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LETTER OF TRANSMITTAL.

TO HON. ALBERT E. SLEEPER, *Governor of the State of Michigan:*

SIR—I have the honor to submit herewith the XIX Annual Report of the Michigan Academy of Science for publication, in accordance with Section 14 of Act No. 44 of the Public Acts of the Legislature of 1899.

Respectfully,

I. D. SCOTT,
Secretary.

Ann Arbor, Michigan, June, 1917.

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ADDRESS OF THE PRESIDENT OE THE MICHIGAN ACADEMY OF SCIENCE.

Delivered March 28, 1917, at the Auditorium, Natural Science Building.

THE MAKING OF SCIENTIFIC THEORIES*.

BY WILLIAM H. HOBBS.

The ancient Hebrews conceived the earth to be a disk hemmed in on all sides by mountains and surmounted by the crystal dome or firmament of the "heavens." This covered disk floated upon "the waters under the earth" and from the "windows of heaven" waters were poured out upon the "thirsty earth" from another reservoir which was above the firmament. To the denizen of the humid temperate regions it is perhaps a little difficult to see how this theory could have come into existence. The rains with which he is so familiar are showers, and they suggest not so much windows in the sky as they do a ceiling with innumerable perforations or some other glorified sprinkling device. To the Children of Israel the phenomenon of showers was unknown, for the rains to which they had become accustomed both during their wanderings in the desert of Sinai and in Palestine were of the local downpour or cloudburst type, the characteristic precipitation of the arid lands. So also their country was one in which earthquakes have been frequent, and they were not unaccustomed to seeing the earth open and water shoot upward from the fissures in much the same manner that it spurts into the hold of a ship from the opening of a seam. This oft-observed phenomenon is with little doubt responsible for the conception of the "waters under the earth" referred to in the twentieth chapter of Exodus. We see, therefore, that this crude theory of the world which was held by the early Hebrews and which appears to us so fantastic, was, after all, based upon facts, but like many theories which have followed it, upon too small a body of fact to supply a firm foundation.

It has often been said that the theories so tenaciously held by one generation are abandoned by the next. To a large extent this has been true of the past, and the explanation is in part that scientists are not less fallible than others, but are subject to like limitations in prejudice, in undue reverence for authority, in regard for the science vogue of their time, and in many other conditions. To an even greater degree the overturning of scientific doctrines has been due to the failure of both the scientists and their critics to distinguish clearly between legitimate theory within those fields where views may be rigidly tested, and audacious conjectures which have been offered under the verisimilitude of facts to explain problems whose complete solution belongs to the remote future, if they may not be regarded as insoluble by any methods which have yet been discovered.

The process of eruption within a volcanic vent as regards its physical and chemical aspects offers a problem which, though by no means simple, may yet be subjected to observation and experimentation and doubtless belongs to the realm of soluble scientific problems. The materials present at the earth's center and their peculiar state of aggregation, are by contrast very largely a subject of conjecture, and attempts to class these problems together lead to inexcusable confusion.

A theory has been defined as an explanation founded upon inferences drawn from principles which are established by evidence. By contrast the hypothesis is a supposition as yet untested. The working hypothesis of the scientist occupies an intermediate position and aims to explain, at least in part and better than any other, a set of related phenomena which are already known, and it is considered to be in a probationary stage until confirmed through rigid tests the nature of which is suggested by the hypothesis itself. When so examined it may be found wanting; but, if well founded, experimentation is likely to result in its improvement by pruning of error quite as much as through enlargement of the body of truth which it contains.

The inheritance of knowledge by the ancients was, compared to ours, small indeed; and with their limited resources in materials and in methods of investigation, even more than we, they saw "through a glass darkly." It was therefore but natural that the theories which they evolved should have been largely the product of introspective reasoning. In consequence it was in the field of mathematics that they achieved their greatest triumphs, and as an inheritance a mathematical language was common to other fields of science even late in the seventeenth century. Viewing the marvels of the universe with their limited outfit of exact knowledge, the ancient philosophers invoked the supernatural and the mysterious to explain whatever was baffling and otherwise incomprehensible. Without books the dissemination of knowledge was limited to the narrowest channels and was accomplished by the disciples of each leader of thought, who was thus under the temptation of finding an answer to all questions and founding an individual school of philosophy.

With the invasions of the barbarian Huns and the Germanic tribes in the fifth century of the Christian era, there ensued the eclipse of civilization which we are accustomed to refer to as the "Dark Ages." Out of the darkness of these centuries of intellectual stagnation we

catch a glimpse which indicates that individual minds were still active in their search for the truth.

It is the twentieth day of June in the year 1330. The bells of Verona arc ringing in the bright Sabbath morning and the crowd is saluting with respect a tall and serious figure—the great Dante—who with slightly bowed head is entering the chapel of Santa Helena. Dante has today invited the whole educated world of Verona to assemble in this chapel and listen to his discourse entitled '*De acqua de terra*." He proposes to discuss the relative position of land and sea, and as he tells us himself, every one came at his bidding, "with the exception of a few, who feared by their presence to confirm the exceptional importance of others." . . .

With a gift for picture-writing never before equaled he has led his astounded contemporaries up to the abode of the saints and down into the depths of the lower world. Now today he is returning to the starting-point of his most powerful creation, to the critical examination of that which is greater than all the conceptions of poetry—the actual ordering of the universe.

Dante argued cogently for the spherical form of both the earth and the seas, and in accounting for the elevation of the land areas above the oceans, he even offered an early hint of the law of gravitation. The earth, he argued, can not elevate itself; nor can the cause be water, fire or air. He therefore suggested that the fixed stars might exercise this influence "*after the manner of magnets*."

The new era which opened with the revival of learning after a thousand years of stagnation, was one dominated by new considerations within the realm of thought. The keynote of the period was the dominating influence of the Christian church, and for centuries all thinkers were required to make their expressions conform to the dogmas of the church of Rome. The emancipation supposed to have arrived with the Protestant Reformation was a partial one only, and complete freedom of thought was not secured until the modern period of science was ushered in in the latter half of the nineteenth century.

Living as we do when few obstacles are opposed to a full and free expression, it will be profitable to review by means of examples the position of science in the sixteenth and seventeenth centuries. In declaring his belief in the heliocentric theory of the planets which Copernicus had promulgated, Galileo in 1597 wrote cautiously to Kepler:

It explains to me the cause of many phenomena which according to the generally accepted view are entirely incomprehensible. I have assembled many arguments for combatting the latter, but I do not dare to bring them into the light of publication. I would certainly risk it if there were more men like you.

With the telescope which he invented Galileo nightly studied the heavens from his little tower in the outskirts of Florence, and to his friend lie unburdened his soul in unbounded admiration for the works of his Creator. He writes:

The prohibition of science would be contrary to the Bible, which in hundreds of places teaches us how the greatness and the glory of God shine forth marvelously in all His works, and is to be read above all in the open book of the heavens. And let no one believe that the reading of the most exalted thoughts which are inscribed upon these pages is to be accomplished through merely staring up at the radiance of the stars. There are such profound secrets and such lofty conceptions that the night labors and the researches of hundreds and yet hundreds of the keenest minds, in investigations extending over thousands of years would not penetrate them, and the delight of the searching and finding endures forever.

From this revelation of intellectual exaltation in one of the greatest apostles of science of all time, it is necessary to turn to a far different scene staged in one of the dark chambers of the Inquisition, if we would correctly interpret the spirit of his age. Bowed with years and threatened with the cruel torture, Galileo is seen kneeling before the crucifix and repeating in broken sentences the dictation of his persecutors:

I bow my knee before the Honorable General Inquisitors, and touching the holy gospels I do promise that I believe and in future always will believe whatever the church holds and teaches for the truth. I was commanded by the Holy Inquisition that I should neither believe nor teach the false doctrine of the motion of the earth and the stationary attitude of the sun, because they are contrary to the Holy Scriptures. In spite of it I have written and caused to be printed a book in which I teach this cursed doctrine and have brought forth arguments in its favor. I have on this account been declared a heretic and worthy, of contempt.

In order now to redeem myself in the eyes of every true Christian who with justice must hold me in contempt, I forswear and curse the errors and heresies referred to, and above all every other error and every opinion which is contrary to the teaching of the Church. Also I swear in future never either in spoken word or in writing to express anything on account of which any one could have me in like contempt, but I will, if I anywhere find or suspect heresy, reveal it at once to the Holy Tribunal.

It is not pleasant to dwell on the extreme conditions which determined the making of theories at this period and which continued for fully a hundred years beyond the time of Galileo. For advocating the Copernican doctrine Giordano Bruno was burned at the stake. More prudent, de Maillet left his theories of nature to be published only after his death and then with his name disguised as Telliamed through printing the letters in reverse order; while Scheuchzer avoided persecution by describing as a human victim of the Noachian deluge a gigantic fossil salamander, and thus became the butt of succeeding generations. Steno, "the wise Dane," through enjoying the favor of a powerful Christian prince, was more fortunate than most of his contemporaries, and has left us in his "Prodromus" one of the great scientific legacies of his age, now accessible to all through the excellent translation from the Latin by Professor Winter.

Inductive methods of reasoning came to play a larger part in the construction of theories as the control by both branches of the Christian church began to be relaxed. The feeling of relief from restraint brought, however, a reaction in what was almost an epidemic of theories characterized by a carelessness of construction and an

insecurity of foundation that were surpassed only by the ardor and the vindictiveness with which they were defended. The latter half of the eighteenth and the first part of the nineteenth centuries was thus a period characterized by notable controversies in science which affected the greater part of Europe. Theories were attacked or defended with almost fanatical bitterness, the aim of the advocates of each theory being apparently less to arrive at the truth than to win in the struggle. Geologists were divided into two hostile camps over the origin of basalt; the Neptunists led by the Freiberg school of Werner in Germany claiming that it was a chemical precipitate in the ocean, and the Vulcanists who followed James Button of Edinburgh and believed the rock to be a product of the earth's internal heat. National boundaries were largely broken down and some of the most pertinacious and vindictive of the Wernerians were to be found in the British Isles.

On the other hand, the Neptunists had to meet in Germany a formidable champion of vulcanism in the poet Goethe, who, like Dante five centuries earlier, had a keen interest in science. For a time the bone of contention was found in a small hill near Eger in Bohemia, known as the Kammerbühl, a hill which Goethe stoutly maintained was "a pocket edition of a volcano." He suggested a simple method by which the question might be settled, and proposed that a tunnel should be driven into the hill to its center. If the mountain was a volcano, as he believed, a plug of basalt should be found occupying its axis. A wealthy friend, Count Casper von Sternberg, undertook extensive excavations, which when completed in 1837 abundantly proved the correctness of the poet's position.

Another great controversy was waged over the theory of the German geologist von Buch, known as the "Elevation Crater Theory," which assumed that volcanoes were pushed up in much the same manner as is the cuticle in the formation of a blister upon the body. Like the theory of the Neptunists, this doctrine was overthrown as soon as inductive methods of examination were applied to it.

Two doctrines of geology which, were destined to play a large role; in the history of science were developed, in France. The '"pentagonal network" theory of Élie de Beaumont furnished the age of every range of mountains from the direction of its trend referred to the cardinal points; while the cataclysmic theory of Cuvier held that the earth's history had been punctuated by great cataclysms resulting in the destruction of all life upon the globe and followed always by a recreation of new faunas and floras. These doctrines, like those emanating from Germany, were destined to succumb to the rigid tests of the observational methods.

The control of scientific theory by the Church whenever it felt that its doctrines had been invaded was, if less formal and direct, none the less potent even as late as the latter half of the nineteenth century. This became apparent so soon as attacks began to be made upon the theory of catastrophism, for this theory was regarded as harmonizing with the biblical account of the creation. The evidence for the overthrow of this doctrine had been long collecting by a group of giants in science which developed in England toward the middle of the nineteenth century and which included Darwin and Huxley, Wallace, Lyell and Hooker. In the field of geology Lyell's theory of uniformitarianism was the counterpart of evolution in the organic world.

The battle was joined in 1859 with the appearance of the "Origin of Species," and it was fortunate for the scientific world that the crisis brought to the front a Huxley who could face "such a storm of wrath and flood of contumely as might have overwhelmed a less resolute and clearheaded champion." Gifted with a clarity of thought and expression and a vigor of utterance which are without a parallel in the whole field of science, Huxley had an utter contempt for dishonesty in thinking and little patience with mere meta-physical abstractions. To his friend Kingsley in one of the most remarkable of all his writings he says:

> I have champed up all that chaff about the ego and the non-ego, about noumena and phenomena, and all the rest of it, too often not to know that in attempting even to think of these questions the human intellect flounders at once out of its depth.

He correctly gauged the nature of the struggle which was coming and to Darwin he wrote on the appearance of the "Origin of Species":

> I trust you will not allow yourself to be in any way disgusted or annoyed by the considerable abuse and misrepresentation which, unless I greatly mistake, is in store for you. Depend upon it, you have earned the lasting gratitude of all thoughtful men. And as to the curs which will bark and yelp, you must recollect that some of your friends, at any rate, are endowed with an amount of combativeness which (though you have often and justly rebuked it) may stand you in good stead. I am sharpening up my claws and beak in readiness.

