is especially noticeable in, heavy soils. Bouyoucos[3] has suggested that the ice crystals form in the larger spaces, pulling the water from the small capillaries and causing an upward movement of water which eventually freezes near the surface. The work of Lebedeff[4] and others shows that there is considerable movement of water in the form of vapor, as would be expected where large differences in temperature exist within short distances. It is probable that both forms of movement contribute to the accumulation of water near the surface. Some water is probably supplied from the surface, but yet the amount of heaving seems to be quite independent of the precipitation at the time heaving takes place.

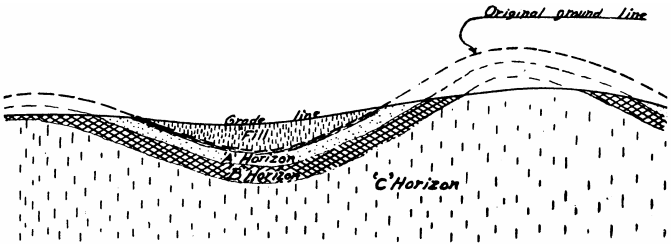

FIG. 10. Longitudinal section of typical grade showing how the pavement crosses the soil horizons in a rolling country

We know that clay holds a large part of its moisture in a combined state that does not permit freezing; thus, with equivalent total amounts of water, silts and sands expand more upon freezing than do clays. Further, clays tend to impede the movement of water more than sands. We often find our greatest damage from frost action in situations where the pavement lies on a poorly drained sand, especially fine sands or silty fine sands.

Soils as encountered in the field are very seldom uniform, and the subgrade is especially variable where we go from cut to fill as is the case in a rolling country. It has already been pointed out that soil horizons vary greatly in their physical properties. In going from cut to fill the pavement crosses these soil horizons, as is illustrated in Figure 10. As a result, in freezing weather we have large variations in the amount of heaving and the pavement is bound to be damaged by the unequal pressures. This type of damage is prevalent in most of the rolling, till plain areas studied where such soils as the Onoway, Miami, Napanee and Isabella series occur.[5] Often we find that in certain soils where deep cuts are made the 'C' horizon may be stratified in such a way as to give us the same effect that we observe in the soil profile. Several soils, such as the Allendale, Ogemaw, Ottawa and Berrien series, are developed upon formations consisting of sandy material, often wind-blown, lying over impervious clay. It is obvious that cuts in soils of this type are especially likely to give trouble.

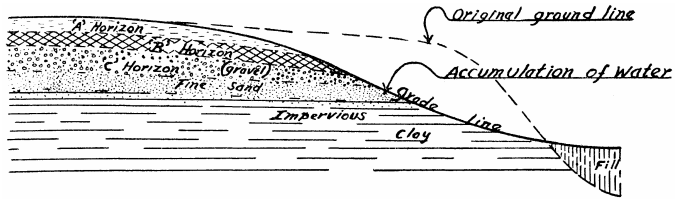

FIG. 11. Longitudinal section of grade, sketched from observations east of Brighton on U. S. Highway 16

Many cases have been called to our attention where a heavy clay layer or other impervious structure may prevent drainage and give rise to an accumulation of water. This may be a zone of clay concentration ('B' horizon of certain soils), bed-rock, or some other stratigraphic feature. Figure 12 shows how this may be effective in a cut on a side hill. This diagram is drawn from observations on a location east of Brighton on U. S. Highway 16. In this case the 'B' horizon of the Fox loam serves to prevent free drainage and seepage water is allowed to accumulate under the pavement. Figure 11 illustrates a condition existing on the same road. An impervious clay layer is overlain by layers of silt, fine sand and gravel. All these layers are crossed by the pavement and considerable damage has resulted.

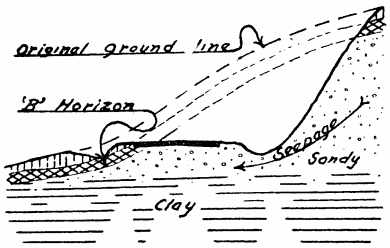

FIG. 12. Cross-section of grade showing how the 'B' horizon may be a factor in preventing drainage in a side-hill cut

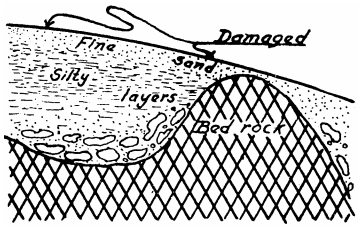

FIG. 13. Longitudinal section of grade. This condition exists on U. S. Highway 41, between Marquette and Negaunee

Crystalline rock may prevent drainage and give rise to an accumulation of water under the pavement (Fig. 13). This condition was observed on U. S. Highway 41 between Marquette and Negaunee. The pavement through St. Ignace on U. S. Highway 31 lies directly on the limestone in several places and the rock is close to the pavement elsewhere, yet no damage had been observed from this cause. This difference has been found to be significant. In the limestone rocks the breaks and fissures in the rock seem to afford sufficient drainage.

Another serious condition arises in the low, flat, sandy areas where drainage is impractical or impossible. For example, just south of Alpena on U. S. Highway 23 there is a low-lying sandy plain which has a high water table. The soils developed are all very sandy.[6] Because of the proximity to the lake, drainage is practically impossible. Owing to the comparatively even topography, little grading was done. As a result, the pavement rests just above a saturated sandy soil, especially during the winter and spring freezing weather. Much heaving has occurred and only the uniformity of the soil has saved large strips of pavement from complete destruction. The only effective method now known to remedy this situation is to elevate the grade sufficiently, so that the pavement is well above the water table.

Not only do we have sharp contrasts when crossing the horizons of one soil type, but also when crossing the borderland between types. If we take, for example, the Miami series, we find several variations from the typical (if we may use the term "typical" in the sense of "average"). In many places we have found the typical Miami profile to be underlain by fine sand at depths of four to fifteen feet. This same condition has been observed in the Isabella series. The effect of these various conditions is sometimes beneficial and sometimes harmful. In cuts where the Miami profile is underlain by pervious sand, no drainage structures may be needed, while in the typical Miami elaborate structures may be necessary to prevent frost action. Near Novi on U. S. Highway 16 there is a typical Miami profile underlain at considerable depth by an impervious, slate-colored, sandy clay that was probably laid down in a previous glacial period. Between these two heavy materials is a layer of sand in which water may accumulate. The pavement is ruined where it crosses these layers in a cut.

These few examples herein presented will serve to show the great importance of soil studies in planning proposed highways. Where it is possible, the route chosen for a concrete pavement may be selected according to the types of soil, after previous observations have shown which types are best suited for subgrades. Where the route has been established, a detailed soil survey will give information as to what situations will be encountered and the designs may be made accordingly. It cannot be expected, however, that definite rules can be established for each type and followed blindly. Each location will have its own peculiarities. These individual cases must be studied in the field by men whose knowledge of the general relationships give them sufficient background for judgment. It is believed that a more careful consideration of soil character will aid in the perfection of better subgrade design and lead to the construction of highways of greater durability.

MICHIGAN STATE HIGHWAY DEPARTMENT

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[2] Rose, A. C., "The Present Status of Subgrade Studies," *Public Roads* 6:137. 1925.

[3] Bouyoucos, G. J., "Movement of Soil Moisture from Small Capillaries to the Large Capillaries of the Soil upon Freezing," *Journ. Agr. Research*, 24 (No. 5): 427. 1923.

[4] Lebedeff, A. F., "Die Bewegung des Wassers im Boden und im Untergrund," *Zeit. Pflanz. Dung*., B. 10, s. 1-36. 1927.

[5] See Figure 8 for the profile of the Miami series. Onoway, Napanee and Isabella are quite similar in physical condition, except that the Napanee series is considerably heavier.

[6] The soils were recognized as types of the Saugatuck, Newton and Eastport series.

GEOGRAPHY OF THE SOILS OF SCOTLAND*

JETHRO OTTO VEATCH

SCOTLAND is rich in historic and scenic interest and its people and institutions have exerted a widespread influence upon civilization. There is a voluminous literature dealing with the country and the people. Aside from poetry, novels and general literature, there are numerous scientific publications on the physical features and scenery, the geology, the botany, the zoology, the climate, and the agriculture, and many of these publications are classics. But, as is true of most other countries also, there has been relatively little published about soils per se, that is, from the purely pedologic viewpoint. Since, however, civilized agriculture has been carried on in Scotland for several hundred years and in some parts of the country has reached a high stage of development, some reference to soils in agricultural investigations and in geographic descriptions could scarcely be avoided. But it appears that the soil has been generally described in terms of its environment rather upon the basis of systematic

classification and upon the intrinsic characteristics of the soil itself. References to geographic distribution of soils have been made upon the basis of the distribution of the old geologic formations or upon the glacial drift overlying them; or in relation to natural features, as "heather soils," "moor soils," "carse soils," "Lowland soils," "Highland soils," etc. Comparisons have been made in terms of productivity under existing agricultural practices, while the laboratory studies of soils have been pretty largely confined to plow soil, or to land under cultivation, and with reference to some particular farm crop or agronomic problem, rather than in relation to profile and taxonomic type. In these statements no disparagement is intended inasmuch as this condition has obtained throughout the world, at least until very recently.

It is the purpose here to describe briefly, and in a tentative way, the soils of Scotland, according to their regional characteristics and the distribution of broad taxonomic groups, rather than to present a technical paper based upon details of chemical and physical studies of samples in the laboratory. The paper, therefore, is essentially geographic in nature as well as pedologic. The observations presented were made during my appointment, in 1925, by the International Board of Education of America, for the purpose of conducting studies in soil classification in cooperation with the three national agricultural colleges of Scotland located at Edinburgh, Glasgow and Aberdeen.[1]

SOILS, GENERAL CHARACTER

The soils are not as homogeneous or uniform as one might infer knowing the small size of the country, a total area of only 29,796 square miles of land surface, and its relatively small extent, an extreme of only 274 miles of latitude including the outermost island. There are at least three families, or subfamilies, of soils and a very great number of types based upon differences in texture and other physical and chemical peculiarities. All the great classes of soils are represented: (1) common mineral soils (Communisols); (2) organic soils (Plantasols); (3) rock soils (Lithosols); and (4) water soils (Hydrosols). There is a range from tundra-like and the barren rock soils of high mountains, through peaty moor soils to something approaching the character of the "gray-brown" forest soils of the glaciated region of northern United States, but without as completely a developed soil profile. The textural classes, sands, sandy loams, loams, silt loams, clay loams and clays are all represented, and, excluding the peat covering, textural and other wide variations may be observed within short horizontal distances. The impression gained from extensive observation is that sand textures are relatively small in the aggregate of arable land, and that loams are perhaps most common. A surface soil of peat or peaty mold under natural conditions, and excessive stoniness are perhaps most generally characteristic.

There is no evidence of either a conspicuous amount of leaching, or on the other hand of enrichment, of parent or underlying inorganic geologic material such for example as may be observed in the mature profiles of the "yellow" forest soils of warm temperate humid regions and the black and brown soils of sub-humid and arid regions like those of the Central Mississippi Valley and the Great Plains of the United States. The chemical composition, therefore, may be expected to be essentially that of the underlying glacial drift, if the superficial covering of peat in virgin soils and the highly artificial plow soils are excluded. Since there is a wide range in the lithologic nature of the rocks and drift, corresponding differences in the ultimate chemical analysis may also be expected. The inferred chemical changes which have taken, place through soil-forming processes are those due primarily to waterlogging. Otherwise there has been some staining due to infiltration of humic compounds, and a very minor amount of leaching. The deep peat deposits and peaty covering of virgin soils may be expected to exhibit the peculiarities common to this class, namely, relatively high nitrogen and carbon and relatively low amounts of inorganic constituents. Upon the basis of field tests it appears that these organic soils are likely to be generally highly acid.

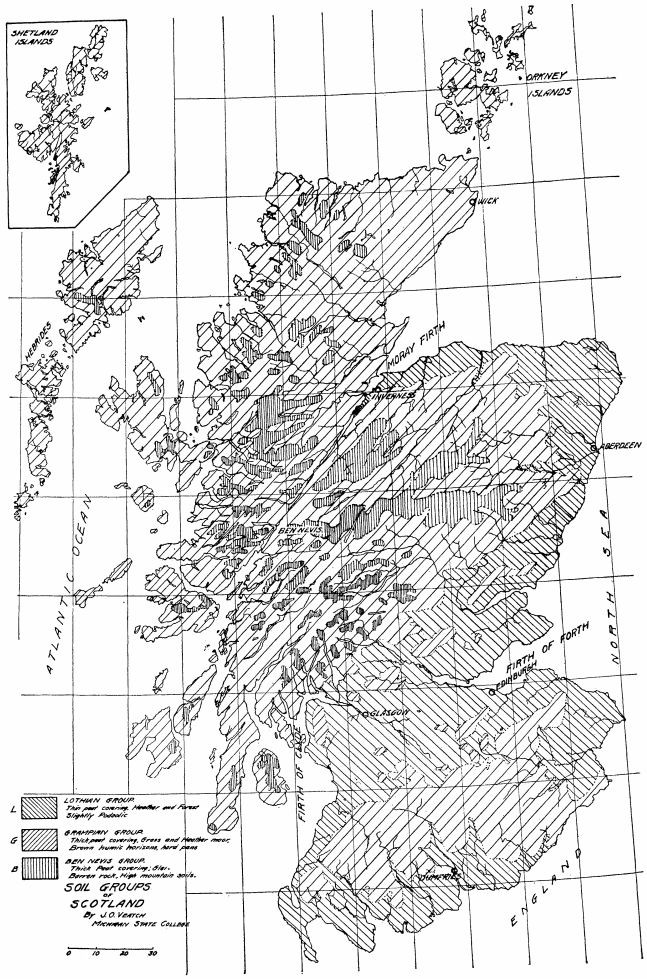
In general, the soils can hardly be regarded as "poor" in the sense that there is a deficiency in the total amounts of so-called essential inorganic elements, although most of the land is "poor" in an agricultural sense, because of excessive moisture and coldness of soil, extreme stoniness and small thickness of detrital matter over hard bed rock, or because of a thick covering of peat. As is well known, much of the land could not be utilized for cultivated crops, even if the soil were cultivable, because of adverse climatic conditions.

The distinctive pedologic process has been the concatenate accumulation of a peaty surface covering, the reduction of inorganic matter underlying, and the development of "ortstein" and subsurface humic horizons; this in contradistinction to leaching and accumulation of clay-colloid horizons in temperate regions; lateritization in the tropics; and the formation of carbonate horizons and alkalization in semi-arid and arid regions. Were the land surface without marked relief, it would be composed entirely of vast bogs and dreary moors, under the climatic conditions prevailing. Accumulation of peat is rapid, especially accretion in thickness and area of bogs, so much so that it has been destructive in places and has completely buried pine forests. Destructive erosion has been a counteractive force to excessive accumulation, and elsewhere the slope of the land, in conjunction with pervious substrata, has permitted subsurface drainage, thus lessening the amount of water held and retarding peat accumulation.

TAXONOMIC GROUPS

The soils in general are podsolic, in the respect that at least some evidence of leaching, although generally minor, is present beneath the peat or peaty mold, where

a climax profile is developed. There appears, however, to be no true forest Podsol, and nothing which is precisely the same as the "gray-brown" and "Braunerde" forest soils of the United States and continental Europe. At high altitudes there is probably something not greatly unlike "Tundraboden" in that the drift or rock underlying the mossy and peaty covering is simply bleached or simply stained by iron compounds, but here there is no permanently frozen ground. There is a resemblance to published descriptions of "Moorboden" of northern Europe, but here again the climatic conditions and consequently the profile are perhaps not precisely the same.



MAP 8. Showing soil groups of Scotland

L (Lothian Group). Thin peat covering. Heather and forest. Slightly podsolic
G (Grampian Group). Thick peat covering. Grass and heather moor. Brown humic horizons, hard-pans
B (Ben Nevis Group). Thick peat covering. Glei. Barren rock, high mountain soils

[8. Soil groups of Scotland]

On the basis of the observations made, the opinion is expressed that at least three broad divisions of soils, of the rank of families or subfamilies, should be recognized. The distribution of these groups is shown on the accompanying map (Map 8), and their generalized profiles in Figure 14. These groups are designated by local geographic names for convenience of description.

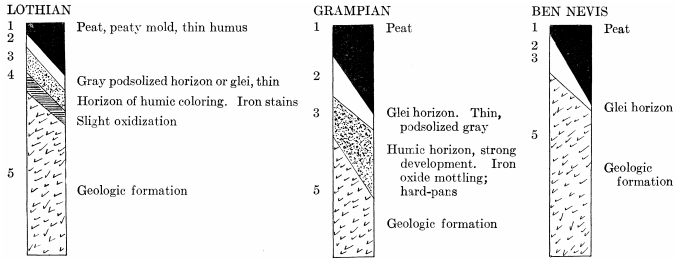


FIG. 14. Profiles of soil groups, Scotland.

The Lothian group of soils is characterized by: (1) a relatively thin peaty covering or thin humous layer; (2) a thin leached horizon; (3) a weakly developed "brown" subsurface horizon or a mottled horizon in the case of the heavier and wetter soils; (4) a faint but recognizable development of a horizon in which reddish and yellowish oxidation colors are present and in which there may be a slight increase of colloids over the parent material.

This group is capable of subdivision into a large number of types, since there is a wide range in the texture of the parent materials from sands and gravels to fine plastic clays; in colors of parent material; and in the lithologic composition of the rocks and drift from highly acidic to highly basic. The plow soils are generally some shade of brown, due in part to original peat and humic coloring and in part to heavy manuring under cultivation.

This group lies mainly in the Central Lowland and the eastern part of the country, where it occupies in general a position from sea-level up to altitudes of 600 to 900 feet. On the western side there is a much smaller aggregate and the range in altitude is less. The Lothian group comprises probably not more than one fourth of the total area.

The Grampian group of soils is characterized by: (1) a relatively thick peat covering; (2) a relatively thick bleached or "glei" horizon in the case of heavier soils, or a thin leached horizon in the lighter; (3) a horizon marked either by a brown organic color, or by rust-colored staining, spotting and veining, or by hard-pans. There is practically no development of yellow or red colors which are the result of oxidation of iron minerals under conditions of low moisture or good drainage and practically no accumulation of inorganic colloids resulting from soil-forming processes.

In the virgin soil practically all the vegetation is growing in the peaty covering. On the cultivated land the plow soil is generally brown or umber-colored, owing to the influence of the peat and the brown subsurface staining, but may be grayish in some places where the texture is heavy and a thick "glei" horizon has been developed. A large number of types may be recognized in this group, based upon the thickness of the peat covering, the texture and lithologic composition, and the thickness of detrital matter over the bed rock.

The Grampian group comprises probably more than one half of the total area of the country: the soils of most of the country north of the Clyde and north of Inverness,

and most of that of the islands, while in the Southern Highlands it includes most of the land above 900 or 1,000 feet.

The Ben Nevis group comprises soils characterized simply by a covering of peat over a "glei" horizon. There is very little development of the "brown" horizon, owing to infiltration of humic compounds, and no accumulation of inorganic colloids due to soil-forming processes. Disintegration is dominant and the detrital matter is, therefore, almost wholly psammogenous. Over a great part of the land the thick peat covering is missing because of precipitous rock slopes, water and wind erosion, and landslides, so that the soil is simply hard rock upon which there may be only lichens or a thin mat of living vegetation, or it may consist of avalanches of broken rock, the interstices being filled with peat and sand and gravel. The Ben Nevis group occupies a smaller total area than the other two groups and is present chiefly at altitudes above 2500 feet.

In addition to the classified soils just described there is a considerable aggregate of miscellaneous soil and land consisting of: deep peat deposits; shifting sand dunes and ocean beach or strand; and recently deposited alluvium. The peats are almost universally brown or yellowish, raw or highly decomposed, strongly acid, coarse in texture, matted and spongy or in felt-like layers. They appear to represent for the most part accumulations on flat or basin-like land surfaces rather than filling of lakes, and on most of the deposits the accumulation is still in process.

SOILS IN RELATION TO ENVIRONMENTAL AND CAUSATIVE CONDITIONS

There is a fairly close correlation between the nature of the soil and the geologic formations, both the old country rock and the glacial drift. This follows, first, since the drift is thin over the greater part of the area, and in many places is absent, and, secondly, because, owing to the prevalence of a peaty covering, there is little possibility of oxidation and complete alteration of rocks and minerals by weathering processes. Certainly there is less alteration than in the glaciated region of the United States where the land surface is probably no older, measured by the date of the final retreat of the ice-sheet. But even so, it does not follow that types of soils will necessarily coincide with boundaries of geologic divisions even on the most detailed geologic maps, since types must be based to a large extent on fine textural distinctions, and since moisture or drainage conditions and consequently the covering of peat and other profile differences may vary greatly on the same formation. Given the same underlying rock, the soil conditions are quite different at 3,000 feet as compared with sea-level, or a few hundred feet, near Edinburgh.

There is a close correlation between the soil groups and differences in elements of climate. The climate in general is moist and cool, but without any great range in temperature, neither excessively cold nor hot. The mean annual temperature at Edinburgh is 47° F., and the range between July and January temperatures is only about 19 degrees. The precipitation varies from 25 to 35 inches on the North Sea side to 40 to 80 inches on the Atlantic side, at the lower elevations, while it is probably as much as 150 inches on the top of Ben Nevis.

The distribution of the Lothian group of soils can be, in general, correlated with the region of lower precipitation, higher temperatures and higher sunshine; the Grampian group with higher precipitation and greater humidity; and the Ben Nevis with the highest precipitation and lowest temperature. Snow and temperatures considerably below freezing are common in winter at the higher altitudes.

The existing soils have been influenced most by smaller vegetation, grasses, sedges, mosses, and Ericaceae, and less by forest. In the region of the Lothian soils there may have been originally considerable forest, possibly oaks, ash, maple and Scotch pine, but heather is also characteristic, consisting of the species *Calluna vulgaris* and *Erica cinerea*. Here the gorse, *Ulex Europaeus*, and broom, *Cytisus scoparius*, are also common.

In the region of the Grampian soils, the "wet" or "grass" moor is more characteristic, containing such species as *Nardus stricta*, *Molinia caeruluea*, *Deschampsia flexuosa*, *Festuca ovina*, *Juncus squarrosus* and *Scirpus caespitosus*. Common in this region are blueberries, *Vaccinium sp*., crowberry, *Empetrum nigrum*, bearberry, *Arctostaphylos Uva-ursi*, mosses and bracken. Some forest appeared in the glens and in the more protected places, particularly the Scotch pine and the oak, *Quercus sesquiflora*, but in general the soils are nearly treeless under natural conditions.

The vegetation characteristic of the Ben Nevis soils are mosses and lichens and species of Saxifraga, Draba, Carex, Silene and Festuca at the higher altitudes and in the most exposed situations. Bearberry and crowberry and other small shrubby vegetation are present, but trees are entirely absent, other than an occasional dwarf willow.

HUMAN RELATIONSHIPS

Whether worked out according to climate, geologic divisions, physiographic divisions or soil divisions, pretty nearly the same relationships with agriculture and use of land, distribution of population and social conditions obtain. The correlation between soils and agriculture is apparent even from the most casual study. While no painstaking statistical comparisons have been made, it is probably safe to state that at least 75 per cent of the farms, cultivated land, and rural population is restricted to the Lothian group of soils. These soils are principally in the Central Lowland, on the benches bordering the sea, and in the wider straths at elevations generally less

than 900 feet. They comprise perhaps less than one fourth of the total area.

On the Grampian group of soils there is mostly grazing of sheep, a small amount of cultivated land, large estates and game preserves, a meager rural population, poverty, and a bitter struggle for the necessities of a bare existence for the tenants and the landless. The soil on which profitable farming is carried on lies chiefly at low altitudes not greater than 500 or 600 feet and mainly on the Atlantic side. The Grampian soils comprise probably more than one half of the total area.

On the Ben Nevis group of soils there are no agriculture and no permanent population. It is not improbable that there are over five million acres of land in Scotland that is literally waste in the sense that it has no value for agriculture, the grazing of domestic animals, or for afforestation. For the most part it constitutes scenery here weird or fantastic, there beautiful and grand, and in many places as desolate and dreary as can be imagined.

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* This paper was presented before a joint session of the Sections of Forestry and Geography.

[1] The writer wishes to express here his appreciation for favors and courtesies on the part of officials and colleagues in both America and Scotland.

SOME GREENLAND SAND DUNES

RALPH L. BELKNAP

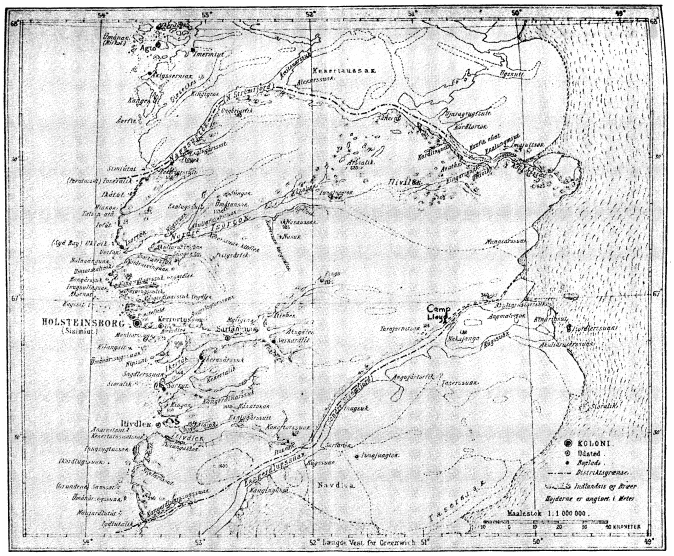
WIND action is commonly considered as being effective only in arid regions or along the shores of large bodies of water. That is, it is confined to areas more or less flat where there is a long sweep, and to areas where the bare rock surface is exposed to the blasts of the sand-filled air.

In the summer of 1927 several trips were made from the base camp of the University of Michigan Expedition, located as shown in the map of the Holstensborg district (Map 9) at the head of navigation on the Söndre Strömfjord over one hundred miles inland from the coast and in a latitude of slightly less than 67 degrees. The trips were for the most part to the ice-cap which is about twenty-five miles farther inland. On these trips a number of observations were made relative to the effect of wind action. A brief description of the features and conditions observed with reference to wind action is presented here with the hope that some valuable suggestions may be given toward the solution of this much-discussed problem.

Although Greenland is by no means to be considered as an arid region, yet within a narrow hinterland zone in the Holstensborg district close to the inland ice certain conditions favorable to wind action are to be found. Nordenskjöld, who made his trip into the interior of the Holstensborg district in 1909, has described this area as being steppe-like. This is indicated more clearly by observations taken by Church, one of the meteorologists of the University of Michigan Expedition. He found that the average relative humidity in the interior, between the middle of July and the last of August, was 63 per cent.[1] The low humidity is explained by the fact that moderately warm weather with clear skies and practically continual daylight is the predominant climatic characteristic of the region.

Another characteristic of importance is no doubt due to topography. The region is, as a result of its being glaciated, of moderately high relief. It is quite regular, though cut by wide valleys which run out almost perpendicularly from the ice front. With monotonous regularity the wind blows down from the ice through these trough-like depressions. Not only does it blow consistently from the same direction, but it frequently blows with a very high velocity. In one wind-storm during July of 1927 the velocity in gusts was recorded as 120 miles per hour, and for a period of over an hour maintained an average of 72 miles per hour. Later observations have shown that this was not an exceptional storm, as similar ones may be expected at least several times during the year.

For the wind to be an effective erosive agent it must have, in addition to a high velocity, tools with which to work and also bare rock surfaces upon which to act. Glaciation is again important in providing both of these. As a result of glacial erosion the bare rock surfaces are usually exposed, since there are little soil and vegetation to protect them. In addition, as the ice melts back, there is supplied continually to the wind as it sweeps down off the edge of the ice a fresh supply of unconsolidated material to be dried out and picked up, and this serves as a tool for its abrasive action. The effectiveness of its action can best be determined by a study of the results observed.



MAP 9. Holstensborg District, showing Camp Lloyd

Inasmuch as the rock exposed in this area is predominantly gneiss with occasional intrusions of highly basic material, but all very highly metamorphosed, it is not easily eroded. In at least two places erosional effects were found which are believed to be in part attributable to wind action. The first effect is shown in the picture (Pl. XVI, Fig. 1) taken opposite the first or lower rapids of Watson River. The pot-holes and larger depressions in the surface of the fine-grained basalt and gneiss were undoubtedly formed by water action. At the present time, however, this surface is above the level reached by the stream. There are two characteristics shown here which seem to indicate that wind action has been partially responsible for the present condition. In the first place the surface is smoother than it would be if acted on only by water. It is a polished surface. The lighter parts of the surface shown in the picture are due to the light being reflected so perfectly from the polished surface of the rock. It was also observed that the ridges between the depressions extended in nearly every direction and particularly transverse to the direction the water must have taken when the depressions were formed. If they were due entirely to water action, the ridges would be expected to have a direction roughly parallel to the direction of flow. A closer examination shows that many of these little ridges are sharp-crested. Again this would hardly seem to be the result of water action, since in that case the material rolling along would rapidly round off the crests between the hollows. It appears, then, that stream action is responsible for the general condition, the formation of the pitted surface, while wind action has eroded a little, but its action has been primarily to polish the surface over which it moved. This conclusion was considered more tenable after a similar polished surface had been examined farther inland. In this latter place, however, the polished surface was found near the top of a ridge far above any possible level reached by the stream.

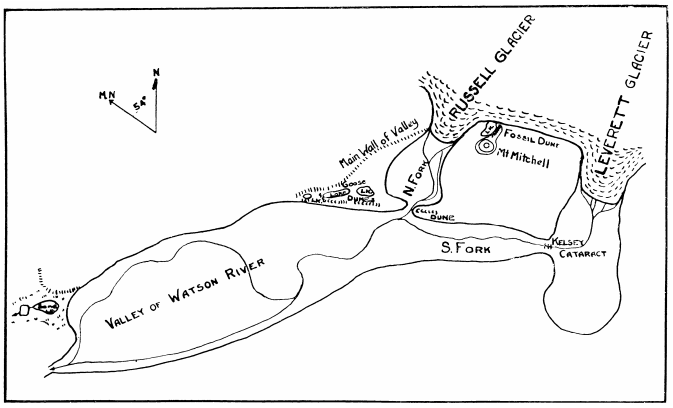
In contrast to the limited erosive action of the wind there are many evidences of its work as an agent of transportation. From near the edge of the ice, clouds of fine loess-like dust are often seen blowing down the valley. This fine material may be found miles away from the edge of the ice, forming a thin coating over the vegetation and the surface of the ground. The coarser material is carried and rolled down along the wide valley flats where it is deposited temporarily, to be picked up again and eventually deposited higher up on the side of the valley unless it has lodged in a stream and been carried away. In the quieter periods the sand, frequently ripple-marked, accumulates over the surface of the drier parts of the sand flats. After a severe wind-storm, however, the surface (Pl. XVI, Fig. 2) is covered by a protective armor of large pebbles, the finer material having been removed.

The most important evidence of wind action under ordinary conditions is found in the accumulation of sand, particularly on the northern side of the valley, both at the foot of the valley wall and on terraces along the side of the valley.

The largest single deposit occurs as a dune opposite the narrows on the north fork of Watson River. It is shown in the diagram (Map 10) that the two upper branches are joined at this point. The material is brought primarily from the north. The wind coming down from the ice strikes the rock ridge, which checks its velocity slightly, but it is reduced still more as it meets the air moving down the other fork. The result is that a dune is formed as a continuation of the ridge separating the two valleys. The dune is long, narrow, sharp-crested, composed of relatively fine material, and is deposited in rather regular layers (Pl. XVII, Fig. 1). In the lower part of the south side a few thin layers of carbonaceous material indicate that the development of the dune has been interrupted. At the present time the dune is built out to the west so far that additional material will for the most part be deposited in the stream at its base.

Another ridge composed primarily of sand extends from the present ice border southward to Mt. Mitchell (Pl. XVII, Fig. 2). This deposit must have been formed by wind action at an earlier time, since it is to be considered now as a fossil dune, the sides being covered with vegetation.

Much has been written on the subject of sand dunes, particularly their origin, but as yet the problem of their exact origin is still unsolved. Several theories have been advanced, but no one of them seems to fit all cases. There is, of course, general agreement on the point that, as in the case of stream action, there must be a decrease in velocity. This may in some places be due to obstructions such as vegetation, or it may be brought about by the eddies caused as the air moves over the irregularities of the surface. This discussion is now given because the reasons for the deposition of sand here appear so evident and because it may suggest possibilities in other conditions. In this discussion the various theories of origin are omitted, but the apparent cause of each deposition is indicated.



MAP 10. Sketch map of eastern end of Söndre Strömfjord

The statement that the winds blow down the valley is in general true. A closer study, however, shows that at

least in the upper, shallower part of the valley, because of the predominating influence of the inland ice, there is a tendency for the air to move in a direction somewhat diagonal to the main valley, and as a result the wind carries its load to the northern side of the valley.

The first definite accumulation of wind-blown material occurs at the foot of the ridge previously described. From a distance of about one hundred feet in front of the ridge the sand slope rises at an increasing gradient until the sand rests against the steep wall of the ridge or at the eastern end, where the wall is higher and steeper, until it reaches a point three to five feet in front of the ridge, where it drops down a steep back slope into a moat-like depression sometimes as much as four feet deep. Such a depression occurs only where the wall is nearly vertical to overhanging, apparently due, then, to the fact that the wind moving almost parallel to the wall is reflected back from the steep wall, thereby preventing the accumulation of sand at its base. The quantity of material deposited here is limited, as most of the sand is carried up, over the top, where it is deposited, burying the top of the ridge and forming a long narrow dune parallel to the ridge. This deposit has a steep back slope (Pl. XVIII, Fig. 1) away from the ridge on the lee side. In each of three places in the narrower western end of the upper valley a large amount of sand has been blown through a break in the ridge forming a deposit clear across the valley, thus damming the outlet and forming three small lakes. At the present time the outlet to the middle one, Goose Lake, is to the south in a channel maintained through the dune to a break in the ridge; this outlet is at right angles to the direction of the former stream.

In the dunes just described the deposition is caused by an obstruction, the rock ridge. This is indicated more clearly by the fact that the deposition forming the barrier across the valley always occurs just below, not opposite, the break in the ridge.

In a wider part of the valley about four miles farther west this same condition is repeated, resulting in the formation of Sand Lake. Here, however, the barrier is formed in part by a moraine that crosses the valley.

Undoubtedly the most of the deposited material occurs in very small dunes located on the rather flat slopes along the northern side of the valley. These dunes are again caused by an obstruction consisting of the vegetation, usually willow. Quite frequently very small dunes or accumulations of sand are found on the drier parts of the sand-flat, where the material has started to accumulate around fire-weed or "bunch" grass. That dunes of this type migrate rapidly is indicated by the frequent occurrence of long bare willow roots, which are uncovered as the dune migrates.