It was not long before the stage was set for one of the most dramatic moments in the history of science, for the British Association for the Advancement of Science was to meet at Oxford in 1860, and it had been given out that the Bishop of Oxford had determined to "smash" Darwin. The meeting place in the medieval university building was in consequence crowded to suffocation with even the window ledges occupied by university dons keen for the excitement of the contest. By a mere accident and at the last urgent request of his friends Huxley reluctantly agreed to be present, for he rightly believed that an appeal would be made to the emotions and to prejudice, and he feared no good could come from the scientific argument. It was the tremendous success which he here achieved that fully decided him to take up the cudgels for Darwin, and at the sacrifice of being branded as a heretic during much of his lifetime, he was destined to go down to posterity not only as the magnificent protagonist of the doctrine of evolution, but as the redoubtable champion of freedom of thought within the whole realm of science.

Of the encounter at the Oxford meeting there are a number of contemporary accounts, one of which says of the Bishop's address:

In a light, scoffing tone, florid and fluent, he assured us that there was nothing in the idea of evolution, rock pigeons were what rock pigeons had always been. Then turning to his antagonist with a smiling insolence, he begged to know, was it through his grandfather or his grandmother that he claimed his descent from a monkey.

Huxley was sitting beside the venerable Sir Benjamin Brodie, arid at this descent to personalities he struck his hand upon his knee and turning to his neighbor exclaimed, "The Lord hath delivered him into mine hands." Without at all comprehending, Sir Benjamin stared vacantly and the meaning of Huxley's words did not dawn upon him until Huxley had arrived at his famous retort. When the storm of applause which followed the Bishop's address had subsided the president called upon Huxley to reply.

On this Mr. Huxley slowly and deliberately arose. A slight tall figure, stern and pale, very quiet and very grave, he stood before us and spoke those tremendous words—words which no one seems sure of now, nor, I think, could remember just after they were spoken, for their meaning took away our breath, though it left us in no doubt as to what it was.

There was first a calm scientific discussion of Darwin's theory after which Huxley turned to the Bishop to say:

I asserted—and I repeat—that a man has no reason to be ashamed of having an ape for his grandfather. If there were an ancestor whom I should feel shame in recalling it would rather be a man—a man of restless and versatile intellect—who, not content with a success in his own sphere of activity, plunges into scientific questions with which he has no real acquaintance, only to obscure them by an aimless rhetoric, and distract the attention of his hearers from the real point at issue by eloquent digressions and skilled appeals to religious prejudice.

"No one doubted his meaning, and the effect was tremendous. One lady fainted and had to be carried out; I, for one," says the chronicler, "jumped out of my seat."

If the emancipation of science from coercion or restraint from without had arrived with the final triumph of the doctrine of evolution, can it be truly said that theories are constructed even in this generation as the result of a process of wholly untrammeled reasoning; or, on the other hand, is it the fact that with the frailties inherent in human nature they still embody elements of weakness which are due either to the deficiencies in training of their authors, to prejudices or bias conditioned upon time or place, or to some other cause?

It is usually considered to be the special function of a president to recount in his address in particular the great triumphs of science, and to touch but lightly, if at all, upon any less encouraging aspects of his science, I propose in the time that remains to me to pursue a somewhat different course, and by the use of examples selected from the field of my own special studies to discuss what may perhaps be called the psychology of theories and the conditions which determine their acceptance.

To some extent it is inevitable that theories should reflect the individuality or the environment of their authors. This is particularly true in the field of natural science, where the laboratory is the world itself, a portion only of which can be brought under the observation of any one individual. Geological processes are different both in degree and in kind according as they are studied under conditions of aridity or of excessive humidity, under tropic heat or polar cold. It is unquestionable that geology having developed as a science in those temperate regions of moderate humidity which have permitted a high degree of civilization, is correspondingly defective, and must be modified if it is to be universal in. its scope. The physical geology of deserts has been studied seriously only during the present generation. It is within the last decade only that the attention of geologists has been focused upon the subpolar latitudes, and the geology of the tropical jungles is yet to be written.

To indicate how the peculiar environment, the conditions of the time, and the special activities of the individual have left their impress upon a well-known theory, I may cite the case of Robert Mallet and his centrum theory of earthquakes, a theory which received general acceptation and was orthodox doctrine among earthquake specialists for full half a century. Robert Mallet was educated as a civil engineer, and in 1831 became a partner with his father in the foundry industry at Dublin. During the Crimean War he constructed monster mortars of thirty-six inch caliber which embodied new ideas and were completed in 1854. Thus becoming interested in ballistics, he made a thorough investigation of the strains developed by explosions in the chambers of guns, and a monograph upon the subject which he published in 1856 brought him general recognition and many honors. A year later, in 1857, occurred the great earthquake in the Basilicata, generally referred to as the "Great Neapolitan Earthquake," since the district was included in the former kingdom of Naples. Believing himself by reason of his studies of explosives to be specially fitted to investigate this disturbance, Mallet applied to the Royal Society for a grant of money, and his request being-approved, he visited the Basilicata, and in 1862 in two sumptuous volumes the earthquake was explained as the result of an explosion that had occurred in a cavity beneath the region affected, the damage upon the surface being explained under the laws of transmission of stress such as had applied in his earlier researches upon cannon. No one familiar with these circumstances can reasonably doubt that the trend of his theory was already determined by his life history before his sailing from England. It should be added that through giving to the problem of earthquakes a mathematical treatment, Mallet's study had the effect of removing seismology from the field of geology for the period of nearly half a century, and giving it over to the clasticians.

It has not been altogether uncommon for students of science, and even those of the highest rank, when drawing conclusions, to fail to take proper account of the fact that the observed rates of change, or gradients, perhaps of temperature or pressure, which they have been able to verify for limited distances only, may not be assumed to continue indefinitely without interruption or variation. No less distinguished a physicist than Helmholtz on the basis of the known aero-thermic gradient as determined over Europe to a height of about nine kilometers, declared that the atmosphere could not extend beyond twenty-seven or twenty-eight kilometers from the earth's surface, since the absolute zero of temperature would be reached at that level. Sounding of the atmosphere has since been carried to fully twice the limit fixed by Helmholtz, and has revealed the fact that a few kilometers beyond the limit of exploration when he made his prediction, or at an average altitude of eleven kilometers, the aero-thermic gradient is interrupted and succeeded by practically isothermal conditions above.

Today in reputable treatises one may read in round numbers the supposed temperature at the center of the earth, and based upon what? The geothermic gradient determined for the shell of rock immediately beneath the earth's surface and verified roughly for about one four-thousandth of the entire distance to the earth's center. Can we assume that our yard-stick in this instance is suitable for measurement throughout the entire radial distance, and is there no possibility of abrupt interruptions such as occur in the temperature gradient of the atmosphere?

William Ferrel, much the most distinguished meteorologist that America has produced, and the one to whom we owe the basic principle upon which modern meteorology is founded, predicted as a corollary to his theory of the winds the existence of whirls about the earth's geographic poles surrounding areas of calm and low atmospheric pressure. As these polar calms and whirls are an important feature of the present theory of atmospheric circulation, it will be profitable to examine briefly their evolution as a study in the psychology of theory. In the preface to his general treatise upon the winds, Ferrel tells us how his attention was first directed to this subject through reading Maury's "Physical Geography of the Sea," the first edition of which appeared in 1855, while the first essay of Ferrel was published in 1856. From Maury Ferrel learned, as he has told us, "that the pressure of the atmosphere is less both at the poles and at the equator of the earth than it is over two belts extending around the globe about the parallels of 30° north and south of the equator." On making reference to Maury we find that upon the basis of recorded observations between the parallels of 40° and 54° south latitude the average barometer reading varies from 29.9 to 29.4 in passing from the lower to the higher latitude. With the gradient obtained from this limited range, Maury has extended the curve as a straight line to the geographic pole through a range of thirty-four degrees of latitude or more than twice the observed distance, and obtained a theoretical reading for the pole of twenty-eight inches of mercury. A similar method applied to the northern polar region has supplied a less marked gradient and a theoretic value for the barometer reading at the northern geographic pole of 29.65 inches of mercury.

Since this theory was promulgated, exploration has been extended to both poles of the earth and has shown that but a short distance beyond the latitudes which limited the data employed by Ferrel, the steadily lowering pressure gives place to a rising barometer in the direction of the poles. Studies of the free atmosphere by means of balloons in the same high latitudes also indicate pretty clearly that no such whirls as Ferrel assumed can exist. Yet so great has been the success of Ferrel's theory as a whole that despite their contradiction by the facts, the polar calms and whirls are still treated in the latest text-books of meteorology.

The polar whirls of Ferrel are by no means a unique example of a large conception in science receiving general support because however carelessly constructed it was an attachment or rider to a still larger theory. The triumph of the larger idea or the prestige of the author due to some other achievement, has by its inertia carried the smaller conception to general acceptance.

So fundamental a theory as that of Laplace to explain the origin of the universe, a theory which has been standard doctrine for more than a century and is only now being replaced as a result of rigidly applied tests, appears never to have been very seriously considered by its author, but was thrown off as a brief appendix or postscript to a general work on astronomy. It has the curious title "Note VII and Last" and Laplace says of it that the hypothesis must be received "with the distrust with which everything should be regarded that is not the result of observation or calculation." Moreover, so far as known, Laplace never subjected the theory to the test of well-known mathematical principles which were involved, although this was his usual habit. The success and general acceptance of the theory seem to have been due to the altogether remarkable prestige of its author as the greatest mathematician since Newton, and as the author of the "Mécanique Céleste," a work which has never been rivaled in its field, and of which it has been said that any one of its twenty-four parts would have made the reputation of a man of science.

Though primarily a theory of the origin of the universe and thus in the realm of astronomy, Laplace's nebular hypothesis left its impress upon geology and particularly upon geophysics, in that it gave continued standing and scientific respectability to the notion that the earth has a liquid interior. It would be somewhat difficult to trace the origin of this belief, which naturally grew up from the observations of volcanic eruptions—no uncommon event in the Grecian Archipelago and in Italy, the regions where science had its beginnings. After the studies of combustion had exploded the notion of "internal fires," the theory took the form which it has retained to our day little affected at first by the proofs of earth rigidity which

were brought forward by Kelvin. With little doubt the associated idea of a congealed crust floating upon a liquid interior is based upon the analogy with the winter cover of ice which forms over our lakes and rivers. This analogy supplies, therefore, a striking instance of the influence of climate in giving complexion to a fundamental theory, and the fact that rock, unlike water, is heavier in the solid than in the liquid state, is a very recent discovery. Save for its intimate relation to Laplace's theory, the conception of the liquid core to the earth must have long since been relegated to the limbo of exploded doctrines, to the great benefit of more than one of the physical sciences.

It would be easy to show that well-known scientific theories have embodied fatal defects, in that assumptions of vital importance have been introduced quite unconsciously by their authors. I have believed, and have elsewhere attempted to show, that the Pratt-Hayford theory of isostatic compensation, which assumes for every mountain a necessary defect of mass directly below, and for the column below every depression of the earth's surface a corresponding excess of mass; that this theory has been set up without due regard to the dominating effect of any hidden masses of unusually high density which may lie near the observing station. This view seems now to have found confirmation in recent studies carried out by the United States Coast and Geodetic Survey. I may perhaps best illustrate what is here meant by the use of an example taken from a related field of study. If one should ascribe the strong magnetic attraction which is exercised by local masses of iron ore in the Northern Peninsula of Michigan to the effect of such an extended system of smaller masses distributed throughout a large district, as might produce the same effect at a given station, the error would be of the same nature as that which must result from ignoring the effect at the gravity stations of any local and very dense masses which may be hidden beneath the surface.

Does prejudice, either national or racial, ever influence the thinking of men of science? I ask you to look back over the history of the past two and a half years and for the answer examine some of the statements which have been signed by men who were counted among the master scientists of their generation. These sweeping statements were many of them false; and if not known to be by those who subscribed to them, it is clear that an unbiased inquiry must either have revealed the truth or have indicated the necessity of withholding a verdict. This debacle of science which came at the outbreak of the present war is one not easily to be retrieved.

If I have succeeded in my endeavor, I have shown that scientific theories as they are constructed even today with the aid of all modern equipment and inheritance, may contain fatal elements of weakness though they be promulgated by scientific men of the highest rank and attainments. Fortunately the student of science today enjoys an independence which was never vouchsafed him in the past, when the learner was by the conditions under which he studied an advocate of the doctrines of his master. There are today no dictators in science such as were Werner in Germany, de Beaumont in France, Murchison in England, or Agassiz, the "pope of American science." For what he accepts and teaches the student of science is today responsible, and it devolves upon him not merely to examine each theory as regards its inherent plausibility and the degree to which it has been confirmed, but to inquire also into the human and other factors which have entered into it or which have accounted for its acceptance into the body of doctrine of science.

It has seemed to me that the excessive stress which in our science training we now lay upon the careful balancing of evidence, has in a measure taken away our capacity for making decisions. The cult of being open-minded has been elevated into a fetich, with the result that the really vital considerations are often hopelessly entangled with non-essentials. A little reflection must show that upon the principle of chances the weight of evidence in the case of but few problems can be evenly balanced; but a clever exaggeration of the non-essentials seldom fails to raise serious doubts in the minds of a considerable proportion of those considered qualified to reach a decision. Why, if this be not so, have so many of our highly trained scholars failed to see that the events which are now transpiring have long been clearly foreshadowed, and were inevitable results of observed conditions in a world controlled by natural laws. This is due to a lack of vision—of prescience—which above all is dependent upon first clearing away from a question the rubbish which has accumulated about it, and then focusing the attention unerringly upon the heart of the problem.

Lack of vision largely explains the great inertia of science which causes the retention of useless or harmful theories long after their inadequacy or falsity has been exposed, and this inertia is greatly aggravated by potent accessory influences. Any successful theory which occupies a basic position in science, is sure to be built upon as a foundation for other theories, and these are likely to crumble with its collapse. Much money and labor are now invested in treatises and popular works, the income from which becomes seriously affected whenever their reliability is brought into question. The ultra-conservative attitude of scientists which results from these and other causes is as obvious as it is deplorable.

As we look back over the past and, studying the advances of science, mark off upon the way the stations at each of which a new horizon has opened, it is easy to see that the successive marches, like the halts between, have been far too long. The attempt to reproduce from each station the entire panorama of the horizon has led to a sketchiness and an inaccuracy in the depicting of all remoter portions of the field, which might have been avoided had the viewpoint been promptly moved forward so soon, as the nature of the nearer terrane had become firmly established. My appeal is, therefore, for an

individual study of those theories of science with which each worker is concerned, arid for an early decision upon their availability whenever a judgment is warranted. Accepted, if necessary, as working hypotheses to be rigidly tested by observation and experiment, the new ideas are infinitely to be preferred to those theories which have been found wanting under the tests either of experiment or of searching observation..

It might perhaps be asserted that the picture which I have drawn of the past and present of scientific theories is one not calculated to cause entire satisfaction; and. I could, hardly deny the truth of the assertion; but when, I would ask, has either an institution or an individual been other than benefited through a searching self-examination? Even the shock to our self-pride which came with the revelations of this bellum period is not fraught with permanent disaster. Since the condition existed, it is far better that we should know it, and so far as may be possible provide against its recurrence in the future.

The encouraging feature of our entire survey is the evidence which it shows of a steady evolution toward better conditions; for no one can truthfully deny that the scientific world is today in a far better position than it has ever occupied in the past; and the outlook for the future is so much the more encouraging.

University of Michigan.

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19th Mich. Acad. Sci. Rept. 1917.

GEOLOGY AND GEOGRAPHY.

PROPOSAL OF AN AGRICULTURAL SURVEY ON A GEOGRAPHIC BASIS.

BY C. O. SAUER.

The immediate, occasion for this paper is the proposed establishment of a soil survey by the State of Michigan. The creation of such a survey marks an important step in government aid to the development of the resources of the state. The manner in which it is organized at the outset will virtually determine the effectiveness of the entire project. A county is surveyed but once, and afterthoughts are of no avail. A full expression and exchange of opinion by the interested parties is desirable therefore at this time. The geographer is one of these interested parties, not numerously represented to be sure, but as his interests correspond in the main to those of the farmer and business man, their definition may be of general value.

Geography is a young science, concerned with a vast field. It is necessary therefore to select the most urgent lines of study and to concentrate upon these. The most urgent demand of the science is along lines of regional studies, to supply a larger body of systematic observations than are now available. In the prosecution of such studies geography is handicapped by the lack of formal surveys such as have been developed in most of the other natural sciences. In the past there have been so-called geographic surveys. In the future, there may be provision for truly geographic surveys. But at present the geographer must rely in large part on the field work of other scientific organizations, as geologic, typographic, biologic, and soil surveys. The manner of their execution therefore is of great moment to the success of regional geography, on which in turn the development of the entire science of geography depends in considerable measure.

In the United States, the soil surveys are undoubtedly the greatest single aid to regional geography, partly because of the importance of rural interests in our country, but more particularly because of the specific form which the soil survey has taken. It has been conducted almost entirely by the Bureau of Soils of the Department of Agriculture, and as thus carried on has the primary purpose of suggesting improvements in agricultural practice and of guiding the prospective purchaser of land in his selection.* It is evident immediately that such a survey must concern itself with many more things than the classification of soil types and their mapping. The survey inevitably becomes an inquiry into the agricultural conditions and possibilities of the region, or, in other words, tends to become a study in rural geography. Accordingly, it must take into account pretty well the entire rural environment, including not only soils. but surface, drainage, climate, markets, character of population, and stage of development. The Bureau of Soils in its county reports is taking cognizance of a number of factors other than soils. The following notes on their more recent field operations will serve to establish the present scope of these studies.

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*See Whitney, Yearbook Dept. Agric., 1901, 117; Boosted, ibid. 1906, 181; Whitney, Bureau of Soils Circular 13.

The usual unit of Bureau of Soils reports is the county, and the reports as a rule, are highly standardized. With minor variations, the plan of one county report holds for almost all others. The Soil Survey of Cape Girardeau County, Missouri, may serve as a type. It consists of 48 pages and a soil map on the standard scale of one mile to the inch. Almost exactly one-half of the text is devoted to the discussion of the properties and uses of soils. The report begins with a formal statement of the location of the county and of the character of the topography, including some indications of its physiographic origin. Perhaps a majority of the reports do not attempt any physiographic statement. Drainage conditions, history of settlement, population of the county, and a sketch of the nature of the original vegetation, comprise the other topics which are included under the somewhat ill-defined heading "description of the area." A section on climate, with the usual meteorologic tables, follows. The discussion of agricultural practices concludes that part of the report which is given over to topics other than soils. In this particular instance the ratio of the general description to the soils section is unusually high. Usually at least two-thirds and not uncommonly more than three-fourths of the total space is given over to soils. The usual order of effectiveness is, soils first, farm practices next, the other topics good to very indifferent. An occasional report is characterized by originality of plan and careful analysis of the economic problems of the district.* Whatever the effectiveness of treatment, an attempt is always made to

introduce a statement regarding agricultural conditions and opportunities.

It is recognized therefore, in part at least, that the soil survey is not an end in itself, but a means to a better understanding of the agriculture of a given district. Any modifications of existing procedure which improve this understanding must be considered desirable, whether they are associated with soils or not. In other words, is not the soil survey a preliminary step to a more comprehensive study of farming districts, a study in which the problems of farm production are viewed from various angles? By expanding some of the lines of inquiry which to date have been of minor significance in soil surveys, restricting some of the technical phases of soil studies, and adding certain new features, the soil survey will readily evolve into an agricultural survey. A proposal for such a broadening of scope is embodied in the following sections, to be organized on a geographic basis. The program as outlined, in practice would be subject to many modifications. The peculiar needs of the individual area must dictate in each case the best manner of treatment. The purpose of a survey of this kind is to be of greatest use to those who are most interested, and is not the publication seriatim, by units, of a uniformly executed reference work on soils or even agriculture for a state or for the country at large.

*Reports of this type in the 1913 Field Operations of the Bureau of Soils are those on South-Central Texas and on Stevens County, Washington.

1). The least significant thing about a location is to give its exact position. The most important thing in the location of a rural area is its distance to markets and their accessibility. A sketch map, accompanied by a few words of explanation can show readily the major markets to which the district ships, the transportation lines involved, arid, in some cases, potential markets with which commercial relations may be established.

2). Topography and drainage should be described, usually as one topic, but the enumeration of topographic features and of streams is not worth while. The map supplies all this information better than the text possibly can do. Geographic place names, unrelated to other facts, are of no more value in soil reports, where they still persist, than they are in grade school geography, where they have been long since abandoned. It is pretty well demonstrated that for layman and scientist alike the best presentation of surface features is by means of casual description, that is, describing them in terms of their origin. A belt of low, short hills acquires a new significance when it is stated that it is a terminal moraine. This method not only gives a more accurate sketch than the purely descriptive method, but in the long run it is an economy of space as well. That topography and drainage may be portrayed simply in physiographic terms, has been demonstrated amply by the educational bulletins that have been published by several state geological surveys. That this may be done effectively is indicated by the large demand for these bulletins on the part of the residents of the areas concerned.

3). The classification of soil types has been a most fruitful source of dispute and cause of the division of soil students into opposing camps. No single basis of classification can in general be carried through consistently without defeating the practical purposes of a soil survey. In all soil studies Hilgard's principle is applicable: "The many different points of view from which the subject may be approached precludes the adoption of a strictly uniform plan. We may approach the matter from the geological, physical, chemical, or botanical standpoint, as well as from that of the practical agriculturist; but neither of these, alone, will be found satisfactory; for soil-classification must always depend more or less upon the numberless and infinitely varied local conditions that influence vegetation, and must be correlated with these."* Contrasts in kind and amount of growth must be the ultimate criteria by which soil types are differentiated. Hilgard had this in mind in classifying soil types by natural vegetation, wherever significant. His soil map of Mississippi still stands as one of the most useful and readily intelligible soil studies that have heen made. In it the farmer's viewpoint dominates and no attempt is made to vindicate any particular scheme of subdivision. In the State of Michigan, with its surface materials determined largely by glaciation, Leverett** and Sherzer*** have demonstrated the general utility of origin as a guide to the classification of soils.

4). Local names of soils should be retained wherever possible. One of the most difficult things in the use of federal soil maps by the average person is the recognition of the familiar soils which are concealed by their standard system of nomenclature. The layman, for instance, is not helped by giving to the simple soil types of the glacial prairies of northern Illinois such imported names as Carrington, Miami, Fox or Waukesha, which cannot possibly come into general use. Different types of alluvial soils are designated as of the Huntington, Holly, Wabash, and other series, although the localities from which these names are derived may be hundreds of miles distant from places where they are applied. Evidently alluvial soils are not identical over such areas, but only similar. Loess is known as Knox silt loam. The attempt is made to proceed in classifying soils with stratigraphic precision where nature herself has drawn no hard and fast lines. The placing of every soil of the United States into its own particular pigeon-hole which is supposed to be in definite alignment with every other pigeon-hole undertakes an impossible, and what is more, an unprofitable task.

*Overland Monthly, Dec., 1801, p. 3.

**Map of Surface Formations, Mich. Geol. Surv., 1911.

***Geology of Wayne County, Mich. Geol. Surv.

5). In many localities the value and utilization of land is far more dependent upon slope than upon kind of soil. In some places it is almost the only soil consideration of practical importance. The relation of soil to slope is a negligible local factor only in smooth plains. Present soil surveys neglect this important consideration almost entirely. In mountainous areas the federal survey uses the designation "rough, stony land" for non-agricultural slopes, partially soil-covered. A few soil maps are printed on topographic bases. No consistent attempt has been made, however, to show steep slopes on soil maps. It is manifestly impossible to hold up soil studies until topographic maps are available. Excessive slopes

may be represented, however, without a topographic base, by indicating through shading or similar means the slopes that exceed a certain angle. There is probably not even for a single soil type in an individual area a definite angle beyond which cultivation becomes inadvisable. The manner of cultivation and kind of crop produced make a sharp separation of agricultural from non-agricultural land impossible. It is easy, however, to indicate on soil maps slopes on which the use of the land becomes affected by their steepness, whether field cultivation is prohibited or not. By supplying this most needed information regarding slopes the value of many soil maps would be increased several fold.

The following illustrations of the importance of slope are taken from observations in the Ozark Highland: "In general the most desirable soil types are those which are associated as a rule with gentle slopes, the undesirable ones those found for the most part in regions of great relief. The physical and chemical characteristics of soils are much less significant than the attitude of the surface on which they lie. The dissected margins of areas of Springfield soils, in general the most desirable residual type of the region, are in many places as unproductive as is the poorest Clarksville land, the least used soil of the region. The two types in general are strongly contrasted because most of the Springfield soil is on level prairies, the rock-formation from which the Clarksville is derived, however, expressing itself principally in rough hillsides. Low-lying solution basins in tracts of Howell soil, generally second-class land, furnish farming areas as choice as can be found in the Ozarks. The most important thing about the residual soils, therefore; is their depth, which in turn is dependent on the topographic expression of the rock-formation from which they are derived and the position of the area with reference to drainage lines. In Osage County, excepting the loess lands, the type of soil is not so significant in determining the value of land, as is the slope of the surface. Parts of the Union soil are worth as much as 50 dollars an acre on the level uplands. Near the rivers, however, where dissection has been extensive, this soil forms some of the cheapest land in the county, worth five dollars an acre and less. In Pulaski County, situated in the interior of the Ozarks, land values have little relation to soil types, with the exception of the alluvial lands, which have satisfactory depth because of their position. Prices on the upland are determined almost entirely by the amount of dissection, and the distinction of soil types for practical purposes becomes almost a matter of indifference."*

6). An agricultural survey offers an unusual opportunity for the practical application of climatic studies. The usual meteorological tables mean very little to the average reader. They should be condensed to the minimum amount of statistical material and for the rest replaced by a brief interpretation of the climate. Average length of growing season, frequency of unseasonable frosts, depth of frost action, amount and duration of snow cover, distribution of rain during growing season, frequency of droughts and rainy "spells" at critical periods, intensity of precipitation, occurrence of hail and violent wind storms—these and other topics will readily suggest themselves as appropriate objects of inquiry. Official weather records may be amplified by the weather experiences of the farmer, who is a valuable observer if not a satisfactory theorist. Local data regarding the relation of topography to frosts are available in many places.