It is not unusual for these small dunes to widen and for the vegetation in the center to die, so that the wind is most effective through the middle. This soon results in the formation of a depression through the middle which is rapidly deepened until there is formed a "blow-out" or horseshoe-shaped dune (Pl. XVIII, Fig. 2) with the concave side toward the direction from which the wind is coming. Very shortly, however, the wind cuts completely through the dune, forming two longitudinal ones. These are of an erosional rather than a depositional type, but are of the most common occurrence along the side of the valley.

To summarize this discussion in reference to the depositional features formed, the following facts should be emphasized. Although there is some very fine loess-like material deposited rather uniformly over a large area arid in some places at a considerable distance from the ice, most of the material is found on the sand-flat or on the terraces along the side, particularly the north side, of the valley. The deposition is always due to an obstruction. In the larger dunes a rock ridge forms the obstruction; the deposition occurs mainly in the lee of the ridge. In the small dunes, vegetation has formed the obstruction. In the former case the deposits sometimes blocked drainage lines, thus forming lakes. In the latter, erosional types have resulted from the removal of material along the medial line, forming blow-outs and, eventually, longitudinal dunes.

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[1] From unpublished data kindly furnished by J. E. Church.

PLATE XVI

FIG. 1. Polished rock surface opposite the first rapids of Camp Lloyd

FIG. 2. Pebbly surface of sand-flat after a storm

PLATE XVII

FIG. 1. Sand dune opposite Upper Narrows, Watson River

FIG. 2. "Fossil" dune at edge of ice

PLATE XVIII

FIG. 1. View of lee side of sand dune opposite Goose Lake

FIG. 2. "Blow-out" or Horseshoe dune

AN EXCEPTIONAL SPECIMEN SHOWING RHYTHMIC BANDING

CHARLES W. COOK

THE paper on the progress of replacement and the formation of nodules I which was presented before the Academy last year has produced an influx of specimens showing phenomena bearing on that subject. It is the purpose of this paper to describe one particularly fine specimen which not only affords definite support of the ideas advanced in the earlier paper but also clearly demonstrates that the nature of the action may vary with a change in conditions.

DESCRIPTION OF THE SPECIMEN

The specimen, which is shown with the natural surfaces in Plate XIX, Figures 1 and 2, and with one surface polished in Plate XX, Figure 1, is a rectangular cleavage fragment, approximately ten inches long, eight inches wide, and one inch thick. It is bounded on four sides by joint planes and on two sides by planes of schistosity. According to such information as is available, the specimen was found in the glacial drift near Ann Arbor. It seems probable that it came originally from the pre-Cambrian area to the north.

A microscopic examination of thin-sections from the specimen shows that the rock is a sericitic schist, the essential constituents of which are sericite, quartz and the oxides of iron, hematite and limonite. The hematite and limonite are segregated into two zones, the hematite occurring in the outer zone (see Pl. XIX, Figs. 1 and 2), and the limonite in the inner zone. The more even distribution of the hematite in closely spaced rhythmic "rings" gives a red color to the outer zone, whereas the unequal distribution of the limonite in the inner zone causes the color to vary from light buff to dark brown. The outer red and inner buff zones are separated from each other by a heavy band of limonite. A second heavy limonite band divides the inner zone into two sub-zones. This shows especially well in the photograph reproduced on Plate XX, Figure 1.

It is to be noted that the "rings" in each of the zones show decided differences in form. In the outer, hematite zone, the "rings" conform closely to the form produced by the joint planes; the heavy limonite band separating this zone from the limonite zone also tends to conform to the joint form. Within that part of the limonite zone between the two heavy bands of limonite, the tendency toward a spheroidal shape becomes apparent in the "rings" and this tendency is very marked in the inner heavy limonite band, as may be seen from observation of this band on opposite sides of the specimen (see Pl. XIX, Figs. 1 and 2). Inside the inner heavy limonite band, the "rings" conform to neither the joint form of the specimen nor to the spheroidal form of the inner heavy limonite band. Instead they appear as a series of overlapping waves with the inner margins convex rather than concave toward the center of the specimen. This shows especially well in the photograph of the polished surface (Pl. XX, Fig. 1).

Another feature of the specimen to which attention should be called is the difference in the nature of the distribution of the hematite and the limonite. The hematite, although sufficiently concentrated at points to make the "rings" visible in the hand specimen and also in a thin-section, when the section is viewed in reflected light, is so evenly disseminated that the "rings" are but slightly visible in transmitted light. Plate XXI, Figure 1, which is a reproduction of a microphotograph of a thin-section from the hematite band, shows the nature of the dissemination. Although one of the "rings" passes across the center of the section, it is invisible in the microphotograph.

In the limonite zone, in addition to its disseminated occurrence, the limonite has been concentrated also in fractures. The microphotograph of a thin-section from this zone (Pl. XX, Fig. 2) shows such a concentration of the limonite in a fracture. This relationship of the limonite deposition to fractures is also shown at the inner margins of the heavy limonite bands by the pronounced triangular protuberances extending from the bands toward the center of the specimen, along visible fractures.

Chemical analyses by Justin Zinn of samples from the two zones show a much higher concentration of iron in the hematite zone than in the limonite zone, the percentages, calculated as ferric oxide, being respectively 7.53 and 3.65. The analyses also show a slightly higher percentage of silica in the hematite zone, the percentages being 68.40 for the hematite zone and 67.84 for the limonite zone. The microscopic examination shows that quartz is a more prominent constituent of the hematite zone than of the limonite zone, the crystals of quartz being both larger and more numerous (compare Pl. XXI, Figs. 1 and 2).

INTERPRETATION OF THE OBSERVED FACTS

That the hematite deposition and the limonite deposition mark two definite periods of deposition under two entirely different sets of conditions is, I believe, unquestionable. Two other stages in the specimen's history are possibly suggested; namely, a pre-hematite stage and a late limonite stage.

The pre-hematite stage is suggested by what may possibly be the vanishing traces of a concretionary structure. This structure shows in the upper left corner and lower left corner of the photographs of opposite sides of the specimen reproduced on Plate XIX. If this does indicate the existence of a former concretion, that concretion was probably formed in the shale from which the schist has been derived and the traces of it have been largely removed by the process of metamorphism.

A late limonite stage is suggested by the nature of the "rings" within the inner heavy limonite band. These "rings" I have described as appearing in overlapping waves with convex fronts, which suggest diffusion at different times from different centers. The idea suggests itself, although there is no proof, that this marks the stage of migration of the iron during the time the specimen existed as a constituent of the drift.

Since these two stages are merely suggested, let us attempt rather to interpret the two stages which are unquestionably indicated. The lithological nature of the specimen indicates that the rock was formed under dynamo-metamorphic conditions and at depths sufficient to prevent fracturing. After metamorphism it was exposed at the surface by erosion and contributed to the glacial drift. As erosion proceeded after the formation of the schist, the weight of the overlying rock was reduced until incipient joints were formed, along which iron-bearing solutions circulated. The iron, diffusing from the solutions into the joint block, was deposited by replacement of the constituents of the rock in the form of hematite, owing to the demands of pressure for the formation of minerals with small specific volume; and possibly to high temperature. With further removal of the overburden, the incipient joints developed into definite openings. With this reduction in pressure, the deposition of the iron in the form of limonite occurred, both in diffusion rings and along irregular fractures. During the earlier stages of the limonite deposition the influence of the joint planes is apparent in the shape of the "rings." However, as already pointed out, the shape and the interrelationship of the innermost "rings" suggest the possibility of solution and re-deposition of the iron previously concentrated in the specimen.

CONCLUSIONS

If the foregoing interpretation is correct, it shows clearly that, during the time iron was being contributed by solutions in the joint openings, the form of the deposit gradually changed from that of the joint block to that of a concretion. Subsequently the action was to diffuse the iron from, points of concentration with the formation of "rings" concentric about given points. These "rings" are often observed around a nucleus of pyrite in a weathered pebble and mark dissemination rather than concentration of the iron.

Therefore, I believe that the conclusion stated in the earlier paper[2] to the effect that "concretions do not necessarily represent segregations of minerals around an original nucleus, but may result from the rhythmic deposition of minerals, the constituents of which have diffused from solutions in joint and bedding planes, the shape of the concretions being determined by the spacing of these planes," should be made more positive by stating that concretions are generally formed in this way.

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[1] *Papers of the Mich. Acad. Sci., Arts and Letters*, VIII (1927): 285-292.

[2] *Loc. cit.*

PLATE XIX

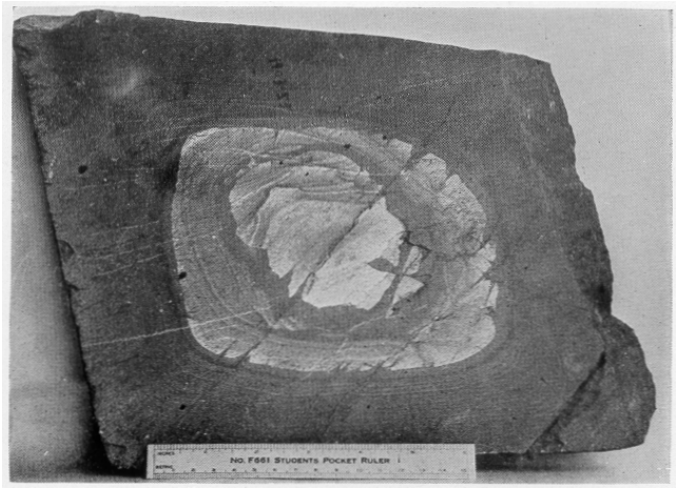


FIG. 1. The original surface of a specimen showing rhythmic banding

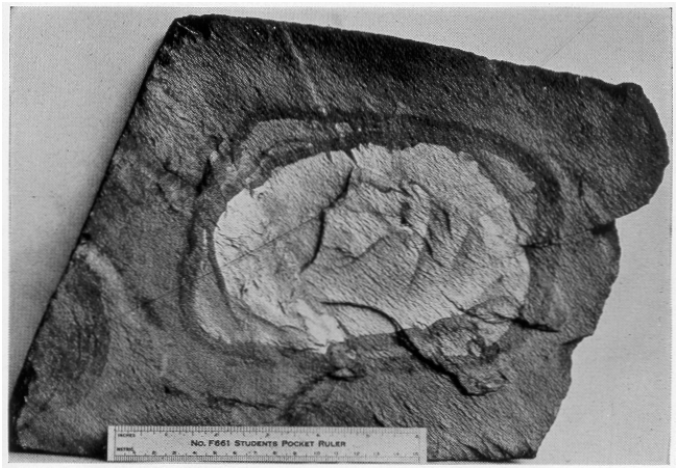


FIG. 2. The original surface of the reverse side of the specimen shown in Figure 1

PLATE XX

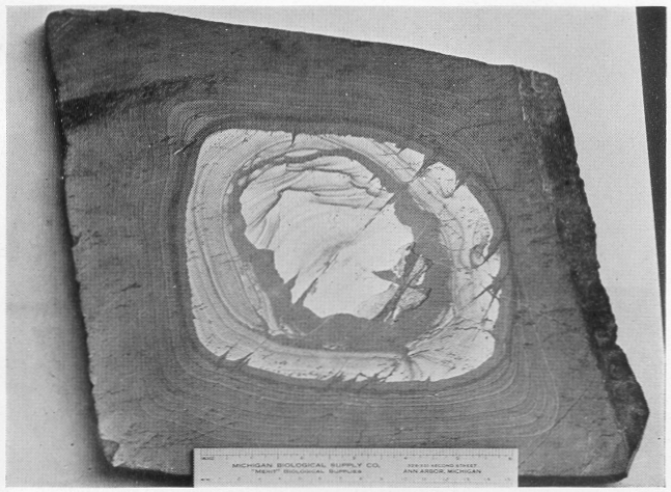


FIG. 1. Surface shown on Plate XIX, Figure 1, after polishing

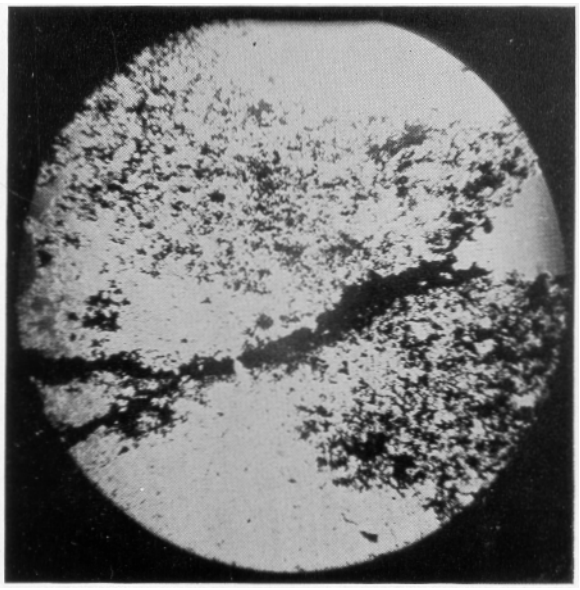


FIG. 2. Microphotograph showing deposition of limonite in fractures. x 50

PLATE XXI

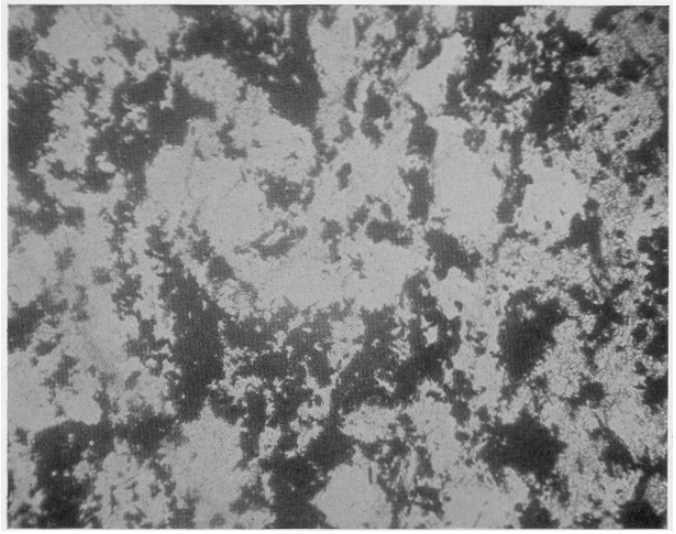


FIG. 1. Microphotograph showing distribution of hematite and quartz. x 100

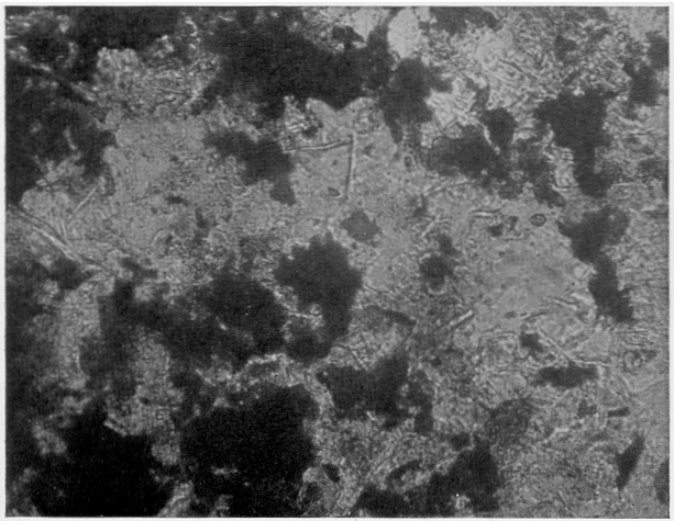


FIG. 2. Microphotograph of section from limonite zone showing the scarcity of quartz. x 400

CORRELATING GEOLOGICAL MARKERS IN MICHIGAN SECTION

ROBERT B. NEWCOMBE

GENERAL ASPECTS OF CORRELATING MARKERS

CERTAIN characteristics of a rock bed or formation may be such that it stands out from all others, or at least from the strata adjacent. Most important among these is the property of color which is more likely to give a contrast that is at once visible and easily distinguished. Those colors that are bright and unusually different from the general character of a section are very serviceable in making a horizon useful as a marker. In Michigan the beds which are red or black have found the most common use in this regard.

Lithologic properties often stand out to make a layer significant as a marker. Hardness and size of grain are most important as they are usually quite easily distinguishable. It is obvious that some shales are harder than others and certain dolomites if not highly porous are harder than limestones. Sandstones are usually intermediate in hardness between shales and limestones and are identifiable by size of grain. The shape and the assorting of grains often make certain sandstones easy to separate from others.

The substances found in a bed are occasionally very unusual and characteristic. Water or brine may have peculiar physical and chemical properties which will serve to identify them if carefully observed. The presence of easily determined minerals like mica and pyrite in shales and of the unusual rare minerals in sandstones often indicate very sharp division points. Paleontologic evidence is paramount in the identification of limestone and calcareous shale horizons when nothing else will apply for accurate separation of one stratum from another. A further aid in identification is the position of one bed above or below another. Neither may be positively determined separately, but the occurrence together is absolute proof in correlation.

IMPORTANCE OF GOOD CORRELATING MARKERS

If a rock bed is to have significance as a correlating marker, it must have not only definite characteristics which make it easily identified, but also a stable position in the rock column. That is, for at least a given area, the intervals to other beds below and above this formation should not be decidedly variable.

The importance of good correlating markers stands out more vividly in the practical application of geology than in the scientific sense. Subsurface data from wells can be accurately obtained only when easily recognized beds are present, and the entire principle of geological mapping of surface rocks depends on a good key-formation.

Recent shallow testing for structure in Michigan has necessitated a diligent search for suitable key-beds. Strata suitable as markers have been sought out in following the trend of new development. Technology has also demanded accurate data on the relative location in the rock column so as to determine the proper place to set casing, check distances to pay formations, and adjust drilling difficulties.