*Author's manuscript "The Ozark Highland of Missouri."

7). The addition of the following features will aid in the presentation of agricultural conditions:

a). In most regions there exists a distinct farm type. A description of general farm practices can indicate only imperfectly the nature of this type. Usually it is not difficult to select an individual farm which will approach very closely to the type condition. If for such a farm, the system of farm management be described briefly and a sketch made of the use, character, and location of fields and of improvements, a concrete example of an average farm is supplied that will be of great value in understanding the rural economy of the district. In many counties one or more farms are far in advance of average conditions. In some cases such a farm may be cited as representing in a sense an ideal type toward which the development of the region will tend.

b). One-fourth of the 1913 soil reports were illustrated with an average of four half-tones each. The other three-fourths are not illustrated. The contrast in the intelligibility of the reports of the two groups to one who is not familiar with the ground demonstrates that the photograph is quite as indispensable a vehicle of description in agricultural reports as it is in areal studies of other kinds. Topography, character of unimproved land, fields in crop, manner of tillage, nature of farm buildings are in some instances of such a nature as to require photographic illustration for effective presentation.

c). A large part of the information regarding agricultural conditions can be summarized in a map which shows the uses to which the land is put. This map, primarily economic in nature, is the natural complement of the soil map. Attempts of numerous kinds have been made to map the economy of the land, with varying degrees of success. One of the most notable of these is the map of the "Distribution of Cultures in the Austrian Alps" by Norbert Krebs. In this the following conditions are represented: barren ground predominant, grazing land predominant, forest predominant, meadows in excess of fields, fields in excess of meadows, fields in excess of 50% of the total area.* The grouping is by large headings as the scale of the map is small. A far more ambitious map of similar nature is published as the Botanical Survey of Scotland, which is not botanical in the ordinary sense, as it shows primarily the uses of the land. The map shows such areas as "Cultivation with Wheat," "Cultivation without Wheat, oats chief crop," and "Hill pasture with grasses predominant."** In the State of Michigan the classes of land to be differentiated would

include the following: 1) Land appropriated to residential and industrial uses; 2) barrens, or areas permanently unproductive because of scanty soil; 3) bogs and swamps, perennially wet; 4) marshes and meadows, less wet than the preceding type, and yielding hay or suitable to grazing; 5) forested areas; 6) permanent pasture lands; 7) cultivated lands. Land that is occupied by cities, factories, and transportation lines is unproductive, in the ordinary sense of the word, and should be distinguished from the producing areas. Barrens are in the main areas of bare rock and of unstable sand dunes. Land that is continuously wet may be classed according to its origin as river-swamp or glacial bog, and further by the dominant vegetation. Wet, grassy land that .dries out sufficiently to make it of use for hay or grazing should be distinguished from the more swampy tracts. Forested areas may be subdivided according to their tree associations, and as well into tracts of standing and cut-over timber or slashings. Seriously burned tracts, in which the soil is partially destroyed, may be indicated in some places. The cultivated lands are to be classified by the dominant crop or the type of cultivation. There will thus be areas of field cultivation with corn, wheat, hay, beets, or some other crop dominant, and areas with garden, vine-yard and orchard cultivation. Many other uses can be represented, but enough has been outlined to show that such a map is the logical consequence of soil studies. As in the mapping of soils3 the units represented should not be too small, probably 10 to 40 acres as a minimum. Otherwise the problem of mapping becomes excessively complicated and tedious and the map loses its value in a brief period.

*First published in Festschrift dein deutschen Geographentag zu Innsbruck (1912); also in Landerkunde der Osterreichischen Alpen by the same author.

**Scottish Geog. Mag., XX, 617; XXI, 23, 57.

A map of this type unfolds a complete panorama of the rural conditions in a county. It will enable comparative studies in rural economy that are now impossible. For the geographer especially, it will supply much material now unavailable. To the prospective purchaser it supplies a bird's-eye view of stage of development and character of farming conditions that can be equalled only by spending much time on the ground in making careful observations. It will prevent many of the regrets attendant upon purchase of land with a few bits of information regarding farm conditions. If properly executed such a map will not readily become antiquated. In Southern Michigan, as in large parts of the Middle West, farm practice is pretty well established. There are many areas in which such a map if it had been made 25 years ago would need few alterations. If, in an old farming district the character of farming changes, it is important to have it recorded. To a careful purchaser the past history of land may mean nearly as much as its present appearance. The drainage of swamp lands, abandonment of grain production, introduction or abandonment of orchards are instances in point which it may be desirable to know. If the region is beginning its agricultural development, as northern Michigan, then, it is true, a few years will see striking changes. The map then does establish, however, the primitive character of development, and puts into their true light the conditions which the, settler will need to face. A map of uses of the land at such a stage serves a much more important purpose as well. It will indicate primarily the distribution of forests and their dominant trees, of prairies, meadows, swamps and barrens. In short, it shows primarily the distribution of native types of vegetation. Hilgard, in fact, urged that this is the time to make a soil study, when man has not disturbed the order of nature. From this native vegetation can be deduced "the same results we now gather from long experience, or from culture tests with fertilizers. . It is, then . . important that the original state of things should be put on record as quickly as possible."* In such a new area the map would be an index not only of the agricultural fitness of the soil, but would give indications as well of the difficulty of clearing and otherwise reclaiming the land. Whether the area be young or well developed the execution of such a map will be helpful.

These proposals embody some ideals of the geographer, in the working out of which he believes that his science eventually will participate. Here it will find the opportunity for practical field work, which alike will benefit the progressive resident of the area, protect the home-seeker, and accumulate valuable information for the student of rural conditions.

University of Michigan, March 29, 1917.

*Cited above, p. 81.

ON THE PROSPECT OF OIL BEING FOUND UNDER THE ONTARIO-OHIO-MICHIGAN SECTION OF LAKE ERIE.

BY THOMAS NATTRESS.

From Detroit City to the inter-state boundary of Michigan and Ohio on Maumee Bay there is a long line of deep wells that have developed pockets of gas and showings of oil. But not even in the Potter well in Erie Township, at the southeast corner of Monroe County in Michigan, and in close proximity of the Toledo field was there more than "some gas and some oil."

Mr. R. A. Smith[1] of the Michigan Survey, reporting upon Monroe County, has stated logically the conclusion for the entire distance traversed: "Monroe County is too far down the western slope of the Cincinnati anticline to contain oil and gas in any great quantity."

On the Ontario side of the northern reach of the Cincinnati uplift, in Essex County, there is little gas and less oil in the Maiden and Colchester wells; little oil and much gas in the Kingsville-Leamington field; and on Pelee Island some gas and some oil. The Ontario-Ohio system of islands, shoals and points of land across Lake Erie from Pelee Island to Marble Head is also, from all the evidence to be adduced, lateral to a main supply and too far down the *eastern* slope of the Cincinnati uplift for quantity.

Eastward of this section there is no indication of any series of anticlinal folds that might hold a main supply. Westward there is the Cincinnati dome, with minor transverse folds, at least in the rocks of the later and overlying formations, from the Ohio shore northward to Ballards Reef in Detroit River and the Canard River mouth on the Canadian side of the Detroit.

Over all this anticlinal section, westward of Pelee Island and Kelly's Island, in which lie East Sister, North Harbor, West Sister and Middle Sister Islands and shoals, there is the same surface extension, the Lower Monroe formation. The only exception to be made to this statement is that there is an outer edge of Sylvania Sandrock overlaid by Upper Monroe material along the east and west sides, and an outcropping of rock of earlier age on West Sister Island and in spots east and west and south of it.

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[1]Oil and Gas in Michigan, Publication S, Geol. Series 5, Michigan Geol. & Biol. Survey, 1911, p. 371.

A local indication of what the older strata capping the anticline over this area may be holding in reserve is observable in the old Judge Christiancy quarry near Dundee in Monroe County, where the Onondaga (Dundee, Corniferous), beds have been heavily petrolated at some time.

The condition thus indicated may have been, and probably was occasioned by a sideward tilt produced by an uplift about middle Onondaga time, which raised the east side of the field above the surface of the sea from Sandusky Bay northward to Pelee Point and the Amherstburg quarry section. From this sideward tilt the area never fully recovered, a fact evidenced by the narrowness of the Onondaga surface extension in southeastern Michigan and northwestern Ohio (until it changes from a north and south direction) and by a comparison of elevations of the lower Onondaga horizons, which are relatively lower on the Michigan side of the territory in question than on the Ontario side of it.

The west side of the field appears to have sustained local uplift at about the close of Onondaga time. Of this there is evidence in the Sibley neighborhood in Wayne county, where thrusting has been accompanied by crevassing in the later Onondaga beds, beds not laid down in Essex County.

Reasons might be assigned for looking to the east side of the area for gas, the more volatile quantity, and to the west side for oil, preponderatingly. As has been stated the mid-Onondaga east side uplift and westward tilt was only partly balanced up by the later west side uplift. A second reason is the centuries long gradual tilting to southwestward of the continental mass from the direction of James Bay and beyond, which is resulting in Lake Erie waters encroaching upon the land surface over the south and west shores of the lake. (See U. S. War Dept. Coast Chart No. 7.)

Wells in Monroe and Wayne Counties, at Monroe, at Dundee, Trenton, Sibley, Gross Isle, River Rouge, Detroit and Windsor, do not pay, in oil and gas, the cost of putting them down, and for the reason already assigned in the case of the Erie township well, too far down the side, or northward over the nose of the Cincinnati anticline.

Stony Island, possibly Sugar Island and Point Mouillee, Stony Point, the Raisin River Delta, and the islands of north Maumee Bay, together mark a promiseful base-line of operations from the westward over the area delimited; whereas the locality of the mouth of the Canard River in Anderdon Township, Bois Blanc Island, the Detroit River shore in Maiden Township, South Colchester and Pelee Island, in Essex County; and the Bass Islands and west of the base of Marble Head Peninsula in Ohio, together mark an east side limit of probability.

If a line A. . . .B be used to represent the state line from Sylvania, Ohio, eastward into Lake Erie; and a curved line C. . . .D the surface of the Trenton—for example; and E. . . .F the Potter well, 1,555 feet to and 112 feet into the Trenton in Erie Township, Monroe County, Michigan; then it is shown how, located as it is, that well penetrated only the upper or outer strata of the Trenton and trends away from the possible reservoir of the arch of the anticline, the angle at G being obtuse.

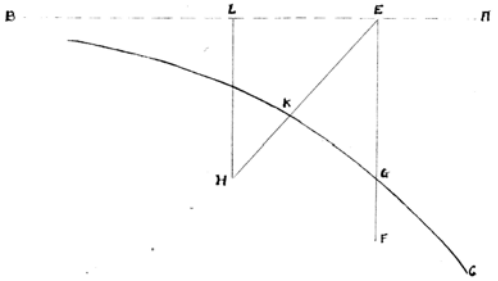

Figure 3. Diagram of geological conditions with reference to oil wells sunk in the region studied.

To penetrate the Trenton strata directly from point E the drill should follow the line E. . . . H to take the Trenton surface at right angles at K, and penetrate the depth of possible supply: the logical meaning of which is a well at L, (in relation to point E) and preferably at some point along the line L. . . . B, on the west shoulder of the anticline, or along L. . . .B projected, on the east shoulder. The line E. . . .F, however, illustrates the relative position of each and every well that has been put down in search of oil on the Michigan side of the field and, in a less degree only, on the Ontario side of it. None but lateral tests have been made, and most of these remote.

Unfortunately the only land surfaces within the enclosed area are the Sister Islands, East, Middle and West, North Harbor, the Hen and Chicken Islands, and the associated banks and shoals.

EXAMINATION OF THE FIELD BY CROSS SECTION.

A Ballards Reef east and west section of the northern part of the field under review would show these surface extensions in order, westward of the reef: Lower Monroe for a short distance; Sylvania sandstone over at least a part of Grosse Isle; Upper Monroe on westward part of Grosse Isle, throughout its entire length and over nearly all the Trenton Channel of Detroit River; Anderdon limestone beds all about the outer edge of the Sibley quarry area from about the River Road westward, probably reaching the west bank of the Trenton Channel, opposite the Church Company's dairy barn well, and possibly reaching over to the east bank of the channel at this point, from evidence of Sibley cores; a showing of Oriskany sandstone at both the base and the surface of the Anderdon Beds, this heavy silication embracing the characteristic Anderdon fossil-bed and invading the dolomitic limestone base of the overlying Onondaga.

Eastward of Ballards Reef: Lower Monroe, Sylvania—pumping up in one water well on the Stevenson Stock Farm; Anderdon limestone beds probably, and Onondaga, in the same order as on the west side of the reef, but in reverse direction.

A section from Elliotts Point, Essex County, southwestward to the Huron River, shows Lower Monroe over the whole distance from inshore on the Essex side to the inner mouth of the Huron; and northeast of the point, Sylvania, Upper Monroe, and a shallow Anderdon Beds-filled trough in the Monroe.

A section from the Huron River southeastward to Pelee Island would show Lower Monroe over the entire Detroit River mouth distance, until the later formations would be crossed in ascending order off the west side of Pelee Island, which is itself Onondaga.

A section east and west from the south end of Pelee Island to the town of Sylvania would traverse these in reverse order again, developing Oriskany and Anderdon doubtless, Upper Monroe, Sylvania, Lower Monroe, Clinton and Niagara probably, Salina and Lower Monroe on West Sister Island, possibly Clinton and Niagara again, and again Lower Monroe, until the Sandrock is again reached at Sylvania.

The Trenton rock, popularly regarded as the natural cap of mineral oil deposits since it is the containing cap in so many oil areas, is covered everywhere throughout the whole triangular territory now being theoretically exploited, by newer strata.

All the evidence invites to the trying out of the Michigan-Ohio-Ontario part of the west end of Lake Erie, from Ballards Reef south to a base line about six townships in length, connecting the point where the Michigan-Ohio state line comes out on Maumee Bay, and (say) Danbury on Sandusky Bay.

The northern part of this territory may be thought to be unpromising because of its very narrow width and also its remoteness from the known broad tested field in Ohio. There is this favorable indication, however, *a series of minor* folds across the general trend of the underlying Cincinnati arch.

Ballards Reef in Wayne County, and the mouth of the Canard River in Essex County, mark one upward fold. The Limekiln Crossing (Essex) and Stony Island (Wayne) together mark a second. The upper half of Bois Blanc Island and westward beyond the international boundary a third. And across the greater part of the entire width of the Detroit River, clear of the foot of Bois Blanc and Sugar Islands a fourth.

The same condition prevails off shore in Ohio waters. Also a showing of oil was obtained in the Trenton; in November, 1914, at the Amherstburg quarry in Anderdon Township, Essex County.

There is also *a minor synclinal trough* on both east and west sides of the central and east side Detroit River Lower Monroe area, as was proven with the core-drill in surveys of 1910, 1911 and 1912.

SUPPORTING EVIDENCE PRESENTED IN THE TREND AND CHARACTER OF THE ESSEX-KENT-LAMBTON-PORT HURON FIELD.

It is interesting to observe that a line drawn from beyond Lima, Ohio, past Findlay, N. 40° E., and projected in the same general direction, traverses the central part of the Ohio oil field; passes close by on the west side of the Pelee Island oil field., crosses the Kingsville-Leamington gas field; the Tilbury oil field and the Romney gas field, the Chatham oil field, and the old Petrolia oil field.

Along this surface, beyond the block-faulted, Lake Erie Islands part of the distance, the present rock elevations are lower toward the north. Overtop of the Lower Monroe are added on in order the Sylvania Sandrock, Upper Monroe, Anderdon limestone beds probably, the Onondaga limestone, the Hamilton rock, and the overlying shales. It thus becomes evident that whatever of local Cincinnati anticline there may have been in Ordovician-Silurian time, branching off into Canada (as Michigan and Ohio geologists for the most part assume) there is small room for it now, unless it lies deep down.

It is not; therefore, a matter of surprise that gas and oil have escaped by the Lake Erie faults into the strata of higher horizon and relatively lower elevation in the southwestern Ontario fields.

In all of these fields, as in one connecting field, the oil and gas appear to be held in the rock of newer formations overlying the deeper parts of that broad Silurian syncline which carries, exposed in surface extension along its northern side; the Onondaga (Corniferous); the Hamilton and the associated shales, across Cheboygan, Presque Isle and Alpena Counties in Michigan; across Bruce, Huron; Perth and Oxford counties in Ontario, in southeast direction; thence east by south into New York state about Buffalo.

Doubtless the whole of the western Ontario oil and gas area thus far investigated, Pelee Island, Kingsville-Leamington, Tilbury, Romney, Chatham, and Petrolia (and also the Port Huron field in Michigan) are one continuous overflow field receiving its supply from a main reservoir, the pressure in which is relieved by this outflow through disturbed strata.

It follows, if these deductions be correctly drawn, that west of Port Huron and toward the centre of the state there is but little reasonable expectation of oil or gas in paying quantity, since the strata dip rapidly westward, a dip which may be illustrated by the comparative statement that the salt horizon at the foot of Saginaw Bay is 2,200 feet lower than it is in Goderich harbor on the opposite side of Lake Huron.

The cause of change of direction of the field from N. 40° E. across Ohio and Ontario to Chatham and beyond to northwesterly, by way of Oil Springs and Oil City and Port Huron, was unquestionably the movement which produced the uplifted exposure of Hamilton rock across the northeast corner of Lambton County from Arkona to Thedford and the shales at Kettle Point.

FURTHER EVIDENCE SUSTAINING THE ARGUMENT.

If, by earth movement, or a series of movements somewhat violent in character, a major anticlinal reservoir is faulted laterally, gas and oil will escape and be forced by the dynamic of the reservoir into higher strata adjacent.

If the line of fault be continuous across country the escape of gas and oil from the reservoir is facilitated.

If the strata into which the oil flows be laid down in a major syncline, as from Lake Erie across to Lake Huron and northward, "lakes" arid "pools" of oil and "pockets" and reservoirs of gas will result, deposited according to the natural inequalities of the synclinal floor and of the overlying strata, inequalities probably emphasized by disturbance. Crevices, unless on a major scale, are nearly always capped by beds that overly, whether by deposit or by readjustment, or capped and plugged by glacial detritus. Consequently both gas and oil are confined and forced into the interspaces of the strata. Pressure from behind, both hydrostatic pressure and the pressure of gas, will continue to force both oil and gas further afield, even beyond the reach of the fault line. And always the tendency will be for the escaping substances to find their way into strata of ascending horizon and to higher elevations.

As an oil field is pumped and the oil pressure decreases because the supply begins to be exhausted, if there be a suitable reservoir left thus to receive and retain the gas the supply and pressure of gas will be increased. This for two reasons: gas rises naturally from the oil and, as the more volatile substance, it finds freer vent from the main reservoir.

Accordingly, in addition to these peculiarities in the southwestern Ontario field already read as lateral phenomena, there is this series of facts to be considered:

Oil flows from about 155 feet below mean tide level on Pelee Island, or from some 700 feet below the surface of the Onondaga. In the Tilbury-Romney field oil is obtained at about 137 feet below tide, or some 600 feet below the Onondaga surface; whereas in Romney gas flows copiously from the Onondaga[2]. In the Chatham field oil comes from about 108 feet above mean tide level, and from something over 40 feet in the Onondaga. In the Petrolia field the oil horizon is about 202 feet AT. and about 65 feet in the Onondaga. At Sarnia, flanked by the Hamilton uplift at Thedford, and with the Michigan basin in front, the gas horizon drops to about 190 feet AT., but, from the shale depths at this point, this would appear to be up in the rock of the Hamilton formation.

It is of interest to note that, whereas in Romney Township the very limited flow of oil is from small pools, in Tilbury alongside the greatly enhanced supply is held in crevices. And the parties chiefly interested commercially state that in Romney, as the Tilbury and Romney and Chatham oil continued to be drawn off, the pressure of gas became measurably greater.

The new discovery of gas at 1,800 feet in the Petrolia field, at Oil Springs, does not affect the argument except to lend it support. The oil in this field is obtained at from 300 to 400 feet from the surface, and some 65 feet in the Corniferous (Onondada of New York state). If strong flow of gas be obtained from below this at 1,800 feet, or at any depth whatever below, it follows that the oil at the upper horizon must be an overflow supply from some other source than that of the lower gas.

At precisely the same time at which the Pelee Island and Amherst-burg quarry Onondaga sustained uplift in Essex County on the northeast shoulder of the Cincinnati insular dome, the same lower Onondaga beds were disturbed on the north shore of the Ontario arm of the Devonian sea. This is shown in the Horse Shoe quarry at St. Marys, Perth County, where there is a crevice across the field. On one side of this break are the same lower Onondaga beds as were laid down in Essex County in the parts uplifted. But on the other side of the crevice, no fault having developed from the break, the later Onondaga strata begin at once to be added on, and with much sharper dip. The adjacent hard, brittle Anderdon Beds limestone on the north side of the town of St. Marys is heavily faulted, just as it is shattered along the east bank of the Anderdon-Maiden trough.

Add to this evidence the corresponding fact that the rock surface along the Lake Erie shore of Elgin, Kent and Essex Counties, has a greater elevation than the extension north and south of it, and but one conclusion can be drawn. That conclusion is that *a barrier has been lifted up* dividing the late Devonian and subsequent seas of Michigan and the southwestern waterfront counties of Ontario, from the seas of the same period and periods which built up the greater remaining part of the present Lake Erie bed material, the western part of Pennsylvania, southern New York, the western part of Virginia, the eastern third of Kentucky, and northern Tennessee.

The bearing of this upon the oil question is thus stated: Any possible segregated overflow or other supply of oil there may have been east of of this barrier and between it and the uplift across the Niagara peninsula, would naturally find its way down the incline of the basin which has for its center the Ohio-Virginia coal measures.

The absence of oil in the Cayuga and Port Col borne fields of gas supports this conclusion.

It may possibly be that deep down under all the disturbed area of the west end of Lake Erie and the associated counties in Ontario there is a major anticline. In such case there is not only one but a second promising field awaiting the drill, of which, as in the case of the first, merely the outer edge has been essayed.

Chalk River, Ontario, February, 1917.

[2]So stated by the operating companies.

SOME NEW THERMO-OPTICAL OBSERVATIONS ON GYPSUM AND GLAUBERITE.

BY E. H. KRAUS AND ALBERT B. PECK.

INTRODUCTION.

Several years ago a number of articles were published from this laboratory dealing with the changes in the size of the angle of the optic axes with temperature and also with the determination of the temperature of uniaxiality of gypsum[1] and glauberite[2].

In the first paper dealing with gypsum a comparatively large oil bath was used, the source of heat being two Bunsen burners. While the apparatus was somewhat crude in character, it nevertheless permitted extensive observations to be made with a considerable degree of accuracy on the variation in the size of the optic angle with temperatures between 18.2° C and 132.5° C. It was definitely determined that uniaxiality for sodium light, the only type of monochromatic light employed, occurs in the neighborhood of 90° C. Observations were also made by heating gypsum in an air bath and it was shown that the greatly divergent results concerning uniaxiality temperatures obtained by previous investigators were due to too rapid heating and the use of air baths. In the second article the study of the uniaxiality temperatures for gypsum for a large number of wave lengths was made employing a new heating apparatus consisting of a small glass container for the oil which was heated by an electric resistance coil. Light of various wave lengths was obtained by the use of a Fuess monochromator. The curve showing the temperatures of uniaxiality indicated clearly that the maximum temperature for uniaxiality occurs when light having a wave length of about 560$\mu\mu$ is used. In making the observations for gypsum recorded in these two papers, plates prepared by Steeg und Reuter, Homburg v. d. Höhe, were employed. Unfortunately the localities from which the material was obtained were not known. It was therefore thought advisable to repeat the second investigation using sections from several known localities. The first portion of this paper, therefore, gives some new observations on the uniaxiality temperatures of gypsum from Ellsworth, Ohio; Eisleben, Germany; and Cianciana, Sicily.

In 1913 observations on the change of the optic angle of glauberite were published but for only two types of monochromatic light; lithium and sodium. In the present paper new observations are given on the variation in the size of the optic angle of glauberite for light of several different wave lengths and on the temperatures for uniaxiality for wave lengths between 511$\mu\mu$, and 687$\mu\mu$.

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[1]Neues Jahrbuch fuer Mineralogie, Geologic und Palaeontologie, 1912, Vol. 1, p. 128-46, and Centralblatt fuer Mineralogie, Geologic, und Palaeontologie, 1914. p. 350-9.

[2]Zeitschrift fuer Krystallographie, 1913, Vol. 52. p. 321-6.

APPARATUS.