MARKERS IN THE MICHIGAN SECTION

Some formations of local significance for markers could not be used over a broad area because they vary in thickness, change in character, and are often lacking. Beds of this type in the Michigan section which may be used locally are the red horizons in the Coldwater shale, the Sunbury black shale, the blue-gray Bell shale, and the Sylvania sandstone. Efforts to use the coal seams of the Saginaw formation and the gypsum beds of the Michigan series as key-horizons for structure have been very unsatisfactory. They show unusually high dips due to slumping, and carry uniformly over only extremely short intervals. The nature of their deposition in small local basins practically eliminates them as useful markers. Other formations which occur at great depth in the Southern Peninsula, but which have color possibilities as markers, are the Guelph white dolomite, the colored shales of the Cataract formation and the Cincinnatian series, and the brown Utica shale.

Several other formations which might have use as key-horizons if it were not for their irregular position are the Parma sandstone and conglomerate, the Bayport limestone, and the red beds of the Lower Marshall formation. The Parma and the Bayport are found at the contact of the great Pennsylvanian-Mississippian unconformity, and are, therefore, decidedly variable even locally. The red, micaceous, sandy shales of the Lower Marshall may be found adaptable in the future, but in thirty wells platted[1] for the limited area of the Saginaw Oil Field, they showed no uniformity in position either at the top or for individual red zones. The bottom of the last red zone may serve as a fairly good index, since it conforms very closely with the top of the Marshall above and the Berea below. The Berea is not applicable as a marker except in connection with the Sunbury black shale, as it is so easily mistaken for local sandstones in the bottom part of the Coldwater formation. The red shale which replaces part of the Berea in the southwestern part of the state may be used as a marker in a few limited localities, but the stability of its position is not certain.

The two formations which have state-wide importance as good correlation markers are the Napoleon or Upper Marshall sandstone and the Antrim shale. Their position in the section is fairly constant and they are nearly everywhere to be found if within reach. Even these

horizons, however, exhibit local difficulties and are not perfect checks for correlative purposes. In some places the Antrim occurs together with the Bedford shale, which is gray, but usually the Antrim proper can be determined upon careful examination. The Napoleon is generally a greenish, angular-grained sandstone and regular in its occurrence. The presence of a heavy flow of water and the chemical composition of the brines are added corroborative evidence to separate this sandstone from others. Specific difficulty in determining the Upper Marshall is the similarity to sandstones of the Michigan series and the Parma formation. Associated sulfates with the latter beds alleviate this difficulty.

A red calcareous shale in the Coldwater formation has served as aid to delineate structural trend at Muskegon. This bed occurs in Muskegon Township at from 800 to 950 feet and has been found in every well drilled in the area. The distance of this horizon from the top of the Traverse limestone in which oil and gas production occurs is remarkably uniform at about 780 feet. In the future the usability of the red marker may be found to be limited, but at the present time it is very helpful in a new development.

One company has done considerable shallow testing of the Upper Marshall formation in the Saginaw Bay region for the purpose of determining structural conditions. It has confined its efforts largely to localities of thin glacial drift and where the Napoleon sandstone can be found at a depth of 200 to 500 feet. Although all the problems which have been encountered cannot be divulged, several matters of correlation show, upon careful examination of conditions, the possibilities of key-horizons. It has been found that locally the Marshall water has a very milky appearance due to suspended material. The flaky white substance in the drill cuttings is evidently kaolinitic or aluminous and microscopic examination[2] shows a possibility of the mineral Gibbsite. No chemical analysis has yet been made of the substance, although there have been efforts to get it into solution by the fusion method. Further studies[3] have been made upon the sulfate content of shales and brines by the use of comparative cloudiness in qualitative tests. Results along this line have been found to be very satisfactory and the method has proved unusually decisive in certain instances.

CONCLUSION

More and more is becoming known of the rock section in Michigan and new correlating markers are constantly being found for practical use. Details which would often pass unnoticed are being carefully observed by those on the lookout for every sign of structure. The rocks of the state contain numerous key-horizons and a great deal can be done in the search for folds by carefully directed shallow drilling.

STATE GEOLOGICAL SURVEY
LANSING, MICHIGAN

[1] Unpublished data supplied by W. Osgood in a personal communication.

[2] Examination made by Professor A. B. Peck, University of Michigan.

[3] By W. A. Thomas, of the Pure Oil Company.

STRUCTURAL INFLUENCES ON RECENT MICHIGAN OIL DEVELOPMENT

ROBERT B. NEWCOMBE

PREVIOUS NOTIONS OF MICHIGAN STRUCTURE

THE nature of the major structure of the Michigan Basin has long been understood in a general way. The saucer-shaped outline, the isolated position, and the character as a structural basin of deposition have always marked it as a separate province. Minor structures or local folds that occur within its borders have been considered to be of a type somewhat different from those associated with the usual major structural disturbance. Nearly all these folds are more or less radial to the basin and plunge sharply toward its center. It has been stated[1] that the folds occur mainly toward the margin of the basin and that they are of small size.

In 1922 Robinson[2] advanced the foremost theory explaining the origin of the minor wrinkles occurring around the border of the Michigan Basin. He contended that these small folds were not the usual type caused by lateral pressures, but were more of the nature of wrinkles in the border of the basin and were primarily due to vertical forces involved in the stress relations of the larger feature. His premise was mainly one of depositional settling and compensation according to the irregularities of the basin. Illustrative of this principle would be the crumpling caused in a sheet of paper when pressed into a circular container.

Further consideration arising from this radial arrangement of structures was the facility of drainage out of the immediate Michigan area. If the general trend of folding were parallel to the regional dip, it would be only logical to assume that drainage would take place by up-dip migration. In this way the structures might act as a favorable trap for temporary accumulation, but they would also furnish a channel of escape to the outcrop or adjacent regions.

All these early ideas were decidedly discouraging for oil exploration and the possibility of any large output seemed very meager. Michigan certainly had excellent source rocks; the reservoir bodies were present, but any large effective barrier to migration was considered lacking.

MODIFICATIONS INTRODUCED BY RECENT DEVELOPMENT

Several modifications to previous notions have been introduced by recent development. Intensive drilling campaigns have begun to show that we must change or at least modify some of the previous current notions. At the present time considerable is known about one structure at Saginaw which is a mile wide, three miles long, and has a closure of about forty feet. Over three hundred wells have given this information of a very limited area and other scattered drilling has more or less outlined conditions in other districts. Certain general deductions which pertain to size and characteristics of structures may be arrived at from these findings.

The size of many Michigan local structures is much larger than heretofore supposed, and minor structures have been found to link up together so as to approach major magnitude. Already the length of one structure is known to be from 80 to 100 miles and to extend across four counties. The width of this will probably vary from 4 to 10 miles, but these dimensions are by no means accurate. Such a fold, although not characterized by high dips, has important significance for its size. There is further evidence that large-sized folds extend into the center of the basin. A successful well drilled on the basis of a structure outlined from confidential data of the Dow Chemical Company has just recently been completed in the western part of Midland County. To judge from the depths penetrated, this location is only a few miles from the exact center of the structural basin. Some have gone so far as to join lines of disturbance south of Port Huron, at Saginaw, near Mt. Pleasant, and south of Manistee, and have assigned them structural connection across the state. Although this type of thing will undoubtedly be found to be possible where future drilling warrants it, for the present the gaps are altogether too wide and the wells too far apart. The joining of local structures which seem to have alignment entirely across the state should have further basis in fact.

From the data accumulated on Michigan structures, they seem to have certain characteristics in common. There is a tendency toward elongation and the known folds have narrowness in comparison with length. The trend toward the center of the basin is common and they generally plunge in that direction. The structure carries down with depth below the Pennsylvanian, as no large structural disturbance is involved in the unconformable relationships below until the slight folding in the Monroe is reached. Structure is accentuated at depth and thickening is present on the flanks of anticlines, as would be expected. High points of structure seem to be shifted toward the center of the basin with depth. All the known folds appear to be asymmetrical with the steep dip toward the basin side.

LOCATION OF RECENT WELLS ON STRUCTURE

Since the Saginaw Oil Field showed such a close correspondence of production and structure, greater effort has been made to locate wells on possible structurally high points. The tendency has been to assume a trend of the crest of an individual structure and to locate the wells along the direction of this supposed trend. However, with the wide spacing in "wildcat" territory, several dry holes located in this manner show very little about exact structure. If wells are not staggered on supposed structure, the only possible way to delineate the folding is by shallow tests. One large company operating in Michigan has adopted this procedure and results should be forthcoming in another year.

Drilling has been extensive enough in certain districts to give the structures somewhat of a major testing. The difficulty has been to show the exactness of location on structure, and dry holes, though discouraging, have not disproved the possibilities. Those structures revealed more clearly are the ones south and southeast of Saginaw; the Ann Arbor, Howell, Owosso anticline; and the fold north of Muskegon. Much is yet to be learned about these structures, but they are at least in part outlined so as to act as a guide for future prospecting.

Recently many other "wildcat" wells have been drilled in scattered localities throughout the state. Most of these have been located as close on structure as information would permit, but they have been fostered largely by promotion enterprises. They have contributed considerably to correct areal geology, give thickness variation, show local formation conditions, and ascertain points of control on structure.

LOCAL STRUCTURAL FEATURES IMPORTANT FOR ACCUMULATION

In view of the present knowledge concerning the structural features of the Michigan Basin there are local changes that should have considerable effect on accumulation. Local porosity conditions will certainly exercise a controlling effect and the coral reef character of the Traverse limestone will determine a great deal of the production in that formation. The type of folding that should be regarded as having high possibilities is that which is parallel to the regional strike or at a very small angle to the strike. Back dip or terrace effects coming up the regional dip from the center of the basin will probably be found to be of major importance in productive areas. Structural nosing with closure like the Saginaw Anticline will undoubtedly be the most significant type of fold to warrant testing, and many more should exist of similar character.

POSSIBLE NEW LINES OF STRUCTURAL INFLUENCE

In addition to the numerous radial structures due to vertical forces in the depositional settling of the basin, which no doubt exist, it is entirely possible that the more pronounced structures have had additional causes entering into their formation. Possibilities which at once suggest themselves are adjacent major structural features, deeply buried granitic masses, deep-seated faulting, and glacial load effects. Some of the factors have been previously suggested, but not particularly amplified as of any significance.

The causes of structure in northwestern Ohio and southwestern Ontario are closely connected with the Cincinnati Arch. It should consequently be expected that some dying-out effects from this feature should make themselves felt in the southern and southeastern parts of the Michigan Basin. Some of the structural disturbances in Michigan trend from across Canada and one seems to link very closely with Carmen's "drop off" which he has traced through western Ohio as far north as the Michigan boundary.

Another structural feature which manifests its presence in one form or another throughout a large part of Paleozoic history is the supposed land mass of Kankakeeia, which was one of Schuchert's positive elements. Some of the structural disturbances in southwestern Michigan could well be affiliated with this conception. According to the idea that Kankakeeia had a northeast-southwest directional trend, it would serve as a buttress for forces acting toward it, and would cause folding parallel to its alignment. In a general way the known arch which extends from the vicinity of South Bend northeastward and crosses Cass County, Michigan, a little east of Niles might have been somewhat controlled in its origin by the presence of this land mass.

The LaSalle Anticline in Illinois is another broad structural arch, and although the forces which produced this feature probably did not have any large direct effect on Michigan structure, its proximity is sufficient to merit attention. It does not seem logical to assume that such an extensive structural upwarping could take place without having some effect on adjoining regions.

Major structural features, such as the Cincinnati Arch, the land mass of Kankakeeia, and the LaSalle Anticline, must have had some effect upon the folding in the Michigan Basin. It is quite possible that many of the small structures radial to the basin due to vertical forces acted as rudders to localize pressure from major movements. These pressures were probably greatly dampened when they reached any distance into the center of the basin, but the forces must have caused some of the wrinkling which now exists in the rocks of the state.

The fact that pre-Cambrian masses exist at the surface in the adjoining state of Wisconsin, to the northeast in Canada, and in the Northern Peninsula of Michigan would suggest a possibility of buried ridges extending under the Southern Peninsula. Since extensive peneplanation of the basement rocks is known to have taken place, ridges were probably never developed as in eastern Kansas, but the chance nevertheless is present that something of this kind exists. The close proximity of the "Wisconsin Island" is a factor that should not be neglected in any consideration of Michigan structure.

Deep-seated faulting has been used to explain many peculiar types of folds, and the narrow elongation and asymmetrical shape of most of the known structures in the state are quite evident. Faults of large displacement have not been observed in the surface rocks, but several showing movement of from 50 to 100 feet are known. Among the possible causes of local deep-seated faulting are submarine creep at the time of deposition, ablation of the salt beds, and gypsum-anhydrite reactions. Actual supporting facts to prove the presence of large faulted conditions at depth are very meager, and much future drilling will be necessary to sustain such a theory.

The location of southern Michigan in the avenue of glacial ice retreat may have a significant bearing on structure. Studies of old lake beach levels have already shown the general northward tilting upward which resulted from the relief of load. The fact that the basins of Lake Michigan, Lake Huron, and Saginaw Bay were the location of glacial ice lobes at the time of retreat is important in consideration of local structure. Many would argue that glacial effects would not be likely to extend to any depth, and this is no doubt true. Structural control of the direction of ice movement and the load involved in a body of ice as thick as the continental glacier cannot, however, be dismissed as unimportant factors.

SUMMARY

Both the realization of the importance of existing structural features in Michigan and the possibility of new influences heretofore unrecognized have controlled recent oil development in the state to a large extent. Those characteristics of the Michigan Basin which loomed up to condemn the state as an oil producer have been found not so potent as previously considered. The drill will constantly throw new light upon the conditions of structure and aid to prove or disprove present hypotheses. In brief, the structural influences on Michigan oil development may be summarized:

(1) There is a close relationshp between oil accumulation and structure in the Michigan Basin.

(2) Structures are present which actually do contain pools of commercial oil.

(3) The size of the structures is much larger than heretofore considered and they trend into the center of

the basin. Some folding may go entirely across the state in continuous lines of structural disturbance.

(4) So much is still unknown about actual conditions of structure that many possibilities suggest themselves for testing.

(5) Even if outside structural influences did not enter into the formation of folds in the Michigan Basin as contended, still, according to the postulated origin from vertical forces involved in stress relations of depositional settling, a number of simple and not unlikely conditions of structure would permit considerable local concentration of oil. Closed anticlines, terraces or bench structures, and folds with their axes at an angle to the regional dip should offer favorable places for pools of petroleum to occur.

STATE GEOLOGICAL SURVEY
LANSING, MICHIGAN

[1] Smith, R. A., *The Occurrence of Oil and Gas in Michigan*, Mich. Geol. and Biol. Survey, Publ. 14, p. 19; Robinson, W. I., *Possibilities of Oil and Gas in Michigan*, p. 108, Mich. Geol. and Biol. Survey, Publ. 32 (1922), p. 106.

[2] Robinson, W. I., *National Petroleum News*, Sept. 6, 1922.

THE ORIGIN OF PEARL HARBOR, ISLAND OF OAHU*

JAMES B. POLLOCK

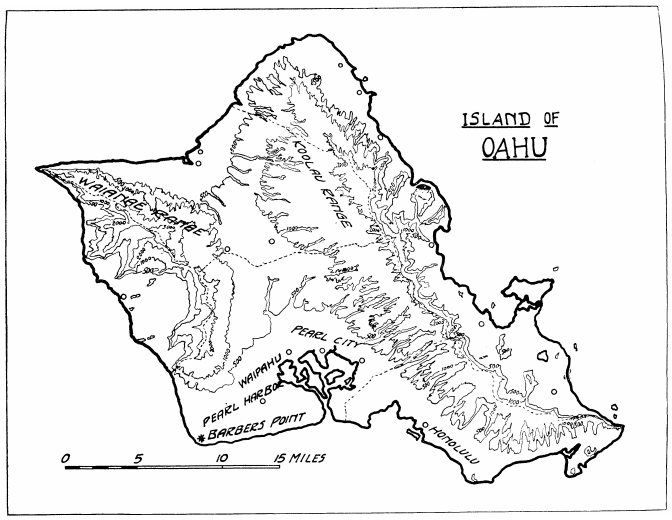
INTRODUCTION

CERTAIN writers on the geography and geology of Oahu have asserted that Pearl Harbor is a series of eroded, dendritic valleys of a simple type. Professor W. M. Davis[1] writes of it that "the elevated reef (on Oahu) is broadest along the western part of the southern coast and here it is entered by the branching 'lochs' of Pearl Harbor which are neither more nor less than drowned valleys of the most normal kind." Doctor J. C. Branner,[2] writing of the origin of Pearl Harbor, says: "Briefly, this harbor has been formed by the depression beneath the sea of a small group of dendritic valleys previously carved by subaërial erosion in horizontal beds of rocks." Both Davis and Branner, therefore, consider Pearl Harbor as a series of dendritic valleys formed by subaërial erosion and drowned by the subsidence of the island.

During a sojourn of two years (1922-24) on Oahu the writer made an intensive study of coral reefs, both fossil and living, around the island. In this study many observations about Pearl Harbor convinced him that its interpretation as a series of dendritic valleys formed by subaërial erosion was not the correct one. The evidence for a less simple interpretation is here presented.