The apparatus used in these new experiments consisted of the axial angle apparatus and the large metallic oil bath of 150 c.c. capacity employed in the original experiments in 1911. This bath was, however, heated by a larger resistance coil than that employed in the experiments reported in the second paper. The heating apparatus consists essentially of a tile plate about 20 cm. square on the under side of which are fastened a series of small resistance coils. The oil bath, containing the section to be investigated and into which the bulbs of the two long thermometers penetrate, and the heating plate are all enclosed in an asbestos box, the sides of which are easily removable. Experience has shown that more accurate and consistent results are obtained when a larger oil bath is employed than when one of smaller capacity such as was described in the second paper is used. An oil bath of comparatively large capacity permits a more gradual increase or decrease of temperature to take place as also an easier maintenance of a constant temperature. These factors are highly desirable inasmuch as gypsum responds more readily to slight changes in temperature than does the mercury in the thermometers. By placing several secondary resistances in the circuit, the temperature within the oil bath could be very easily regulated. The thermometers permitted readings to be made to 0.1° C. The results given in the various tables have all been corrected and take into consideration the temperature of the room surrounding the apparatus, the temperature in the asbestos box surrounding the oil bath, and the length of the thermometer tubes. Curves have been developed from such corrected observations.

Monochromatic light was obtained from a Fuess monochromator using as the original source of light a small hand-feed, direct current arc light. The monochromator was first carefully adjusted for sodium and lithium lights so as to insure accurate readings. This instrument is exceptionally useful in the determination of uniaxiality temperatures as a simple rotation of the drum allows exceedingly rapid changes in the character of the light supplied to be made. In fact, an apparatus of this type is indispensable for observations involving the use of different types of monochromatic light at the same temperature or at temperatures which are changing slowly.

UNIAXIALITY OF GYPSUM.

Carefully oriented sections of colorless, transparent gypsum from the following three localities—Ellsworth, Ohio; Eisleben, Germany; and Cianciana, Sicily—were prepared and observations made for the temperatures at which uniaxiality is to be noted for wave lengths ranging from 435$\mu\mu$ to 702$\mu\mu$. These observations are given in the following table:

Table 1.
Temperature of Uniaxiality for Gypsum.

Wave Length	Ellsworth	Eisleben	Cianciana	Wave Length	Ellsworth	Eisleben	Cianciana
435$\mu\mu$		87.60°C		545$\mu\mu$		90.95°C	
443		87.95		551		90.95	
445		88.00		554			91.25°C
450	88.25°C	88.30		555		91.10	
451		88.35		560	91.35°C	91.25	
452			88.20°C	564			91.20
458	88.65			568		91.25	
459		88.40		575	91.30	91.15	
460	88.90			580			91.00
461			88.55	593			90.95
465		88.98	89.12	594	91.00		
467	88.90			600		90.60	
470		89.20		609	91.15		
471	89.15			611			90.75
472		89.45		613		90.55	
475			89.45	616		90.45	
478	89.45	89.65		617		90.40	
480		89.70		620	90.80		
481	89.70			623		90.35	
485			90.05	624			90.50
486	89.80			629	90.60		
487			90.25	631		90.15	
488	90.15	89.90		634	90.55		
494			90.45	635	90.50		
495	90.30			637			90.15
499			90.60	640	90.30	89.95	
500		90.25		643	90.15		
507		90.50		652		89.40	
508	90.45			656	89.80		90.02
511	90.65	90.65		660	89.55		
515			90.95	663		89.35	
519	90.90			664			89.95
520		90.70		667		89.25	
525			91.00	670		89.27	
529			91.15	676	89.25		
531	90.90			680		89.10	89.80
538		90.90		686		88.95	89.40
544	91.10			702		88.75	

Plate II shows the uniaxiality curve resulting from these observations. While the observations for these sections are all of the same order, nevertheless those for the Sicilian section seem to be a trifle higher than for the other two. These variations were, however, only in one case as great as 0.7° C and usually less than 0.25° C, which may be considered as being well within the limits of error. The uniaxiality curve is of the same general character as the one described in 1914, although the uniaxiality temperatures for any given wave length are somewhat higher than formerly recorded. Thus, we are able to indicate that the highest uniaxiality temperature is about 91.3° C for 560$\mu\mu$ which corresponds to 89.4° C for the same wave length of the earlier report. These new observations are in fuller accord with those published by Hutchinson and Tutton[3] and for reasons previously given are to be considered more accurate than the earlier results. It will be noted from Plate II that for light with the longer wave lengths, i. e. above 600$\mu\mu$, there is a greater divergence in the observations than for light of shorter wave lengths. This is due to the fact that the hyperbolic brushes of the biaxial figures for light of the longer wave lengths are very broad and, hence, it is more difficult to determine when the brushes are exactly crossed thus forming the uniaxial figure for the wave length under consideration. Some of the more important uniaxiality temperatures, as determined from the curve, are as follows:

465$\mu\mu$		89.02°C	589$\mu\mu$	(D line)	91.12°C
486	(F line)	89.90	656	(C line)	89.82
527	(E line)	91.02	670		89.47
560		91.27	687	(B line)	89.02

[3]Mineralogical Magazine, 1912, Vol. 10, p. 257-63.

VARIATION OF THE ANGLE OF THE OPTIC AXES OF GLAUBERITE WITH TEMPERATURE.

In 1918 observations on the variation of the optic angle of glauberite with temperature were published for lithium and sodium lights. It was clearly established at that time that the uniaxiality points for these two types of light are considerably lower than had been previously determined by Laspeyres[4]. In the present study, measurements of the variation in the angle of the optic axes for different wave lengths were undertaken employing the oil bath of larger capacity and the Fuess monochromator.

The section was prepared from material from Villa Rubia, Spain, which was not entirely homogeneous. This was clearly observable under the miscroscope. There were also slight variations to be noted in the observations made in different parts of the section. Kozu[5] has recently called attention to similar variations in certain feldspars studied by him. Our observations are recorded in the following table:

Table 2.

Size of the Optic Angle of Glauberite for Various Wave Lengths at Different Temperatures.

T°C	465μμ	T°C	656μμ
25.5	3°38′	25.65	7° 5′
30.0	5 6	30.15	6 20
35.0	6 0	39.4	5 16
41.7	6 57	69.0	6 25
58.5	10 8	78.5	8 6
62.2	10 44	87.6	9 41
65.4	12 1	97.5	11 23
76.0	12 48		
96.0	15 2		
T°C	**486μμ**	**T°C**	**670μμ**
35.5	4°31′	25.65	7°50′
41.0	5 9	30.45	7 0
45.5	6 58	34.15	6 53
57.0	8 56	39.7	5 41
61.3	9 54	70.0	6 22
76.5	12 5	79.0	8 6
86.5	13 10	88.0	8 52
96.2	14 17	97.8	10 37
T°C	**527μμ**	**T°C**	**687μμ**
44.7	4°37′	25.65	8° 8′
56.0	7 35	30.65	7 12
60.3	7 23	34.15	6 50
67.0	9 48	41.5	5 31
77.0	11 3	71.0	6 0
86.7	11 52	79.5	7 12
96.6	12 58	88.5	8 7
		98.0	10 45
T°C	**589μμ**		
25.65	5°28′		
29.85	3 52		
52.0	3 36		
55.0	4 55		
59.6	5 58		
68.0	8 6		
77.5	9 22		
87.1	10 56		
97.0	12 11		

Plate III shows full curves between 25° C and 98° C for 589, 656, and 670μμ and partial curves for 165, 486, and 527μμ. The full curves correspond in general to those published earlier although the observed uniaxiality points are slightly lower. This means that the angles below uniaxiality are slightly smaller and those above the uniaxiality point are slightly larger for any given temperature than those previously recorded. The agreement between the new and the older observations on glauberite is greater than in the case of gypsum, for both series were made by using the same oil bath, namely one with a capacity of about 150 c.c., and as uniaxiality takes place at lower temperatures, constancy of temperature can be better maintained.

[4]Zeitschrift fuer Krystallographie, 1877, Vol. 1, p. 529-540.

[5]Mineralogical Magazine, 1916, Vol. 17, p. 287-53.

UNIAXIALITY TEMPERATURES OF GLAUBERITE.

Several series of observations were made of the temperatures at which uniaxiality is to be observed for light ranging from 511μμ to 687μμ. These temperatures, as given in the following table, represent the average of three series of readings and from them the uniaxiality curve of Plate IV has been drawn.

Table 3.

Uniaxiality Temperatures of Glauberite.

511μμ	27.0°C	592μμ	41.0°C
516	28.0	609	42.0
523	29.0	611	43.0
528	30.0	619	44.0
534	31.0	626	45.0
540	32.0	633	46.0
546	33.0	639	47.0
551	34.0	644	48.0
556	35.0	651	49.0
560	36.0	659	50.0
566	37.0	670	52.8
572	38.0	672	53.0
578	39.0	687	54.1
584	40.0		

The uniaxiality temperatures for six important wave lengths as developed from the curve follow:

527μμ (E line)	29.8°C	656μμ	48.6°C
560	35.5	670	51.6
589 (D line)	40.6	687 (B line)	54.1

The curve shows an unexpected break at about 600μμ for it was thought that a straight line curve should result. This change in direction may possibly be due to several factors. First, as was noted in the case of gypsum above, the hyperbolic brushes are very much broader for light above 600μμ than for that below. This obviously makes accurate determination of the exact temperature at which uniaxiality takes place extremely difficult. Second, the observations plotted in Plate IV are the average of three sets of readings made from different portions of the same section. As already indicated, slight variations in the character of the section could easily be recognized under the microscope and these may account to some extent at least for the break in the curve. A third reason may be that at a temperature of about 42° C some slight change in chemical composition may take place. Of the three possible explanations, the first undoubtedly is to be considered as the most probable.

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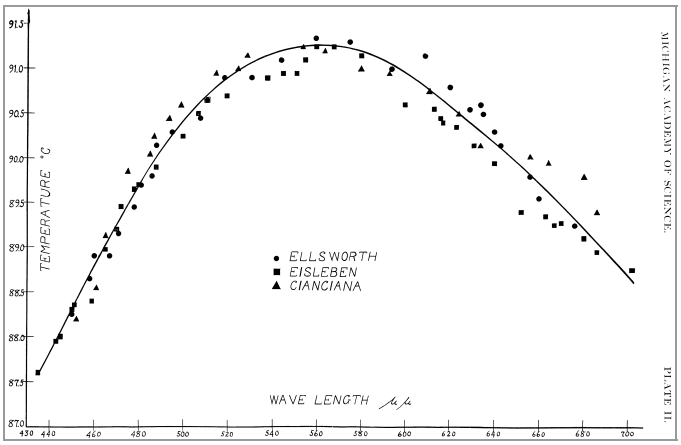
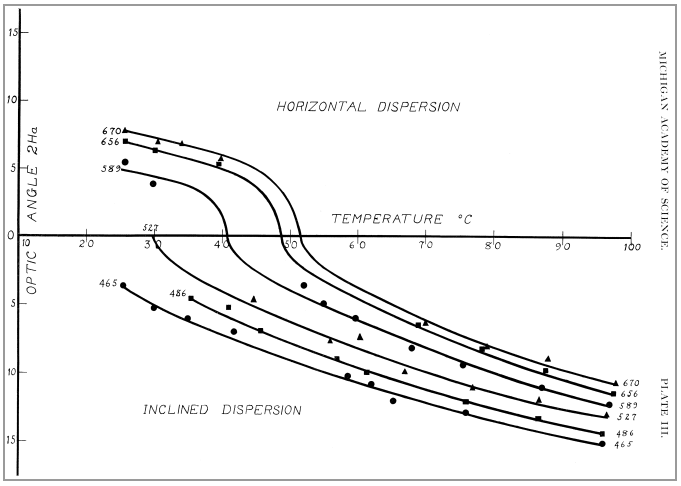
LEGENDS.

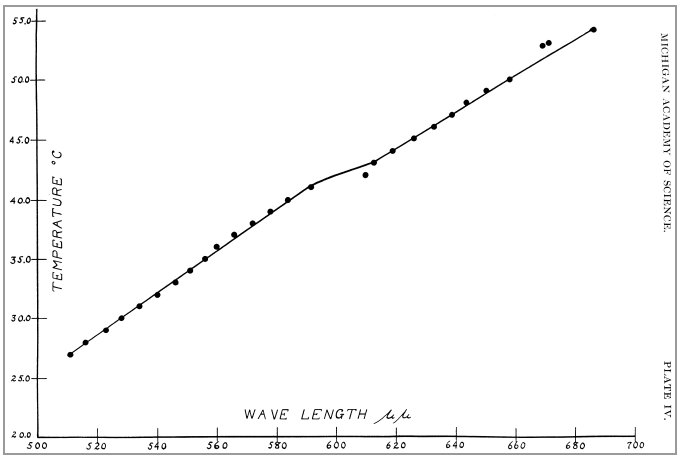
Plate II. Change in temperature of uniaxiality in gypsum for various wavelengths.

Plate III. Change in the apparent optical angle in oil of glauberite for various wave-lengths and temperatures.

Plate IV. Change in temperature of uniaxiality in glauberite for various wavelengths.







GLACIAL LAKES AND THEIR CORRELATIVE ICE-BORDERS IN THE SUPERIOR BASIN.

BY FRANK LEVERETT.

(Abstract.)

The paper deals only with the final recession of the ice from the Superior Basin, and from what appears to be the Port Huron morainic system in that basin. There seems to have been considerable ice recession preceding the Port Huron readvance with a corresponding enlargement of glacial lakes in this basin as well as in the Huron and Michigan basins. The readvance overrode and completely obliterated the glacial lake in the western Superior basin. There was probably also an inter-glacial lake in the Superior basin following the Illinoian glaciation.

The latest lobe of ice that occupied the Superior basin was part of the Labrador ice sheet. On melting away it made a northeastward recession from the west end of the basin past the Keweenaw Peninsula. At the same time there was northward recession of the ice border from the Michigan and Huron basins across the eastern end of the Northern Peninsula into the eastern part of the Superior basin. The latest hold of the ice on the soil of Michigan was in the part of the shore of Lake Superior between the Huron Mountains and Whitefish Point.

The ponding of glacial waters at the west end of the Superior basin was at first in a chain of small lakes, separated by higher unsubmerged areas, which extended to the border of the ice. Lake Nemadji, at the extreme west end of the Superior Basin, discharged past Moose Lake, Minnesota, to Kettle River and thence to the St. Croix and Mississippi Rivers. Lake Brule occupied a narrow strip along the Brule valley and discharged southward to the St. Croix River. The next lake to the east covered a lowland south of Ashland and will be termed Lake Ashland. This lake discharged westward across the Bayfield Peninsula, just south of Iron River, Wisconsin, to Lake Brule. The northern part of the peninsula was still covered by the ice sheet. Still farther east was another lake covering part of the Ontonagon drainage basin in the western part of the Northern Peninsula of Michigan, and called Lake Ontonagon. This discharged westward into Lake Ashland near Saxon, Wisconsin. At this time the ice still covered the plain between the Copper Range and Lake Superior.

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With the melting away of the ice from the Bayfield Peninsula and other prominent parts of the district south of Lake Superior, the ponded waters all became merged into a single body of water, Lake Duluth. which had the level of Lake Brule, and utilized its outlet to the St. Croix River and Mississippi. This outlet channel has a floor about 420 feet above Lake Superior at the present summit swamp, and beaches turning into it are still

higher, for the outlet was deepened by the discharge of the lake waters through it. The ice seems to have melted from the Keweenaw Peninsula soon after Lake Duluth had been formed, for strong beaches of Lake Duluth are found on the Keweenaw Peninsula as far northeast as Calumet.

The ice held its front on the Huron Mountains for a relatively long time, and thus formed the eastern limit of Lake Duluth. With the recession of the ice border down the east slope of the Huron Mountains the glacial waters soon found a passage around the edge of the ice southward and discharged into Lake Algonquin, which by that time was occupying the Michigan as well as the Huron Basin. The recession from the Huron Mountains opened lower and lower passages until the lake in the western part of the Superior Basin was drawn down to the level of Lake Algonquin and became a part of that lake.

The lowering of the lake waters from the Algonquin to the Nipissing level occurred when the Ottawa Valley became freed from ice. This seems to have taken place soon after the waters in the western end of the Superior Basin were lowered to Algonquin level, for the Algonquin beach is very weak in the western Superior Basin. It is not as yet known whether the ice had entirely disappeared from the eastern part of the Superior Basin before the Ottawa Valley was freed from ice. There is thus a possibility that part of the northern and eastern border of the Superior Basin does not have an Algonquin beach. So far as the Michigan part of the Lake Superior Basin is concerned, there was complete disappearance of the ice sheet prior to the Nipissing stage. The Nipissing shore is strong all along the south shore of Lake Superior as far west as it stands above the level of Lake Superior. West from the Bayfield Peninsula the Nipissing shore is below Lake Superior level.

Ann Arbor, Mich.

BOTANY

ECOLOGY OF NORTHERN MICHIGAN DUNES: CRYSTAL LAKE BAR REGION.

W. G. WATERMAN.

I. GEOGRAPHY AND GEOLOGY.

A. Geography. (Fig. 9.) Crystal Lake Bar region comprises the territory extending north from Frankfort Harbor, between Crystal Lake and Lake Michigan, past Point Betsie to the mouth of Platte River. On the east it contains the western end of Crystal Lake, also Long and Rush Lakes and several small ponds on or near the Platte River. This region is about 10 miles long and extends about one mile inland from Lake Michigan. The only settlements are two summer colonies on Crystal Lake with scattered cottages and farm houses along the state road to the northeast, and a small group of houses around the lighthouse and the coast guard station at Point Betsie.

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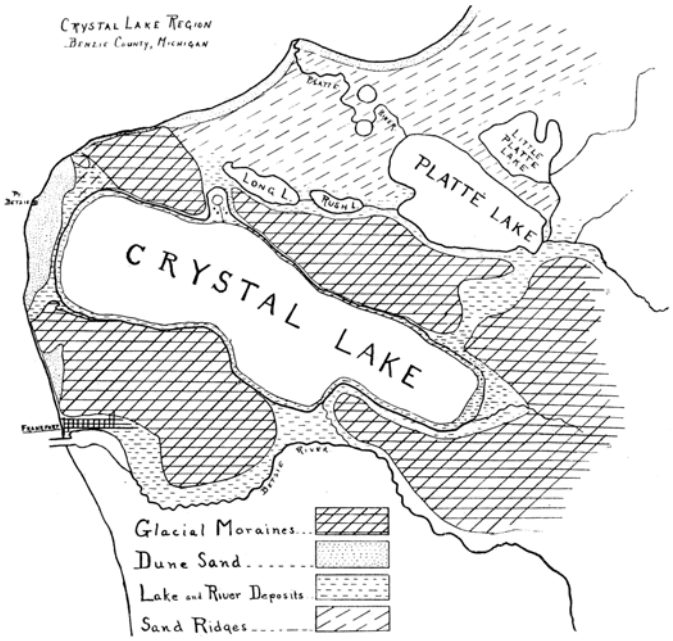


Figure 9. Geography of N. W. corner of Benzie County, Michigan.

B. Geology. (Fig. 10.) 1. Glacial deposits. The dominant features of the relief of the region are two glacial ridges extending from the shore of Lake Michigan to the southeast. They are characterized by gentle slopes and a nearly level sky line, with the exception of two depressions in the northern ridge, one leading to the west end of Long Lake, and the other to the east end of Platte Lake; and one in the southern ridge, now occupied by the outlet of Crystal Lake to the Betsie River. The edges of these ridges originally extended much farther into Crystal Lake, as indicated by bluffs caused by erosion of the lake. They were also much

nearer together at their western ends on Lake Michigan. These ridges are composed mainly of sand and gravel, more or less water-washed and stratified, and they contain at least one layer of laminated clay several feet in thickness, as shown clearly by the exposure on the Lake Michigan bluffs. This layer is marked on these bluffs by a zone of vegetation, which is probably due to the seepage of water held and brought to the surface by this clay layer. The character of the surface soils varies as different layers are exposed by erosion. This glacial deposit was apparently laid down on preglacial ridges, as indicated by the depth of Crystal Lake, which reaches 200 feet in places, and by soundings off shore in Lake Michigan which show the existence of drowned valleys opposite the end of Crystal Lake, and also of Frankfort Harbor. The level areas between the ridges are due to water action at the time of the Algonquin depression.

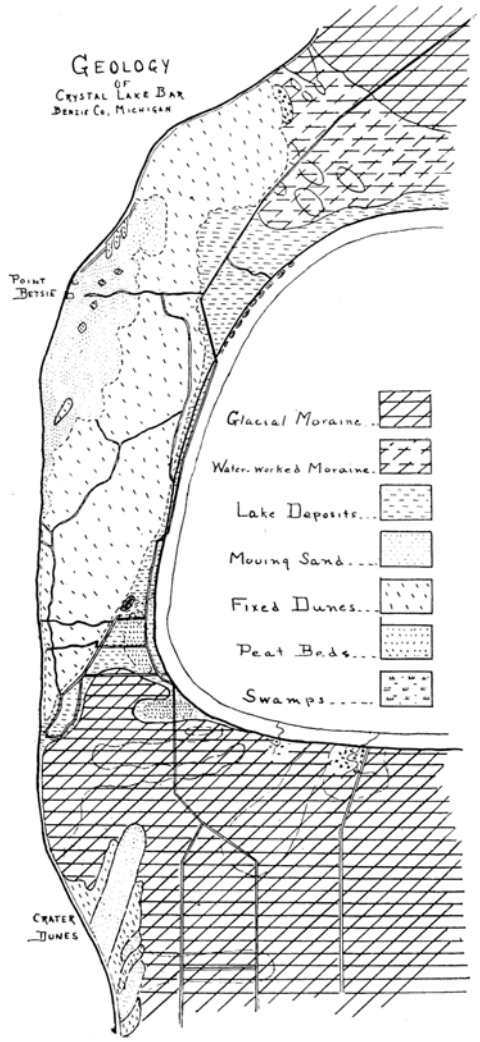


Figure 10. Geology of Crystal Lake Bar Region.

The topography as well as the character of these deposits and the identification of Algonquin beaches, show that in Algonquin times Crystal Lake was connected with Lake Michigan toward the north by channels passing west of Long Lake, toward the south through the valley of the present outlet, and to the west through the then unfilled valley which now contains Crystal Lake. During this time a broad harbor bar was built across this valley between the western ends of the glacial ridges. This bar, which is approximately two miles long and three-quarters of a mile wide, now cuts off Crystal Lake from Lake Michigan, and accounts for the name given to this region. At present the western outline of the bar is convex, but probably when first formed the glacial ridges extended much farther into Lake Michigan, and as they have been cut back the bar assumed its present shape. The region is still being eroded, as shown by the sand and clay bluffs and by the presence of fixed dunes, the western ends of which have been entirely eroded away by lake action.

2. Nipissing formations. Beyond Point Betsie extending to the northeast from the western end of the northern glacial ridge is an expanse of sand ridges of slight elevation with depressions between. This formation extends six miles to Platte River, and beyond that toward Empire, and is about one mile in width. It apparently dates from Nipissing times, and is very similar to the characteristic formation of similar origin at the head of Lake Michigan in Indiana and Illinois. As this formation will not be referred to again, a description of its vegetation will be given at this point.

The sand ridges have a characteristic cover of Quercus rubra, Quercus velutina, Pinus Banksiana, Pinus Strobus, Pinus resinosa, with Vaccinium, Gaylussacia, Epigaea, and Gaultheria undergrowth. The depressions show all phases of hydrarch successions, from Nymphaea up, including sphagnum bogs with Sarracenia and Betula pumila, and Chamaedaphne meadows with Vaccinium corymbosum and similar forms. Along the Michigan shore runs a narrow belt of low shore dunes, more or less rejuvenated. In appearance and vegetation they are similar to those around Point Betsie, to be described later.

Another relic of Nipissing times is an elevated beach just north of the lighthouse at Point Betsie. (Plate VI, Fig. 1.) The reason for its preservation is probably its proximity to glacial gravels which formed a protecting layer of shingle so that now the beach looks very much like a railway embankment, preserving its original sloping front toward the water, with a similar slope on the opposite side, caused by the wind blowing out the sand from among the pebbles.

3. Dune formation. Soon after the recession of post-glacial lakes the wind began its work of piling up dunes. Apparently they were at first located much farther west, on land since eroded by the lake. They have been continually in motion, passing through the usual cycles of fixation and rejuvenescence. They are found in two main localities in this region. A large complex on the Crystal Lake Bar surrounding the present Point Betsie, and a small group of perched dunes, called locally from their chief spectacular feature, the "crater" group.

a. Point Betsie Complex. (Plate VII.) This group is located on Crystal Lake Bar, starting in a point on Lake Michigan at the western end of the grounds of the

Congregational Summer Assembly, and spreading like a fan toward the north, and is about two miles in length and half a mile in width at its widest point. Its elevation varies from the water level to ridges upwards of 200 feet in height. At the southern extremity of the group the dunes are fixed, and extend from bluffs on the eroding shore to a steep lee slope on the eastern side. The contour is very uneven, showing dune ridges and outlines of blowouts. These are covered by a climax forest and have evidently been untouched for a very long time. Approaching Point Betsie the shore cliffs gradually become lower, and give place to a complex of moving sand. Great troughs lead from the shore for half a mile or more inward, to the advancing lobes of the lee front. Among these blowouts are found residual patches of the original forests. Just north of Point Betsie is a rather large patch of relic forest on three dune ridges, which extend southeastward from sand bluffs on the lake. On either side of them the sand has been blown out by both southwesterly and northwesterly winds, and a semicircular trough with a very large horseshoe front has been formed. This is one of the largest blowouts in the whole dune region of Lake Michigan, and is unique in this locality at least in showing the influence of winds from two directions. Beyond this blowout the dunes are higher and the steep sand cliffs begin again, and finally end about a mile north of Point Betsie with a definite lee slope just where the edges of the moraine ridge grade into the level surface of the bar. Under these dunes the moraine apparently extends some distance to the south as glacial pebbles have been found in situ almost to the top of the bluffs on Lake Michigan to a point within a quarter of a mile of the lighthouse.

b. The Crater Group. (Plate VI, Fig. 2.) This second group of dunes is found half a mile north of Frankfort on the shore, forming a most interesting group of detached, perched dunes. They are only half a mile in length and one-quarter of a mile in width, and extend almost north from the shore, which at this point lies northwest and southeast. The group consists of small fixed dunes which evidently once extended much farther out into the lake. They are from 50 to 100 feet, in height, but are placed on a morainic plateau, which itself rises 100 feet above the lake. These fixed dunes have been blown out through the center in a long trough, which is itself complex and shows traces of a number of parallel blowouts. These all end in a large steep-sided, semicircular blowout, popularly called the "crater."