THE ORIGINAL PEARL HARBOR BAY

The origin of Pearl Harbor is of course connected with the origin of the island of Oahu as a whole. This island is basically of volcanic origin and geologists are agreed that it is a doublet. Two distinct centers of volcanic action first built up two separate islands, and these were later united by outpouring of lava from one of them which filled up the area between, raising it above sea-level. One of these centers of volcanic activity is the Waianae mountain range which borders the western side of the island. The other is the Koolau range farther to the northeast, and extending much farther southeastward than does the Waianae range. The highest crests of these two ranges are about fourteen miles apart at their closest proximity. When the latest outpouring of lava from the Koolau range built up the land between the two ranges, a broad open bay was left between the southeast end of the Waianae range and the greater southeastern extension of the other range (see map of the island, Map 11). The western side of the mouth of this bay lay at the southeastern foot of the Waianae range. The mouth of the bay on the eastern side was bounded by the slopes of the Koolau range and must have been located not far from Moanalua a few miles west of the city of Honolulu. The remnants of volcanic cones known as Twin Peaks, and the series of craters in the bottom of one of which is a small body of water known as Salt Lake, are now located near what was originally the eastern side of the broad bay. If this bay originated before the tuff cones of the Salt Lake region, as in all probability it did, the distance across its mouth at first must have been as much as eight miles, measured at present sea-level. Taking as a pivotal point the foot of Waipio Peninsula, in this paper called Waipio Point, where all the outlets of the different lochs meet, the radii of the lochs, measured from this point in five directions to the mainland shore, vary from about three and one half to four miles.



MAP 11. Outline map of Oahu, with a few contour lines to show the elevations. The 500-foot contour line gives an idea of the original shape of Pearl Harbor, but not of its size. The higher ones indicate the two original mountain ranges.

THE DEPTH OF THE ORIGINAL BAY

It seems possible to determine the depth of the original bay at least within certain wide limits of approximation. One of the striking features in the landscape in the vicinity of Pearl Harbor is a small, more or less roughly triangular area on the surface of each downward-sloping intervalley spur of the Koolau range, which stands out as quite different from the rest of the topography. These areas are visible not only in the region of Pearl Harbor but also eastward to Honolulu and beyond where all the broader spurs show such areas. Wentworth[3] has called these triangular patches "flow slope facets" and considers that they are "remnants of the original flow slope of the Koolau cone," and that they "show essentially the same degree of slope as the underlying lava flows." On the lower slopes of this side of the Koolau range the rainfall is only about 20 to 30 inches per annum and near the seashore even less than that, while on the higher slopes of the range it may be 100 inches or more; hence at the higher levels the erosion of the inter-valley spurs has lowered the original surface very considerably and changed the inclination. On the flow slope facets themselves the local rainfall has not modified the inclination nor the altitude to any great degree. The Waianae range is more distant from Pearl Harbor than the Koolau, and the former is separated from the harbor by a broad, gently sloping plain which is in considerable part the product of a much longer period of erosion of the Waianae range, conceded to be older than the Koolau. The slopes from the Waianae range therefore have been so much changed from their original inclination that they cannot serve as a guide to the original depth of the bay. On the eastern side of Pearl Harbor the relatively recent eruptions from the Salt Lake Crater have partially filled the original Pearl Harbor Bay, and have built up shores of volcanic tuff. To the westward the slope around the shore has been modified by deposition of materials eroded from the Waianae range and from the plateau between the ranges.

There is evidence that the island of Oahu in former times has been submerged to two or more levels higher than present sea-level, one of about 20 feet, another of 40, one at 80 and possibly one at 250.[4] Wentworth[5] believes that at a stand of the sea 40 feet higher than at present, sea-cliffs were cut at the front of the Koolau spurs with a height at the top of about 200 feet above present sea-level. The modifications of shore-line at these various sea-levels make it inadvisable to use the slope up to 250 feet as a basis for the measurement.

It is clear that only the flow slope facets on the spurs of the Koolau range show approximately the original slope and surface of the island, and that the inclination indicated by the contour lines from 1000 or 1500 feet to 500 feet on those spurs will furnish the best basis for determining the depth of the original bay at Waipio Point, which will also be the minimum depth of marine deposits at this locality.

To make the desired determination five lines were measured on the topographic map, along the spurs of the Koolau range, between contour lines of 1500 and 500 feet altitude. The slope of these was projected to Waipio Point and the depth calculated by proportion. Of these five lines the minimum depth found along single lines was 1090 feet, the maximum was 1988 feet, and the average was 1549 feet. If shorter lines were used for projection the average result was not very different, though the range for individual lines was different. When the slope from 1500 to 1000 feet was the basis of the projection, the range was 418 to 2263 feet, but the average was 1536 feet. If the slope between 1000 and 500 feet was used for projection, the range was 1134 to 2236 feet, and the average was 1506 feet. If the slope of the Waianae range from 1500 to 500 feet is taken as the basis of projection, the indicated depth of the projected lines is between 3000 and 4000 feet below present sea-level at Waipio Point. Since, in this region at least, the original depth of the bay at Waipio Point cannot have been less than about 1500 feet below present sea-level, the bottom at Waipio Point has never been above sea-level, even though the island of Oahu once stood 1000 feet higher than it does now, as is asserted by Palmer.[6] In his study of records of artesian wells in the region of Honolulu, he has shown that the basal lavas underlying "coral" rock, found in the wells drilled in the Honolulu region and the valleys eroded in those lavas, were about 1000 feet below present sea-level within the present shore-line of the island. If similar ancient valleys were present in the vicinity of Pearl Harbor there is no reason to suppose they had any different relation to present shore-line and sea-level. The facts warrant the following conclusions as to the depth of the broad bay in which Pearl Harbor developed:

1. At Waipio Point the bottom could not have been less than 1500 feet below present sea-level, and may have been considerably lower.

2. The surface of the flow slope facets, if projected toward Waipio Point, falls below present sea-level before reaching the shore-line of Pearl Harbor; hence, no erosion valleys in the original Koolau lava flows nor any remnants of ridges between such valleys could appear in the land forms now visible in the harbor.

3. The materials that filled the broad bay and made the present harbor were deposited beneath the sea, except those that were built up above sea-level by local volcanic eruptions.

THE ISLANDS AND PENINSULAS

On the topography of Pearl Harbor Branner writes:[7] "We shall readily understand the process by which this topography was made if we imagine the whole island elevated fifty or seventy-five feet and the original rock beds restored right across the present channels. We should then have the streams that now enter the upper parts of Pearl Harbor flowing across a table land of

horizontal rocks, uniting at or near the point marked A on the map [Waipio Point] and entering the sea below the boat landing through a single channel. In the course of time these streams would all cut steep-sided gorges, and where the gorges, by bends in the streams, approached each other the watershed between the two streams would be lowered below the general land surface. Such a place would eventually be a bit of high land and after depression would form an island, such as we have in Mokuumeume. A depression of the island would back the sea into the valleys; the cutting of the streams would then cease, and land silts would settle in the quiet waters of the submerged channels, forming shallows, later mud flats, and then the swamplands."

Branner's interpretation assumes that Pearl Harbor was at some past time completely filled by submarine and volcanic deposits to a former, higher sea-level, and that the islands and peninsulas are the remnants of ridges between the gorge-like valleys in these deposits. It is a logical inference, then, that these islands and peninsulas should be so situated as to be considered extensions of the ridges between the fresh-water streams from the mainland, that their topography should conform to that of ridges between gorge-like valleys, and that the channels of the harbor should be so situated as to be continuations of the fresh-water streams. None of these implications is in agreement with conditions as they actually exist. Kuahua, or Magazine Island, is the only one that could be considered such an extension, and that it is not such an extension will be shown later.

FORD ISLAND

Fold Island is the largest island in Pearl Harbor (Branner's Mokuumeume is its native name). It was studied by traversing about three fourths of its shore-line on foot, and by observations in an oil-pipe trench running nearly the full length of the island on the southeast side, and varying from about one and one-half to twelve feet deep. The observations were recorded in a field note-book as made.

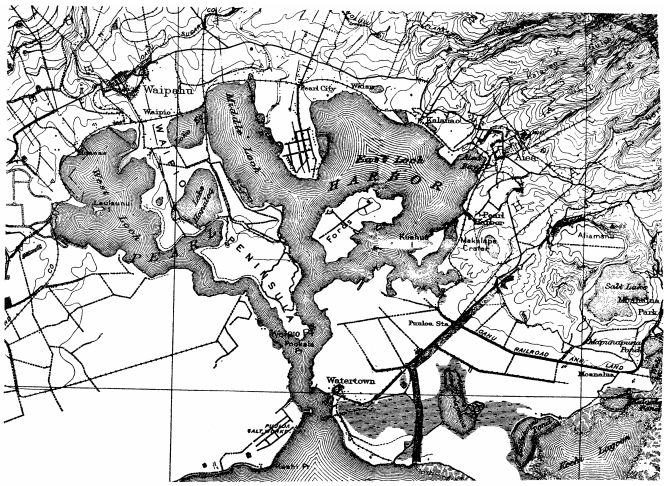
The materials composing Ford Island are of three kinds: calcium carbonate, the product of living organisms, both animal and plant; volcanic tuff in definite strata, a product of eruptions in the group of Salt Lake craters; and a clay-like earth varying from a distinctly reddish to a very dark color.

The calcium carbonate is in some places in the form of thin strata of calcareous rock composed of sand, fragments of coral, some shells and other kinds of animal remains, sloping gently downward toward the shore. These materials were evidently deposited beneath the sea. Shore cliffs composed of this kind of rock were seen on the westerly part of the northwest shore, along Middle Channel. Most of the calcareous rocks exposed in the shore cliff were not in such definite strata, and were composed to a larger extent of coral, some of which was in position as if in place where it grew and other portions of which were obviously wave-washed fragments. Of that which appeared to have grown in place there was a considerable amount composed of slender vertical branches, often anastomosing, but also sometimes rather widely separated and surrounded by the clay-like earth, or by sand, that filled in the spaces between the branches. These slender, vertical branches have been called "finger coral." Another type of coral structure, seen both in the shore cliffs and in considerable quantities in materials dredged from the channels in recent dredging operations, was composed of thin layers of coral overlying one another. These layers of coral are often in a horizontal position, but sometimes are convex, or dome-shaped. This has been called "superposed coral." This type is more or less abundant wherever materials dredged from the channels were available for observation, as was the case in several places in the harbor. Other forms of coral, branching in various ways, were present, and may be referred to as "branching corals." No attempts were made in the observation about Ford Island to distinguish the calcareous materials derived from plants, but on the shore of Waipio Peninsula opposite Ford Island quantities of coralline algae were seen growing along the shore, in the form of rounded nodules that were readily rolled about by the waves, and were so brittle that they were easily disintegrated into fragments and ground by wave action into a fine, sandy, grayish marl.[8] They undoubtedly contribute material to form calcareous sand of all grades of fineness.

While most of the shore observed was composed of calcareous materials, at various localities on the southeast side of Ford Island strata of volcanic tuff composed the shore cliffs wholly or in part. This region is opposite that portion of the eastern shore of Pearl Harbor which is formed mainly of the tuff thrown out by explosive eruptions from the Salt Lake Crater and carried to this region by the trade winds that blow strongly from northeast to southwest during most of the year. This wind-drifted tuff forms a broad, gently sloping ridge from those craters to the main outlet channel of Pearl Harbor. The strata of tuff observed on Ford Island are undoubtedly of the same origin. The lowest ones observed at low tide were the thickest, some being six inches or more thick. They gradually became thinner toward the top; the highest ones were not more than one or two inches in thickness and were frequently separated from one another by seams of calcareous material slightly consolidated into a soft lime rock. This was probably formed chiefly if not wholly of calcareous sand deposited under water in the intervals between the later eruptions from the Salt Lake Crater. The conditions described are exactly similar to those observed on the other side of the channel near the coal dock, where the broad, gently sloping ridge from the Salt Lake craters reaches the channel. On both sides of this channel, that is, on Ford Island and on the eastern mainland shore, the highest layers of tuff are covered by calcareous

deposits containing easily recognizable coral fragments. While along the mainland shore on the eastern side of the channel the tuff layers may be followed continuously under the calcareous rock, on Ford Island these tuff layers are not continuous on this side of the island from water level up, but a considerable part of this shore was built up wholly of calcareous materials with recognizable coral among them. No such tuff strata were observed on the northwestern side of Ford Island along the central channel.

In the large oil-pipe trench both the tuff layers and calcareous materials were observed, usually with thin sheets of the latter between the upper strata of the former, as along the shore. In a considerable part of the trench, however, no tuff strata were observed. In some of these places calcareous material showed from the bottom to the top of the trench, but in many places the calcareous materials alternated with the reddish or dark-colored clay-like earth. In certain places the calcareous material was in the form of slender vertical branches of finger coral. Often no coral structure could be recognized in these branches, but in a few places the typical coral structure was recognized with the aid of a hand lens. The slender vertical branches were, therefore, interpreted as being composed of coral, even when that structure could not be recognized. They were sometimes very close together, one to several inches, but sometimes farther apart, a foot or more. Between them was the clay-like earth, which also formed the surface layers of soil in which, during former years, before Ford Island became part of the Navy reservation, crops of sugar cane had been grown. In numerous places, however, patches of calcareous rock appear at the surface of this soil, even on the highest part of the island, which is at an altitude of 40 feet as indicated on a contour map with 40-foot intervals between contour lines (Map 12). The highest part of the island is near the northeastern end and, while the southeastern shore varies in height from 2 or 3 feet up to 10 or 12 feet, most of it is not over 5 to 8 feet above low water. At the most northerly corner of the island, however, the shore cliff rises to about 16 feet in height and around the corner on the northwest side it was estimated to be as high as 20 feet. At the northeastern end, where it was about 16 feet high, as determined partly by measurement and partly by estimate, it was all calcareous with much recognizable coral, except for a stratum of tuff varying from 10 to 16 inches in thickness. This tuff stratum consisted of alternating sheets of tuff with thin calcareous seams, and as a whole was interbedded with masses of calcareous rock both above and below it. The highest level at which this tuff layer was seen in this exposure was at about 8 feet above low water, and it had, therefore, 7 or 8 feet of calcareous rock overlying it. Farther toward the northwest it dipped downward in the calcareous exposure so that it came to lie only 2 to 4 feet above low water. This same tuff layer or one like it in thickness, composition, and relation to calcareous rock, was seen on Waipio Peninsula, almost directly across Middle Channel from this part of Ford Island.



MAP 12. Pearl harbor and vicinity, with the Salt Lake Crater region. The contour lines are at 40-foot intervals, and thus show the high points on Ford Island and Waipio Peninsula. The "flow slope facets" may be recognized on the Koolau spurs. The broad ridge of wind-drifted tuff is indicated by curved southwestward salients of the contour lines to the southwest of Salt Lake craters.

In the oil-pipe trench on Ford Island at various places the sides of the trench showed considerable amounts of the dark or reddish earth mentioned before, which sometimes surrounded the vertical branches of finger coral, or covered this or other kinds of calcareous rock. The materials composing this clay-like earth may have been derived from either or both of two different sources. On the one hand it may have had its origin in the decay of tuff layers such as have already been described and which originated from the Salt Lake craters. Such modification of tuff layers into a dark or reddish clay-like earth, in which no evidence of stratification could be recognized, was observed elsewhere in tuff deposits around the Makalapa Crater, where there was no doubt that the clay-like soil originated from the decay of volcanic tuff composed generally of particles of a size called lapilli. It seems very likely that much of the similar deposits on Ford Island had a similar origin but, since they were farther from the point of eruption, only the finer ash was carried by the wind as far as Ford Island. On the other hand, since these are submarine deposits, such earthy material may have originated in silt brought down by erosion of the mainland by tropical storms. In one of such storms referred to, about thirty inches of water fell in three days and the mud and silt brought down from the highlands discolored the ocean all around the island out to the coral reef and beyond. It was several weeks before the ocean water around the shores regained its usual clearness. The vertical branches of finger coral surrounded by the clay, as they were seen in the trench, must have been able to continue their growth upward while the material composing the earth was deposited around them, whether its origin was from the tuff of the Salt Lake craters or from the mud and silt

formed by the decay of older lava rock on the surrounding mainland. There was a sufficient amount of this clay soil to furnish the substratum for the growth of sugar cane on Ford Island, but in cultivation of the soil the plow must frequently have turned up fragments of coral that were not too massive to resist the impact. Some such fragments turned up by the plow in a cane field were seen on that part of Waipio Peninsula across Middle Channel from Ford Island, at an altitude of almost 40 feet.

In summary it may be said that Ford Island is wholly a product of submarine deposition, that its calcareous materials have originated from corals and other lime-secreting animals, and probably in part from lime-secreting plants. Its tuff layers were derived by explosive eruptions from the Salt Lake Crater region which drifted on the wind to the southwest and were deposited in the sea water that filled the harbor. The soil or other earthy material surrounding or covering the calcareous deposits has probably come chiefly from the decay of volcanic tuff, but may have been added to substantially by silt brought down in floods from the surrounding mainland.

It has been noted that the highest point of Ford Island is near the northeastern end and is at an altitude of 40 feet (Map 12). From this high point there is a gentle slope toward the southwestern end of the island where the shore cliffs are mostly about 5 to 6 feet above low water. The shore on the southeastern side varies from 2 or 3 feet to 10 or 12 feet above low water, while on the northwestern side along Middle Channel it will average a number of feet lower, and only as one approaches the northern corner does it rise rather suddenly to an altitude estimated at 20 feet. The surface topography is not at all such as would be expected if, as Branner implied, the islands and peninsulas of Pearl Harbor are remnants of a "table land" left between "gorge-like valleys" formed by subaërial erosion. The general slope and altitude of the island from the 40-foot altitude near the northeastern end to the 5- or 6-foot altitude at the southwestern end conform substantially to those of the seaward portion of the coral plain that covers all the coastal area of Oahu from Pearl Harbor to Barbers Point. Its surface conforms to the effects of submarine rather than to those of subaërial agencies.

There is no evidence that Ford Island is part of a ridge that once extended to the mainland between adjacent streams. If it were, this ridge should have been eroded from the mouth toward the head of the streams instead of from the head toward the mouth. The island is about one mile from the mainland, and is only about one and one-quarter miles in length, and one-half mile in width.

The latest change of strand line on Oahu brought it to its present position from a stand about 20 feet higher on the land than the present one, and this change probably took place about 5000 years ago.[9-10] Wentworth's work[11] indicates that a stand of 40 feet immediately preceded that at 20. Hence the last two changes in the relative positions of land and sea were emergences of the land, and not submergences. Since the highest calcareous rocks on Ford Island are at an altitude of about 40 feet above present sea-level, in all probability they were deposited when the sea stood at that level or only slightly higher. No higher calcareous deposits were seen anywhere in Pearl Harbor. As at present sea-level, so at former ones the tidal currents have moved in and out of Pearl Harbor tending to keep open channels by tidal action alone. In addition to this action the fresh-water streams that flow into Pearl Harbor, of which there are several of considerable size for the region, bring sufficient fresh water to interfere with the growth of corals and other marine organisms in the vicinity of their outlets. This has had the effect of keeping open bays all along the inner border of the harbor, in spite of the deposition of erosional materials brought down by the rivers or formed by wave action.

The fact that nearly horizontal layers of tuff occur both on Ford Island and on the mainland shore opposite does not by itself furnish proof that the channel between them was wholly eroded in such horizontal layers. Evidence has been presented that these layers have been deposited from the air as wind-drifted ash and have fallen into the sea in quantities sufficient to form strata only 1 or 2 to 6 inches thick at any one time for those exposed in the shore cliffs on Ford Island, and that the intervals between the time of deposit of these strata allowed calcareous materials to collect. After each such stratum was deposited in the line of the tidal currents the flow would be sufficient to remove almost at once the rather finely divided tufaceous material of which the deposits were composed, so that a channel could be kept open continuously in time and yet allow these strata to build up deposits such as are now visible along the quieter margins of channels. Thus it is not necessary to assume, as Branner did, that only subaërial erosion through horizontal strata raised above sea-level could produce the channels. The channels may have been produced by tidal currents and kept open while their margins were building up below sea-level.

At the present time wave erosion is modifying the shore-line and to some extent has shaped the vertical shore cliffs. At the northeastern end of Ford Island, where the waves produced by the almost continuous strong trade wind beat with their greatest intensity, a former extension of the island to the northeast for several hundred yards has been eroded, leaving as remnants a shoal upon which appear a few small islands composed only of calcareous material. It is this erosion by the waves stirred up by the trade winds that has produced the higher shore cliffs at this end of the island.

THE PENINSULAS

Not only is Ford Island the product of marine agencies as regards both its topography and its shape, but this statement is equally true for both of the peninsulas that project into Pearl Harbor from the present mainland

shore. Neither of them is a continuation of any mainland ridge. Both are separated from the adjacent mainland by a strip of land lying only a few feet above sea-level, probably not over 5 feet, in which rice culture is now carried on. The width of this low ground from Waipahu toward Waipio Peninsula is seven tenths of a mile as measured by an auto speedometer. The similar strip of rice land that separates Pearl City Peninsula from the adjacent shore is perhaps not quite so wide. The higher part of the latter peninsula is probably not over 15 feet above sea-level at its highest point and would certainly be completely submerged at a sea-level 20 feet higher than the present.

On the topographic map with 40-foot intervals between the contour lines three points on Waipio Peninsula are seen to have an altitude of 40 feet (Map 12). One of these points is on that region of the peninsula nearest Ford Island, from which it is separated by Middle Channel. The two other points on the peninsula that have an altitude of 40 feet are toward the western side. One of them is at the top of a very sudden rise in land which comes after one has crossed the low area near Waipahu. Between the point first mentioned with an altitude of 40 feet on the peninsula and the other two, there is a broad shallow depression crossing the peninsula diagonally, running nearly from northeast to southwest and only a few feet above sea-level. Near the center of this depression is a body of water known as Loko Hanaloa. It was estimated that a 10-foot rise of water here would completely cross the peninsula and separate it into two portions, and would also cover the low portion of the peninsula near Waipahu and convert it into two islands. The depression across the peninsula is not in line with any of the fresh-water streams from the mainland, nor is it in the direction of any of the main channels that serve as outlets to the sea from Pearl Harbor. It is impossible to interpret it as a product of subaërial erosion. From the high points on Waipio Peninsula at an altitude of 40 feet the surface slopes quite gently down to the central depression, though on the eastern side of Loko Hanaloa there is an outcrop of calcareous rock which, while lying in a position nearly horizontal, seems to be more or less crumpled into wave-like folds. On one of the slopes near the base of this depression the soil was seen to be composed to a considerable extent of the grayish marl mentioned before, which is a product of the decomposition of a nodular, lime-secreting, red alga. The seaward part of the peninsula has a structure, as revealed by a traverse of the shore cliff on both sides of Waipio Point, similar to that of the seaward end of Ford Island. The tuff strata and calcareous rock containing coral have a similar relation on both the peninsula and the island. Less of the shore on the peninsula showed the tuff layers, however, and those showed only near the seaward extremity of the peninsula except that a layer of tuff 10 to 16 inches thick and. similar to that at the northeast end of Ford Island was found in a corresponding position on the peninsula, bedded between calcareous rock above and below it. The peninsula is farther from the source of the wind-drifted ash than is Ford Island. In a cane field near the 40-foot altitude on the seaward part of the peninsula coral fragments were observed where they had evidently been turned up by the plow in preparation of the land for the growth of sugar cane. All the observations made here indicate that this more seaward portion of Waipio Peninsula has exactly the same structure as has been described for Ford Island, composed of the tuff layers, calcareous rock and the clay-like soil, combined and distributed in practically the same way in both the island and the adjacent part of the peninsula.

The part of the peninsula west of the central depression was not observed in as much detail and its exact interpretation is less certain. What is certain, however, is that Waipio Peninsula can no more be interpreted as a remnant of a ridge between valleys formed by subaërial erosion than can Ford Island.

Little need be said about Pearl City Peninsula. It has been pointed out that the seaward portion of it, while not far above present sea-level, and estimated at not over 15 feet, is nevertheless higher than the neck of the peninsula which joins it to the mainland. In this respect it is like Waipio Peninsula, tte necks of both being the seat of rice culture and lying very little above sea-level, probably not over 5 feet. These rice lands are in all probability composed of the silt washed down by the streams from the surrounding mainlands and one of the larger of the streams of this region has its mouth beside the neck of each of the peninsulas. Indeed, it seems not unlikely that without the silt brought by each of these streams in relatively recent times both the peninsulas would be separated from their connecting mainland shores by a strip of water half a mile wide or less. Neither of the peninsulas, then, offers any support to the interpretation of Pearl Harbor as the product of subaërial erosion.

KUAHUA ISLAND

Kuahua Island in the eastern part of Pearl Harbor requires a different interpretation from that of Ford Island. The former island and the channel which separates it from the eastern shore appear to come nearer than any other feature in Pearl Harbor to conforming with the statement of Dr. Branner that the channels have been eroded in horizontal strata, yet that interpretation is as erroneous for the channel that separates this island from the eastern mainland shore as for the features already discussed.

All the shore on this side of the harbor is different from the shore on the other parts of its circumference. It is composed, to a very predominant degree, of the tuff thrown from the group of the Salt Lake craters. The last eruption in this region was only a few hundred yards from the eastern shore of the harbor, at Makalapa Crater. The mainland shore opposite Kuahua Island

shows a nearly vertical exposure in the tuff, having an altitude at the top of at least 20 feet. The strata of this tuff are nearly horizontal. Sentinels on guard would not allow an inspection of the opposite shore of Kuahua Island, but from across the channel the island seemed to be composed of the same kind of tuff strata with about the same altitude at the top. It seems likely, therefore, that at some time in the past the tuff strata were continuous across the channel from the mainland to Kuahua Island. Though this be granted as a fact, other facts make it impossible that this channel could have been formed by erosion, either subaërial or marine. The first of these facts to be noted is that, though the tuff strata may have been continuous from the mainland to Kuahua Island, they were certainly not continued across the wider channel, East Channel, that separates this island from Ford Island, at least not above present sea-level. The exposed shore of Ford Island at the point opposite Kuahua is calcareous from low water level to the top, and not tufaceous. The second significant fact is that, while the two shores of the Kuahua Channel may have an altitude of about 20 feet, the adjacent shore of Ford Island is not more than 10 to 12 feet at its highest point, and has probably not been any higher than this since it was raised above sea-level. The third fact, the evidence for which will be presented later in the discussion of the channels in detail (see p. 243), is that the broad East Channel between Ford and Kuahua islands, even before the last shift of land or sea that established the present strand line, had a depth at its center that brought the bottom to about 16 feet below present sea-level. The fourth and last fact to be noted in this connection is that, at the time when the last eruption took place at Makalapa Crater, the sea stood about 20 feet higher on the land than it does now, as shown by the altitude of the wave-washed calcareous deposits capping the Makalapa tuffs.

The consideration of these four facts shows how entirely impossible it is that any water, either sea or fresh water, could have been impounded behind the tuffs that once blocked the channel between Kuahua Island and the eastern mainland shore, and raised to a level necessary to start the erosion of the tuffs at 20 feet above the present sea-level, when such waters had available, as outlets to the sea, channels whose bottoms at their centers, were not less than about 16 feet below the present and 36 feet below the former sea-level.

ORIGIN OF KUAHUA CHANNEL BY SUBSIDENCE

It may be asked, What, then, was the origin of this channel? It is well known that in regions near to craters in active eruption the eruptions are frequently accompanied by local subsidences and warping of the earth's strata. It seems most likely, therefore, that the channel referred to had its origin in such a subsidence, possibly at the time the Makalapa Crater burst its way through the older tuff deposits of the Salt Lake craters. Indeed there is some direct evidence for local subsidence in this region. On the southern shore of the southeastern loch the tuff strata exposed appear in places to sag and buckle instead of lying as nearly horizontal as they commonly do on the shore along the main channel. Slightly to the southwest of Makalapa Crater, and just beyond the head of Southeastern Loch, the engineers, who built the oil-tanks for the Navy in 1923 and 1924 noted that, in preparing the foundations for the pumping station, they found tree molds in the tuff at a level which allowed the tide water to rise and fall in them. Similar tree molds were observed by the writer in the tank foundations around Makalapa Crater. Since sea-level stood 20 feet higher than at present when the Makalapa Crater was completed and the trees whose molds were seen must have grown above sea-level, it seems likely that the depression of the land at the head of Southeastern Loch has been formed, in part at least, by a local subsidence which could not have been less than 20 feet and may have been considerably more.

Other facts observed in this region furnish additional evidence for the interpretation of local subsidence. In connecting the different oil-tanks with pipe lines, trenches were dug here across one of the depressions and into the slopes on both sides of it and borings were made in it. From tank 38 a trench was followed down the slope several hundred feet. Along this slope the tuff layers exposed in the trench were not at all in a horizontal position or anywhere near it, but the individual strata had almost the same inclination as the general slope of the land, which was here rather steep, with a drop of 35 feet in 315 feet, or 1 in 9. The downward inclination was not in the direction outward from the center of eruption at the Salt Lake craters, nor was it from Makalapa Crater. It was at right angles to a line from the former, and toward the latter. The depression at the bottom of this slope was certainly not eroded in horizontal strata. The inclination which these surface layers of tuff show may well have been because of a local subsidence either before or after the surface strata were deposited. In the bottom of the depression, as it shows at present, several borings by the oil-tank engineers showed coral materials down to some 40 feet below present sea-level. The depressions here, to the south and southeast of Makalapa Crater, do not have the appearance of having been shaped entirely by subaërial erosion. They do not branch out in a series of dendritic valleys. They are very broad in proportion to their length. They are in a very dry region and only the occasional tropical storms would have erosional force. The length of their drainage area is only to the rim of the Salt Lake craters and a straight line from the head of Southeast Loch to the high part of the rim of these craters is less than two miles. This depression is on one side of the broad, gently sloping ridge which extends from the Salt Lake craters to the Pearl Harbor main outlet channel and which was formed chiefly by the wind-drifted ash from the Salt Lake craters. If the local rainfall was sufficient to produce by erosion such broad,

deep valleys as are found here on one side of the ridge, why are there no corresponding valleys on the other side of this ridge? Many observations in this region from different points of view seem to the writer to make it much more likely that the main features of the topography in the depressions between Makalapa Crater and the broad ridge are to a considerable degree the result of local subsidence rather than the result of subaërial erosion alone. It is granted that the latter process has modified them to some extent and is still at work shaping them.

A measure of the minimum amount of the local subsidence may be obtained by adding to the depth of coral in the borings across the depression 40 feet or more, the altitude of the site of oil-tank 38, which was 46 feet before the site was leveled for the foundation. It may be concluded, then, that the local subsidence was not less than 80 to 90 feet at this locality. The fact that the two latest changes in sea-level here relative to the land were in a direction of an emergence of the land of a minimum of 40 feet makes it very unlikely that the coral down to 40 feet below present sea-level in the depression was deposited or grew on the bottom of a submerged valley that had been formed by subaërial erosion; but it is quite intelligible if the depression was formed by local subsidence, whether this took place when the strand line was at 20 or at 40 feet above the present one.

All the region on this side of Pearl Harbor is composed exclusively of the tuff from the Salt Lake craters, except where it is interbedded with or covered by calcareous deposits of marine origin. On this side of the harbor these calcareous deposits were seen nowhere higher than 25 feet above present sea-level, and the highest portions of them were of such materials as lie at the top of the beach above high water.[12] Where the broad ridge of the wind-drifted tuff shows along the shore of the main outlet channel, it is capped with calcareous rock containing easily recognizable coral and also has the thin seams of calcareous deposits between the upper tuff layers. These two facts prove that the shore here was below sea-level when the materials thrown out in the latest eruptions from the Salt Lake craters were carried over to this locality, and that this sea-level continued for some time after the eruptions had ceased in the Salt Lake Crater region, or at least, after they had ceased to drift as far as this locality from their point of origin.

When the Salt Lake craters built up their tuff cones they not only filled the eastern part of Pearl Harbor, but their deposits covered the lower part of the Koolau ridges in their vicinity and filled up the valleys of the adjacent streams from this range. Among the valleys partly filled was that of Halawa stream. Since this stream has its source in the higher regions where precipitation is heavy, its perpetual flow of fresh water overtopped the barrier placed in its path, and by subaërial erosion reestablished the valley at its mouth, removing in the process part of the tuff deposits. The mouth of the valley was, however, deflected westward from its original course, and the stream now flows into the east side of East Loch. The influence of this erosion in shaping Pearl Harbor has been in filling in the bottom and building out the eastern shore of East Loch. It has had nothing to do directly with shaping the outlet channels from the lochs to the sea.

THE CHANNELS AND LOCHS OF PEARL HARBOR ARE NOT LIKE DENDRITIC VALLEYS

It is necessary to give some consideration to the channels and lochs of Pearl Harbor, since Davis and Branner interpreted them as dendritic valleys of the most normal kind. Davis has written numerous papers in which he emphasizes the importance of drowned dendritic valleys in the interpretation of Pacific islands. In a number of these papers he has figured such drowned valleys. A reference to one will be sufficient, since his figures show practically the same contours for them all.[13] Davis' figures show the effects of erosion on volcanic islands, but the subaërial erosion of raised sea bottom should not be essentially different. If one compares his diagrams with the outline of Pearl Harbor, a striking disagreement between the two may at once be noted. In the first place the embayed drowned valleys of his diagrams become narrower toward the head, where they are relatively sharp-pointed, and they are broadly open at the mouths, while the bays or lochs of Pearl Harbor become continuously broader toward the head, where they are exceedingly broad and pouch-like, and the channel outlet of each is decidedly narrower than the loch to which it is the outlet. Also each channel is broader at its head than it is at its mouth, except that the main channel broadens where it reaches the sea. Measurements were made on the map at several points across each of the channels and across each of the three larger lochs. (Figures given below in brackets indicate the number of measurements, of which the average is given.) The differences are very significant. The main channel, from Waipio Point to the sea, varies in width from 0.29 to 0.33 and has an average of 0.30 miles [5]. It is the only one that is wider at its mouth than at its head, where the other channels converge to form it. West Channel, from West Loch to Waipio Point, varies from 0.20 to 0.40 with an average of 0.26 miles in width [15]. Its greatest width is where it leaves West Loch. West Loch itself is 1.66 miles across the inner bays [1]. Middle Channel, which lies between Ford Island and Waipio Peninsula and connects Middle Loch to the main channel, varies from 0.25 to 0.55 and averages 0.43 miles [5]. It also is widest at its head, where it leaves Middle Loch. It may serve as an outlet to East Loch, which thus has two outlets. Middle Loch varies from 0.44 to 0.81 with an average of 0.68 [6] and if the expansion of this loch, known as Loko Eo, is considered a part of the loch, as it properly should be

since they are separated from each other by only a railway embankment, then Middle Loch near its head is 1.18 miles in width [1]. East Channel, between Ford Island on one side and a part of the mainland and Kuahua Island on the other, varies in width from 0.26 to 0.55 and averages 0.43 miles [4]. East Loch, which has both East and Middle channels to serve as its outlets, is 2.33 miles across [2 measurements of equal value].

These figures present quantitative data for the fact that is readily seen on inspection of the outline map of the harbor (Map 12), that the channels and the lochs are markedly different from drowned dendritic valleys. The channels of Pearl Harbor, instead of becoming wider at their mouths as is characteristic for dendritic valleys, have generally only minor variations in width for nearly their entire length, but each, with one exception, widens at its head instead of at its mouth. Only the main channel widens at its mouth, where it reaches the sea. Both Middle and East channels widen landward instead of seaward, and each of the two channels is wider in its narrowest region than that part of the main channel which carries their combined waters. The very great width of the lochs as compared with that of the channels which are their outlets, taken with the facts already presented as to the composition and topography of the islands and peninsulas, makes the interpretation of the channels and lochs of Pearl Harbor as a series of drowned dendritic valleys inadmissible. The erosion that has helped to shape the island forms there has not been to any great extent subaërial. Erosion by the sea at present sea-level has played the major rôle in this process, but not even marine erosion has been the major factor in producing the lochs. The sea has worked in two ways, by tidal currents and by wave action. The currents have excavated the bottom of the channels; the waves are modifying the shape of the present shores. Wave erosion is much greater on those shores which are exposed to the northeast trade winds, since these winds are the agents which impart to the waves their greatest amplitude and power, and they are more constant than the winds from any other direction. Everywhere in the harbor, moreover, those shores which face the trade winds show a markedly greater degree of wave erosion than the shores that are in the lee of those winds. On the exposed shore of Waipio Peninsula along the middle channel a shelf produced by wave erosion was noted. Its upper surface was from a few inches to a foot or more below low water, and its width in this locality was estimated at 100 to 200 feet. At its edge the water suddenly increased in depth to an invisible bottom. This width was not at the point where the wave erosion had been greatest.

It is clear that wave erosion at present sea-level has reduced the size and modified the shores of the islands and peninsulas in Pearl Harbor from their original proportions, and that the process is still in progress. Wave erosion alone could not, however, have been the major factor in producing the lochs, since where they have worked with the greatest efficiency, at the northeast end of Ford Island, they have eroded only a few hundred feet of the shore since the last change of sea-level.

The surface of these islands and peninsulas is essentially that of the sea bottom of periods when the sea stood higher on the land than it does now. Subaerial erosion has modified these surfaces to a very minor degree since they have been exposed above the level of the sea. In altitude, slope and degree of subaërial erosion Ford Island and the seaward part of Waipio Peninsula correspond to the broad coral plain which extends from the mouth of Pearl Harbor westward to Barbers Point. The materials composing the coral plain and those that form the visible parts of the island and peninsula were deposited beneath the sea under the same conditions of sea-level for both, except for the tuffs from the Salt Lake craters, which were deposited near their point of origin in greater amounts.

The three main lochs of Pearl Harbor are filling with silt around all their mainland shores, most rapidly in the vicinity of the streams that empty into them. They have never been any more nearly filled than they are now, except for the effect of wave erosion, and at the higher stands of the sea than the present one they were decidedly larger and deeper than now. These statements may not all apply to the smaller Southeast Loch, since local subsidence of volcanic tuff layers probably played a part in its origin.

PEARL HARBOR OF THE PERIOD BEFORE THE LAST SHIFT OF STRAND LINE

Wentworth and Palmer[14] have estimated the time elapsed since the last downward shift of strand line at about 5000 years, and Pollock[15] has supplied evidence based on the study of the growth-rate of coralline algae in the reefs of Oahu in very close agreement with their estimate. This short period, coupled with the scanty rainfall on the lee side of Oahu, particularly near the seacoast, accounts for the small part subaërial erosion has played in modifying the surface of the islands and peninsulas in Pearl Harbor.

Before the last shift of strand line, while Oahu was submerged about 20 feet more than now, the outlet channel of Pearl Harbor was about 2.5 miles wide. It extended westward over the coral plain more than a mile, and on the eastern side it covered the lower portion of the broad ridge of tuff which drifted on the wind from the Salt Lake Crater, but the sea-level of that time did not reach the present Puuloa entrance to the United States Navy reservation, since the altitude at that point is now about 30 feet. Though the main outlet channel of the earlier Pearl Harbor was 2.5 miles wide, the larger area of water within the harbor required a larger volume of water displaced by tidal movements to flow in and out with each rise and fall of the tide; hence there were tidal currents of sufficient velocity to maintain open channels between the islands in the larger harbor, and prevent

their filling up with either the growth of corals or other marine organisms, with wind-drifted volcanic ash, or with water-borne silt or mud. It seems feasible to ascertain the approximate depth of two of the earlier channels and to compare both with the sea-level of the earlier time and of the present.

If the conclusions are accepted which have already been reached in this study, that the present surface of the islands and peninsulas is that of the sea bottom of the earlier time, with very little modification by subaërial erosion, the slopes on the adjacent shores of Ford Island and Waipio Peninsula may be used to determine a minimum for the depth of the channel whose waters flowed between them at the higher sea-level. The approximate height of these shores was noted in their study. A line measured on the topographic map joining the 40-foot contours on that island and the adjacent part of the peninsula will give the distance between them when compared to the scale of the map, and the vertical drop from the 40-foot contours to the top of the shore cliffs will give the slope. These slopes, projected until they intersect, will mark approximately the middle of the older channel, and also the depth in relation to either the former or the present sea-level.

The required measurements and calculations showed that the sloping lines intersect each other between 13.5 and 14 feet below present sea-level, at a point one third of the width of the channel from Ford Island, and two thirds of its width from the Waipio shore. If the fundamental assumption is sound, namely, that the surface slope of the land here is approximately that of the old sea bottom, then the bottom of the channel of the former sea-level was about 14 feet below present sea-level, and 14 + 20, or 34 feet, below the sea-level of the former period. The depth of water in the present Middle Channel as indicated on U. S. G. S. Map No. 4110 is 6¼ to 6¾ fathoms, or from 37.5 to 40.75 feet. This is a very satisfactory agreement of the results of the projection with the known data of the present harbor, and gives confidence in the method of arriving at the results. The fact that the projected lines intersect in the present channel only one third of the channel's width from Ford Island is accounted for by the much greater effectiveness of the wave erosion on the Waipio side, due to the influence of the trade winds on the height and power of the waves.

The same method was applied to East Channel, except that a projection from only one side was practicable. By using the slope from the 40-foot contour on Ford Island to the east corner of the island, and projecting it toward the southwest end of Kuahua Island, the depth at the middle of the channel was indicated as 16 feet below present sea-level, which, with the 20 feet of the change of sea-level, gives 36 feet as the probable depth of the channel of the former period. These results again are consistent with the others and with the present depth of this channel, which is about 40 feet below sea-level.

Another fact observed on the traverse of Ford Island, and not previously recorded, supports the conclusion that the channel of the former sea-level had its greatest depth below present sea-level and partly covered the present shore of Ford Island. On the shore of this island along that part of Middle Channel nearest to Middle Loch, the shore is lower and flatter than anywhere else around the island, and back from this shore some rods there is a sudden rise in the land to a ridge running parallel to the shore. The significance of this feature was not appreciated at the time of the observation, nor until all the facts upon which this study is based were analyzed and resynthesized. The topography in that locality was then recalled, but its description must be given only as remembered nearly four years afterwards, without exact quantitative data. An estimate based on such recollection makes the flat strip of land along the shore 5 to 10 rods wide, with a rise from water-line of about 5 to 8 feet, or perhaps even more, followed by a sudden rise of 10 to 15 feet to the top of the ridge, in a horizontal distance very much less than the width of the flat strip. In short, the flat area is best interpreted as part of the channel bottom of the time when the land was submerged about 20 feet more than now, and the ridge as the remnant of the shore cliff of that same period.

The Middle Channel of the older time had its eastern shore farther eastward than that of the present one, and this is in harmony with the fact that the two lines projected from Ford Island and Waipio Peninsula intersect at a point only one third of the width of the present channel from Ford Island. The older channel bottom was partly on what is now Ford Island and partly below the water surface of the present channel. In other words, the channel bottom was only partly exposed at the time of the last emergence. In fact, the topography on this part of Ford Island fits into the interpretation of Pearl Harbor here presented like the last piece in a picture puzzle, the fitting of which proves the correctness of the whole arrangement. It may be concluded with a very high degree of certainty that the present channels in Pearl Harbor have not been eroded in horizontal strata by subaërial erosion, but that they have been eroded in the bottom of older marine channels, formed at a time when strand line stood 20 feet higher on the land than it does now. The erosion that produced the present channels has been that of tidal currents and waves at present sea-level. The waves are most effective on those shores that face the northeast trade winds, with the result that the present channels have been shifted somewhat to the westward, as compared with the older channels, and the older shore-lines have been more or less obliterated by the wave erosion on the eastern side of Ford Island and Waipio Peninsula. The central part of the bottom of the older channels was not raised above present sea-level by the last shift, but was about 14 to 16 feet below it. This is a fact that makes impossible the erosion of the channel between Kuahua Island and the nearest mainland shore, by either subaërial erosion or tidal currents, since the shores of that channel rise about

20 feet above present sea-level. The only other explanation that occurs to the writer is the one already given, that Kuahua Channel was formed by a local subsidence of the tuff deposits.

The visible features of Pearl Harbor have been developed at three different stands of sea-level, the present one and two earlier. The oldest and highest must have been a little more than 40 feet, since some marine deposits on Ford Island and Waipio Peninsula lie at that elevation. On the basis of other evidence Wentworth[16] has recognized these different levels and called the one at 40 feet the Waialae stage. He finds that at this stage the Salt Lake craters were active, and the sea-cliffs were cut on the Koolau spurs. During this time Pearl Harbor was a broad bay with an outlet about five miles wide, and having no island nor peninsula within its borders, except possibly three or four small shoals awash at low tide, the high points on Ford Island and Waipio Peninsula as they now exist. There is no clue to the time at which the shift occurred from the 40-foot to the 20-foot level, though Wentworth has estimated post-Waialae time as of the order of 100,000 to 200,000 years. The stage at which benches were cut on different islands of the Hawaiian group he called the Hanauma stage, since the benches are well shown at Hanauma Bay, Oahu. He believed this stage to have been only 12 feet above present sea-level, but evidence disclosed at Makalapa Crater proves it to have been about 20 feet. At this time there were three or four small shoals in Pearl Harbor, and after the formation of Kuahua Island and Makalapa Crater, which occurred at least before the end of this time, there were an additional island and a peninsula around the crater. This stage continued for some time after the eruptions at the Salt Lake and Makalapa craters came to an end, and calcareous deposits on Makalapa Crater showed the height of strand line during this stage. At the time of the last shift of sea-level Ford Island grew larger, two or three of the islands or shoals were transformed into Waipio Peninsula, and the Pearl City Peninsula came into existence, unless the low-lying necks of both the peninsulas have been formed by deposits of silt since the last shift. The last two major events in the development of Pearl Harbor were not submergences that drowned eroded valleys, but emergences that brought certain portions of the sea bottom above sea-level. The two shifts of strand line were about 20 feet each. The channels at the higher levels had a depth at least equal to that of the present channels, about 40 feet, and neither shift was sufficient to bring the bottom of the contemporaneous channels entirely above the sea-level established by the shift; hence there was no opportunity at either stage for fresh-water streams to do any work of erosion on the raised sea bottom, but tidal currents continued to flow in and out of the shallow channels and eroded them to a depth consonant with the volume and velocity of the water. At each stand of the sea, wave erosion added its effect to that of the tidal currents.

If Wentworth's conclusions are correct the sea stood at the 40-foot level for a period so long that it extended far back into the glacial epoch. He ascribes the Fort Shafter gravels to the Pleistocene, and they were deposited at the 40-foot stage of the sea. The shift to present strand line he ascribed to about 5000 years ago, and Pollock's calculations, based on the growth-rate of reef-forming coralline algae, are in close agreement with Wentworth's estimates.

SUMMARY

The story of Pearl Harbor may now be summarized in accordance with the facts herein reported and with the logical conclusions that may be drawn from these facts.

The site of Pearl Harbor was originally a broadly open, nearly semicircular bay between two volcanic mountain masses which at first were separate, but later fused into one. On the basis of present sea-level its radii were 3.5 to 4 miles, the width across the mouth about 8 miles, and its depth at the converging point of the radii, Waipio Point, not less than 1500 feet. Since its origin these 1500 feet have been completely filled with deposits laid beneath the sea, and such deposits are now found within the harbor to an altitude of 40 feet above existing sea-level. The deposits now above the sea represent the product of two different sea-levels higher on the land than the present one. At the higher level the island was submerged not less than 40 feet, perhaps slightly more. The other was more recent, and the submergence immediately preceded and was about 20 feet greater than the present one. Wentworth has named the stage at 40 feet the Waialae stage, and the more recent one, which he believed to be at about 12 feet, but which was really about 20 feet, he has called the Hanauma stage.

The materials which filled the bay have been of three quite different kinds, chemically and physically: first, calcium carbonate, precipitated in sea water by marine plants and animals; second, volcanic tuff or ash thrown by explosive eruptions from the Salt Lake group of craters; and third, silt or mud brought down from the surrounding high land by the erosional action of fresh-water streams. The eastern third of the bay was filled chiefly, though not exclusively, by the tuff from the Salt Lake and Makalapa craters. Much of the tuff was thrown by the immediate force of the eruptions to its present resting place, and massive beds of this were probably continuous as far as Kuahua Island to an altitude of approximately 20 feet above present sea-level. Those massive beds were not continued across East Channel as far as Ford Island, at least not above present sea-level.

The finer ash from the Salt Lake craters drifted with the trade winds and formed a broad, gently sloping ridge which extends continuously as far as the main channel, where the upper layers of it are interstratified with calcareous materials, and at the top are covered by calcareous deposits in which corals are easily

recognizable in considerable quantities. This same relation of calcareous and tufaceous materials may be seen at the seaward ends of both Ford Island and Waipio Peninsula, but they do not by any means compose the whole of those land masses.

The eruptions from the Salt Lake craters were in operation at the 40-foot stage and Makalapa Crater, the last of the craters in this vicinity, came to an end at the 20-foot stage. During the earlier and greater submergence, there were shoals, but no peninsulas nor islands and no definite channels in the harbor, and the entrance was five miles or more wide. At the 20-foot level there were several islands in the harbor with channels between them, through which tidal currents flowed about as now, but with a channel across Waipio Peninsula where none now exists. While a remnant of the bottom of the former Middle Channel with a part of its shore cliff may be seen as a portion of the northwestern shore of Ford Island along the Middle Channel, the bottom at the center of the old channels was still about 14 to 16 feet below present sea-level. After the shift that brought the sea to its existing level (whether by a rising of the land or a sinking of the sea itself is not considered here), the present channels, except one; were eroded in the bottoms of former channels, and they have approximately the same depth now as the earlier ones below their respective sea-levels. The channel between Kuahua Island and the adjacent eastern shore was not formed by erosion, but it and other depressions both in the sea bottom and on the land in this vicinity, were probably formed mainly by local subsidence accompanying some of the volcanic eruptions in this region. None of the land forms in Pearl Harbor owe either their shape or their topography to subaërial erosion, except to a very minor degree. The materials composing them have been deposited in the sea, and the land forms have been shaped by the sea, that is, by tidal currents and wave erosion at present and former sea-levels.

The lochs of Pearl Harbor are not the product of subaërial erosion, forming dendritic valleys. They are much too broad and pouch-like at the head for that interpretation. For the most part they are areas that have never been filled to any greater degree than now, because the fresh water pouring into the bay prevented the growth of marine organisms that without this fresh water would have completely filled Pearl Harbor as it built up the coral plain to the westward. Wave erosion at present and former sea-level has modified the lochs to a small degree relatively, and stream erosion is filling them with silt. Five factors combined in filling Pearl Harbor and have worked together in such a way that at all stages in the filling process and at all the different levels of sea and land that have intervened since the semicircular bay was first outlined, the mouth of the harbor has filled up somewhat faster than the inner bays. The first factor is the marine currents along the shore, which deposit sand and other materials that they carry, behind projections, points of land or similar obstacles, arid across the mouths of open bays. The second is the waves of the open ocean which break on approaching the shore, and toss up sand banks across the mouths of open bays; the tidal currents sweeping into and out of the bays only in part counteracted those two tendencies to fill the harbor mouth, but finally it was filled to sea-level or slightly above, except for a relatively narrow and shallow channel. The third factor is the growth on the sea bottom of marine plants and animals that secrete calcium carbonate. These have played a large part in forming the visible deposits in Pearl Harbor, particularly since the bottom was filled to a level at which these organisms could grow throughout the area of the bay except along the inland shores, where the inflow of fresh water prevented it. The fourth factor, and this has been especially effective in the eastern part of Pearl Harbor, has been the volcanic eruptions from the Salt Lake craters. The massive deposits, thrown to their present location by the immediate force of the explosion, do not extend quite half-way across the original basin above present sea-level, but the finer ash was carried by the trade wind farther to the southwestward and exactly in the direction to fill up the mouth of the harbor. These wind-carried deposits fell into the sea, and they are now to be seen along certain parts of the channels, but tidal currents readily swept them away to a sufficient amount to keep shallow channels open, even though they built up deposits to sea-level in the quieter waters. The fifth and last factor is fresh water poured into the inner bays. It diluted the sea water to such an extent that marine organisms could not grow on the inner border of the bay and thus the lochs were never filled. The effectiveness of this factor may be inferred from the fact that in all the coral seas of the world such basins remain more or less open as "natural harbors" opposite the mouths of all streams of considerable size. The slope of the land around Pearl Harbor causes a number of the largest streams on the island to converge toward it, and their combined supply of fresh water has been sufficient, at all stages of its development, to keep open the unusually broad bays, the lochs of Pearl Harbor. The silt brought by the fresh-water streams has not been sufficient to keep pace in filling the inner bays with the marine agencies tending to fill the mouth of the bay, and those parts within the mouth of the harbor where the sea water was not diluted sufficiently to prevent the growth of marine organisms.

Southeast Loch, as well as the channel between Kuahua Island and the adjacent shore, probably owes its origin to local subsidence in the tuff layers which form the shore of that loch. The conclusion of the whole study is that the simple interpretation of Pearl Harbor as a series of drowned dendritic valleys, formed by subaërial erosion, is entirely inadmissible. Except for the deposits of volcanic tuff and some probable local subsidences in those deposits on the eastern shore, the land forms in the harbor are marine deposits, have been shaped almost wholly by marine agencies, and subaërial erosion has modified their topography to a very slight degree.

The channels have been formed by tidal currents and wave erosion, and the three main lochs have never been filled to much greater extent than now.

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* Paper No. 279 from the Department of Botany, University of Michigan.

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[15] Pollock, J. B., as cited in note 4.

[16] Wentworth, C. K., p. 119 of bulletin cited in note 3.

THE STATUS OF LAKE ERIE IN PRESENT AND RECENT LAND-TILTING

FRANK BURSLEY TAYLOR

IN A paper presented before this Academy two years ago, the studies of Dr. G. K. Gilbert and Mr. Sherman Moore on present tilting of the land in the region of the Great Lakes was reviewed with some care, and the bearing of certain well-determined geological facts upon their results was pointed out. Both authors made painstaking studies of the gage readings of the water levels made by the U. S. Lake Survey, Gilbert's covering the period 1875-1895, or twenty years; Moore's covering the period 1895-1925, or thirty years next following Gilbert's period. All of Gilbert's data were available to Moore, so that the whole period studied by Moore was fifty years. Their results may be briefly summarized as follows:

Gilbert found that the average rate of present uplift amounted to 0.41 feet per 100 miles per century. By the same method Moore found for his thirty-year period 0.43 feet per 100 miles per century. But in determining the rate, neither of these authors took account of the fact that the uplifting, tilting movement did not affect the whole region covered by the gage readings.

In the detailed study of the ancient shore-lines of the Great Lakes, as set forth by the writer in the second half of *Monograph 58, U. S. Geological Survey* (1915), isobases marking lines of equal elevation or contours on the tilted plane show that the tilted surface declines toward the south-southwest (about S. 22° W.) to a certain line at which the tilted attitude of the ancient beaches ceases to exist. Beyond that line to the south the ancient shore-lines are now horizontal, as nearly as can be determined. This line, therefore, is the isobase of zero. It is not so sharply defined as is shown on the map, Figure 15, but in the field its place is easily limited to a belt three to five miles wide, and with more points of measurement might be located within a mile. For convenience, this line is called the hinge-line, and the relatively wide area extending toward the south, in which no measurable tilting is recorded, is called *the area of horizontality*. The older beaches had their hinge-lines a few miles farther south than the later ones (see *Monograph 53*, pp. 405 and 502-505). The Whittlesey hinge-line is the earliest one known. It is shown by a light broken line in Figure 15. The hinge-line of Glacial Lake Algonquin and also that of the later non-glacial Nipissing Great Lakes occur together, no shifting of the line having taken place in the transition to the later stage, as shown in Figure 15. This line appears also to be the present hinge-line or zero isobase, for so far as careful observations have revealed, all the post-Nipissing beaches, including the Algoma beach and later fainter ones, appear to descend to this same line; and these are the latest or most recent of the abandoned shore-lines.

In determining the present rate of tilting, it is obvious that no true result can be obtained without taking account of the hinge-line and the area of horizontality. Recalculating the rates obtained by Gilbert and Moore, with proper allowances for this element of the problem, the writer found that the rate of tilting now going on north of the Algonquin-Nipissing hinge-line in Lakes Michigan and Huron is about 1.48 feet or, roughly, 1.5 feet per 100 miles per century. This epitome of the earlier paper seemed necessary in order to make clear what is now going on in the basin of Lake Erie.

For lack of space, the case for Lake Erie was not discussed in the paper presented two years ago. But the status of this lake in present and recent land-tilting is of considerable interest and importance. The present or Algonquin-Nipissing hinge-line crosses Saginaw Bay and the south part of Lake Huron, as shown in Figure 15, and is determined with considerable accuracy. If it be produced as a straight line running S. 78° E. across

southern Ontario and Lake Erie, it will pass three or four miles north of Dunkirk, New York, and about 32 or 33 miles south-southwest of Buffalo, measured on the line of maximum rise which runs about N. 22° E. The outlet of Lake Erie being at Buffalo, which is within the area of recent and present land-tilting, makes the case of Lake Erie very different from that of Lakes Michigan and Huron in relation to present tilting. (The base used for drawing this hinge-line was the U. S. Lake Survey Chart of the Northern and Northwestern Lakes.)

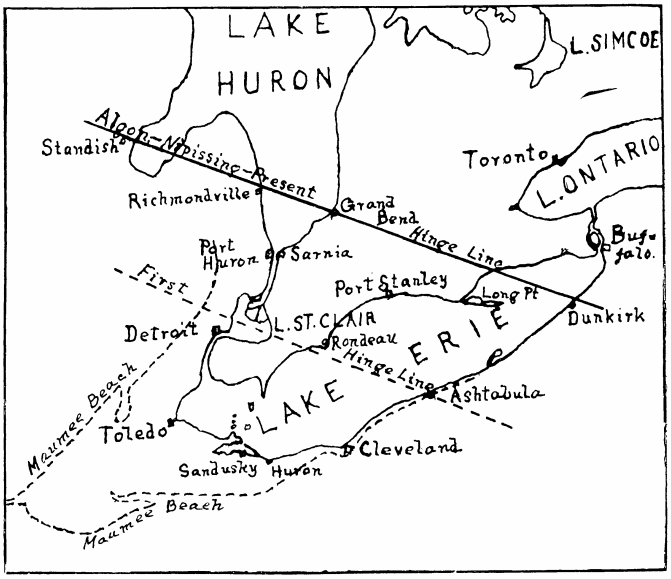

FIG. 15. Sketch map showing the place of the Algonquin-Nipissing-Present hinge-line and its production E. S. E. over Lake Erie. The Maumee beach is the oldest of the glacial lake beaches and is substantially horizontal from Fort Wayne, Indiana, to the First or Whittlesey hinge-line. The present area of horizontality extends up to the present hinge-line, beyond which, toward the north-northeast tilting is now going on.

In the absence of facts to the contrary, it is assumed for the purposes of the present paper that the Algonquin-Nipissing hinge-line is projected straight across southern Ontario and the north-east end of Lake Erie, as shown in Figure 15. But it is to be remembered that this line does not and has not recently served as a hinge-line for the surface of the waters of Lake Erie, because Lake Erie's outlet is at Buffalo, and Buffalo is within the area of tilting and uplifting. Every inch that Buffalo is uplifted carries the water of Lake Erie up on its shores just that much, over the whole area southwest of the hinge-line, and in a diminishing amount northeast toward Buffalo. The hinge-line is, therefore, a submerged one, and is being submerged more and more deeply as the uplift at Buffalo goes on. The water is slowly rising on all the shores of the lake, except at the head of Niagara River at Buffalo. Over the submerged hinge-line, and at all points to the south and west, the water level in Lake Erie is rising at the same rate as the land is being uplifted at Buffalo. Taking Buffalo to be 32 or 33 miles north of the submerged hinge-line in the line of maximum rise, and by calculating the present rate of rise on the same basis as was employed in the calculation for Lakes Huron and Michigan, it is found that Buffalo, being only about one third of 100 miles north of the hinge-line, is being uplifted at about one third of the rate found for points 100 miles north of the hinge-line in Lake Huron or about 0.5 of a foot (six inches) per century. This is the theoretical solution of the problem. What facts are available for testing it?

The most important facts bearing on this question are those collected some years ago by Professor E. L. Moseley, formerly of the high school at Sandusky, Ohio, now head of the science department in the State Normal College of Northwestern Ohio, at Bowling Green.[1] Moseley found several different lines of evidence which, taken together, show conclusively that for more than a century and probably much longer the water of Lake Erie has been slowly rising and flooding the lands around the western part of the lake. Moseley found that all the streams which enter the western part show distinct evidences of drowning in recent time. The Huron River is a small stream, but it has deep, quiet water for five miles up from its mouth. Moseley traced the former bed of Sandusky River and several of its tributaries across the floor of Sandusky Bay, the general floor being a hard clay soil, while the old river beds are filled with soft fine mud of recent accumulation. Some of the drowned beds show a depth of 32 feet, while the former level of the lake at Sandusky could hardly have been less than 12 or 15 feet lower than now, with the beds eroded below that level. It is well known that the waves of a rising lake attack and erode the shore with much more power than do those of one whose level is not rising, and more than one whose level is falling. All around the western end of the lake, the loss of land to the lake by erosion of the shore has been relatively rapid in the last century and in recent decades. Certain islands near the mouth of Sandusky Bay have been entirely destroyed by wave action. Changes in the gravel and sand ridges of Cedar Point and of Sand Point opposite show the same order of change — a rising lake level. In many places stumps of large trees two to three hundred years old were found permanently under water. Some of them, such as black walnut and certain kinds of oak, do not grow in low, wet ground. In certain caves on Put-in-Bay Island there are stalagmites and stalactites now permanently submerged. The caves must have been above lake level when these forms were made. Moseley studied the flora of the islands, and found that the plant population shows clearly that the islands must have been a part of the mainland for a long time after the disappearance of the Wisconsin ice-sheet and its accompanying glacial lakes, before the recent rising of the waters flooded the low ground and separated the islands from the mainland. Moseley's papers contain much detailed and varied information which cannot be presented here.

My own investigations in the same region, carried on in connection with the study of the history of the Great Lakes, showed many facts of the same kind and bearing, especially with reference to the drowning of stream valleys and the erosion of the shore, but my work

was not as thorough as that done by Moseley. I found that the cutting away of the shore was very extensive on the north side of the lake also. Near Port Alma, midway between Point Pelee and Rondeau, the crest of a rather heavy water-laid moraine lay at least a mile or two to the south when the glacial lake waters withdrew, and subsequently small streams which drained toward the north made little valleys eight or ten feet wide and four or five feet deep. Since then the main part of the moraine has been cut away and the little valleys have been decapitated. It seems probable that at least three or four miles of the shore has been cut away in this place. Again, at Port Stanley, midway between Rondeau and Long Point, the recession of the shore has been very heavy. Long Point is a great spit built out from a projecting point of the north shore by shore-currents moving from the west. Its length of 20 miles and the fact that its outer part is projected into water 20 to 25 fathoms deep show the great work done by the waves on the shore to the west. The arrangement of the gravel and sand-bars of which the point is made is also very significant. They show clearly that early in its history the shore for many miles to the west was much farther out (toward the south) than it is now. It seems quite probable that at least ten to twelve miles of land has been cut away off Port Stanley. Presque Isle Point at Erie, Pennsylvania, is of the same origin, but the shore to the southwest was much less favorable for rapid and deep recession. The fact that the lake level was slowly rising for several thousands of years and that the area of the lake was constantly expanding greatly increased the efficiency of the waves in cutting away the shore.

From a study of the old ridges in the ridge section of Cedar Point, Moseley deduced a rate for the tilting of the land which caused the drowning, and found that the lake level has been rising at the rate of 2.14 feet per century (pages 223-236 of third paper referred to above). But the length of time covered by the data available to Moseley was relatively short, and several of the factors involved are incapable of exact valuation. It is believed that the rate obtained from the corrected results of Gilbert and Moore, as given above, is probably much nearer the truth, and it has the great advantage that it can be quite closely checked by data from Niagara history and also from the history of the upper lakes.

The history of Lake Erie is very closely associated with the history of Niagara River and the Falls.[2] The newest section of the Niagara gorge, the section now being made by the present cataract, is called the Upper Great gorge. It begins about 500 feet above the upper railroad bridge, and extends about two and one-fifth miles up to the present Canadian or Horseshoe Fall. It is wide and deep, and was obviously made by the falls with 100 per cent volume, i.e., with the full discharge of the four lakes above the falls. The recession of the Canadian Fall is somewhat irregular in its rate, but a calculation made in 1913, based on all of the surveys from the first by James Hall in 1841, showed the rate to be approximately 4.5 feet per year. If this rate were exact the time taken to make this section would be about 2800 years. The time has generally been stated as 2700 to 3000 years, but there are certain features in the Upper Great gorge which strongly suggest some slowing of the rate and hence a slightly longer total time. Beginning at a point about one third of a mile north of the International Bridge, the heavy, massive, capping layer of the Lockport dolomite is about 40 feet thicker than it has been in the last mile of the gorge-making. This is believed to justify the extension of the estimated time from 2700 or 2800 years to 3000 years, and the latter number is, therefore, taken as probably nearest to the truth.

During the whole time of the making of this section, Lake Erie has been at high stage, receiving the full discharge of the three lakes above, and discharging this in addition to its own overflow through Niagara River, thus giving the cataract 100 per cent volume. Moseley's observations cover about the last tenth or eleventh of the time of this period. If for thirty centuries the rate of uplift at Buffalo has been 0.5 feet per century, the water level in the west end of the lake ought to have risen about 15 feet in the 3000 years since the Upper Great gorge began to be made and the full-volume cataract began work close above the railroad bridges. The old lake-level or base-level, to which Moseley found the tributary streams had been cutting when the lake was at low stage, was about 12 to 15 feet below present lake-level. Thus, his result agrees very closely with that obtained from the corrected results of Gilbert and Moore checked by the time factor obtained from the making of the Upper Great gorge of Niagara. Moseley's rate of tilting as affecting Lake Erie is more than four times greater than that obtained by the other method, but it is to be remembered that his papers were published long before any attempt had been made to extend the corrected rate of uplift to Buffalo or Lake Erie.

When the retreating Wisconsin ice-sheet withdrew from the Mattawa and Ottawa valleys between North Bay and Pembroke, Ontario, the whole discharge of the three upper lakes passed eastward through these valleys to the sea near the latter place, leaving Niagara with only the overflow from Lake Erie, which is equal to about 15 per cent of the full four-lake volume. For 2000 or 3000 years before this time, Niagara had had full four-lake volume, while the Lower Great gorge was being made, but now 85 per cent of its volume was suddenly taken away. In the gorge, this event is marked by the sudden and strongly marked narrowing and shallowing at the south side of the Eddy basin which lies next north of the gorge of the Whirlpool rapids. But the tilting of the land was constantly going on, and the place of the outlet at North Bay was finally raised to a higher level than the outlet at Port Huron, and the discharge of the Upper lakes then came back to Lake Erie and Niagara. The place marking this event is close above the railroad bridges, where the gorge suddenly becomes wide and deep. The gorge of the Whirlpool rapids is about three fourths of a mile long and is narrow and shallow as

compared with the full-volume gorge sections next above and below. This section is the precise correlative of the period during which the North Bay outlet was active, and since, from the rate of erosion of the Upper Great gorge, we found that it was about 3000 years since the full-volume cataract began work just above the railroad bridges, it is also about 3000 years since the outlet at North Bay was closed. On the line of maximum rise on the tilted plane, about N. 22° E., the distance from Port Huron to North Bay is about 238 miles. At this distance north of the isobase of zero, the rate of uplift at 1.48 feet per 100 miles per century would be 3.52 feet per century, and in 3000 years the total amount of uplift would be 105.60 feet. As determined by instrumental surveys made by J. W. Goldthwait and the writer in 1908, the Nipissing beach at Sarnia has an altitude of 597 feet above sea-level, or 16 feet above Lake Huron at that time. At North Bay the same beach was 698 feet above sea-level, or 117 feet above Lake Huron.[3] This makes the Nipissing beach at North Bay 101 feet above the same beach at Sarnia, and the outlet at North Bay has, therefore, been uplifted by the tilting of the land by that amount in the last 3000 years, approximately, or since that outlet was abandoned. This result of 101 feet by instrumental survey compares rather closely with 105.60 feet, as determined from the corrected calculations of Gilbert and Moore from gage readings covering a period of 50 years (1875-1925). From results so accordant as these, showing only 4.60 feet difference, one may project the line by extrapolation to Buffalo and Lake Erie with some degree of confidence that it will not be far from the truth. But of course the small difference of 4.60 feet cannot be depended upon as wholly accurate; it is probably in some measure accidental, but may be taken as showing that the accordance is close.

In approximately 3000 years, then, the waters of Lake Erie south and west of the submerged hinge-line have risen something like 15 feet. To ignore the recent very low stage, which is probably temporary, the difference between the levels of Lake Michigan-Huron and Lake Erie was about eight feet. If the tilting, with uplift at Buffalo, goes on at the same rate in the future, these lakes will come to one level in about 1600 years. If we suppose the original rock still at the head of the outlet at Chicago to have been eight feet above Lake Michigan, it would take about another 1600 years for the water to begin to flow over at Chicago, and perhaps still another 1600 years before the whole discharge would pass that way. This, as now interpreted, would be the course of nature undisturbed if the rate of tilting is uniform. But with man interfering both at Chicago and Buffalo, the direction and amount of discharge will probably be controlled, and safe predictions can hardly be made. Cities, towns and harbors on Lake Erie and Detroit River will be seriously affected by the rise of Lake Erie, and those on Lake St. Clair and St. Clair River in less degree.

Tilting of the land in the region of the Great Lakes had been going on for a long time before the beginning of the period here discussed (reaching back about 3000 years). Gilbert and Spencer picture Lake Erie at its first stage as an independent lake following the retreat of the Wisconsin ice-sheet, and as extending from Buffalo only about as far west as Erie, Pennsylvania — but that is a rather long and complicated story, and will not be entered into here.

FORT WAYNE, INDIANA

[1] (1) "Lake Erie Enlarging," *The Lakeside Magazine*, Lakeside, Ohio, 1 (April, 1898): 14-17; (2) "Submerged Valleys in Sandusky Bay," *Nat. Geog. Mag*. 13 (1902): 398-403; (3) "Formations of Sandusky Bay and Cedar Point" (Ohio), President's Address in *Proc. Ohio Acad. of Sci*., 14 (pt. 5, 1905): 179-238.

[2] *The Niagara Folio, U.S. Geological Survey*, Folio No. 190, 1913, by E. M. Kindle and Frank B. Taylor. See large-scale map of gorge.

[3] *U. S. Geological Survey, Monograph* No. 53, 1915, p. 459.