II. CHARACTER OF ENVIRONMENTAL FACTORS.

A. Climatological. So far it has been possible to obtain only incomplete and not entirely satisfactory observations, so that only a brief general statement will be given. There is nothing exceptional about the meteorological conditions of this region as to precipitation and moisture in the air and in the soil. On account of the marked projection of Point Betsie into Lake Michigan, it is exposed both to southwesterly and northwesterly winds, which probably accounts for the large amount of moving sand around the Point, as well as for the large blowout described above. The wind also has an indirect influence on evaporation and temperature, especially in the summer, as a marked difference in both is observed when a period of easterly winds is followed by a similar period of westerly winds.

B. Substratum. On the dunes the blown sand is generally homogeneous in physical character, but a marked characteristic is the large percentage of calcium carbonate present in the form of residual grains formed by the grinding up of shells, apparently chiefly of Gastropods. This calcium carbonate content varies from one to five per cent. The dune sand is also characterized by a very unequal distribution of organic material, in the presence not only of old soil lines, but also of individual plant parts and of patches of dark material, apparently carbonaceous, with rare ferruginous patches, and also marly layers, indicating apparently the location of former pannes. The surface of the glacial deposits is mainly outwash, consisting of sand with more or less gravel, and even boulders, and with occasional exposures of clay layers.

The moisture content of the soil varies with the location and with the character of the substratum as shown in the following table:

Table I.

Relation of Character of Substratum to Moisture Content.

Locality.	Depth in cms.	Wilting Coeff.	Average moisture content 8 weeks, July and Aug., 1916.
Open Dune Summit	7	.5	2.
Open Dune Summit	25	.5	2.5
Forested Dune Summit	7	1.8	2.1
Forested Dune Summit	25	.3	1.3
Forested Dune Side	7	1.	2.2
Forested Dune Side	25	.3	1.2
Glacial Moraine	7	3.3	7.5
Glacial Moraine	25	2.4	5.

III. ECOLOGY.

(Fig. 11.)

A. Climax forest. The whole region, including at least part of the moving area, was originally covered by a heavy climax forest, (Plate VIII), which is still practically untouched in the southern tip and along most of the eastern edge of the dunes. The level ground on the Bar has largely been cleared, and is covered with second growth of forest trees and clearing pioneers, where not occupied by summer cottages. The climax forest is composed of beech, maple, and hemlock, with much yellow birch. The trees are tall and slender with close stand and very little undergrowth, where undisturbed. Occasional specimens of Quercus rubra, Pinus Strobus, and Pinus resinosa are found. Among the shrubs, Acer spicatum, about at the southern limit of its range, Viburnum acerifolium and Taxus canadensis are conspicuous. Characteristic species in the undergrowth are Aralia nudicaulis, Streptopus roseus, Clintonia borealis, Aralia racemosa, Maianthemum, Linnaea borealis and Mitchella repens, with Aspidium spinulosum, Adiantum pedatum, and Botrychium virginianum.

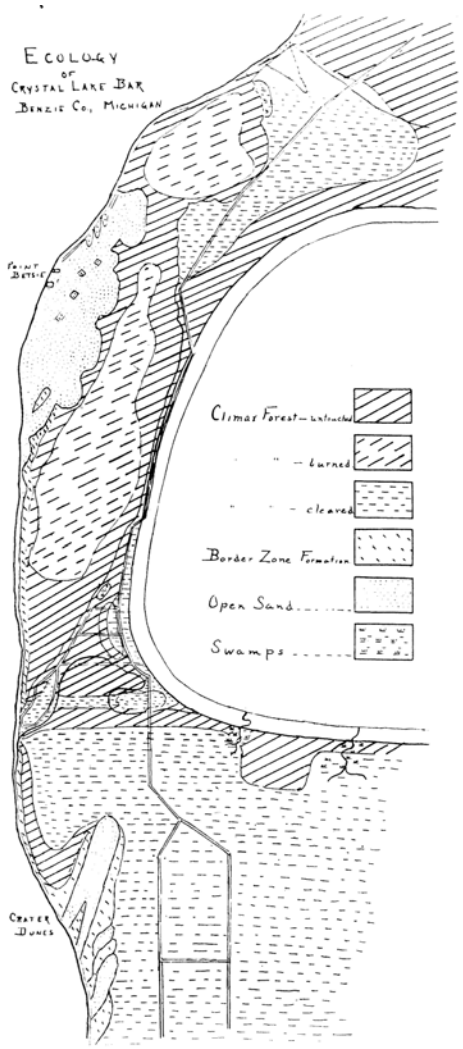


Figure 11. Ecology of Crystal Lake Bar Region.

Burned Area. The northern and central portion of the forested strip has been burned, in some parts repeatedly, in others not so recently. In the much burned portions the tree specimens are young and somewhat stunted. In the other portions the trees are larger and the undergrowth thicker. The species include Betula alba, Prunus virginiana, and Prunus pennsylvanica, with the more xerophytic relics of the mesophytic undergrowth, and much Pteris and Equisetum.

Border Zone Formation. Where the climax forest, still untouched, extends to the shore, a zone 50 to 100 yards in width; shows a very characteristic difference in species. (Plate IX.) The trees are Thuja, Ostrya, Tilia, and Abies balsamea, with Celastrus scandens. The line of demarcation is not sharp, but the climax trees, especially hemlock, mingle with the others almost to the edge of the cliffs. The characteristic border zone species are not found farther back in the climax forest.

B. Dune Complex Vegetation. On the open dune complex there are found a number of forest patches, apparently growing in valleys between former fixed dunes whose summits have been entirely blown away. (Plate X.) The interiors of these patches present all the characteristics of a heavy forest, and their evaporation rate is almost as low as that of the climax forest. But the vegetation is characteristic of the border zone described above, containing especially Thuja and Abies, and is marked by some trees reaching two feet in diameter, but not over 30 feet in height. The undergrowth is similar to that of the climax forest, but is especially characterized by Viburnum acerifolium, Rhus toxicodendron, and Aralia nudicaulis. On the edges, next to the open sand, are found Arctostaphylos, Linnaea and Juniperus horizontalis. These apparently originate in the fixed area, and extend out on to the sand, forming a protective covering, which frequently contains also Juniperus communis. Buried trees and occasional graveyards are to be found all over the moving sand area.

There is not much forest reproduction on the moving sand, and, unlike some similar regions, no young stands of Pinus Banksiana, nor any cottonwood dunes similar to those of the Indiana-Michigan region. There are practically no panne colonies, but a few isolated oval groups, chiefly of Thuja and Betula alba, which seem to have originated from pannes, growing upward as the sand accumulates around their stems. A few other patches have reached the low conifer stage, but seem to have been chiefly invasions from the relic patches previously described. On the open sand the vegetation consists of characteristic pioneer herbs, Ammophila and Calamovilfa among grasses, with Lathyrus maritima, Artemisia, Campanula rotundifolia, Cirsium Pitcheri, some Hudsonia, and Zygadenus chloranthus. There are frequent mounds protected by Calamovilfa, Prunus pumila, Salix syrticola, and Cornus stolonifera.

The growth of grasses, especially Ammophila, is quite extensive, and frequently approaches the character of fixed grass dunes. This is especially noticeable on the advancing lee slopes, where the complex is overwhelming the climax forest.

C. Vegetation of the Crater Group. This group apparently consisted at first of fixed dunes which were at least partly covered by the climax forest of the glacial plateau on which they are perched. At present the outer slopes of the fixed dunes, from which the center has been blown out to form the trough, are covered by a formation similar to the border zone and relic patches already described. On the open sand of the trough are found the usual pioneers of the region, with in addition a great abundance of Anemone multifida and Lilium philadelphicum. The sides of the earlier troughs are frequently covered with Ammophila and Calamovilfa, and in places practically form fixed grass dunes.

D. Crystal Lake Beach. The west end of Crystal Lake is bordered by a sandy beach 400 feet in width, with a slight slope toward the water. The history and ecology of this beach are very interesting. At the beginning of historic times the waters of Crystal Lake were approximately 15 feet above their present level, being impounded by a sand bar across the mouth of the present outlet. The waters of the lake apparently

escaped by seepage through the sand. About 1871 certain individuals formed the ambitious plan for an inland waterway from Frankfort Harbor, through the Betsie River, Crystal Lake, Long and Platte Lakes, and began operations by cutting through the sand bar on Crystal Lake. This of course lowered the water of the lake rapidly, and laid bare this under-water shelf or sand terrace. Nothing further was done with the inland waterway scheme, and the beach has remained exposed to the present. As a result of this exposure of a broad sand area, the formation of dunes began at the first point on the west end of the lake where the southwest winds could get sufficient sweep. These dunes extend for nearly a mile, and increase in size toward the north. At the beginning they are almost indistinguishable from the beach, and at the other end have reached a height of 10 or 15 feet and a length of 50 feet. The vegetation on these dunes is scattered and consists chiefly of Ammophila. The vegetation of the beach is interesting because a definite date can be set for its beginning. At present it consists chiefly of Juncus balticus in the wetter portions, some species of Aster, Solidago, and stunted shrubby growths of Salix, Populus balsamifera, and Betula alba. At certain points there has been a slight invasion of Thuja, apparently from swamps of the high water period. At one point on the beach there can be seen four stumps of trees which apparently grew on the beach at a prehistoric period of low water similar to the present although they may have floated there from the shore at the high water stage. These stumps are about three feet in diameter, and have been identified as Pinus Strobus. They were cut off level by the action of the beach gravel, and the sand has been lowered around them by wind action approximately eight inches. Their presence is interesting as indicating a possible former vegetated period for the beach if they should prove to be indigenous, and in either case they give a measure for the reduction of level of the beach by removal of sand by the wind.

IV. PROBLEMS.

It seems desirable to indicate here certain problems which suggest themselves in connection with the study of this region. At present possible lines of solution can only be hinted at but study of their phenomena will be continued, for their solution would throw much light on some obscure points in the principles of dune succession.

A. Character and Cause of the Border Zone Formation. It will be noted that this formation is found only on the edge of the climax forest bordering on the bluffs on Lake Michigan and in relic patches on the Point Betsie complex. The species involved are more xerophytic than those of the climax forest. Two factors suggest themselves as chiefly contributing to produce this marked difference in vegetation. One is that of light; for Thuja and Abies balsamea apparently are not shade tolerant, and do not grow to any size when they accidentally germinate in the heart of the climax forest. The other would be the moisture situation, but so far as atmospheric conditions are concerned, atmometer readings show that certain hill tops of the fixed dunes covered by a climax forest have a higher evaporation ratio than this border zone, but they are covered by the characteristic climax formation, except that relic pines and oaks seem more common on these ridges. Soil moisture at the deeper levels may also have something to do with the character of this border zone formation, as soil water must drain away more rapidly through the exposed surface of the bluffs than in portions farther away from the lake.

B. Distribution of Pinus Strobus. In prehistoric times the sandy plains to the northeast of Point Betsie were covered with a heavy growth of Pinus Strobus. This was burned over before the arrival of the white man, who cut many of the trees which had been killed by the fire but which were still standing. From the testimony of the oldest inhabitants there are practically no white pines in the climax forest south of Point Betsie. From other observations it would seem that the beech-maple-hemlock forest extended in a strip 10 or 12 miles wide from Point Betsie south practically to the sandy plains east of Manistee. East of this strip white pine was the characteristic tree. The soil map indicates a region of glacial moraines, just about coterminous with this strip of hardwood forest, while east of this strip is a similarly extensive region of sandy soil. On the other hand, within the Crystal Lake Bar region the climax forest extends apparently without change from the glacial soil northward over the fixed dunes to the northern edge of the moraine beyond Point Betsie.

C. The Relations of the Component Parts of the Climax Forest.

1. While the pine-oak stage is not a prominent feature of successions of northern Michigan, there are evidences of its former existence here in the oak and pine remnants found in the climax forest. These are rare, and are generally located as indicated above, on the more xerophytic summits of the ridges in the forest, whether on dune or glacial substratum.

2. The conditions for germination of maple and hemlock seeds seem to be rather different. The hemlock seems to be unable to germinate except on decaying wood. Practically the seedlings are usually found on decaying hemlock trunks, frequently as many as a dozen have reached the height of several feet on a single trunk, (Plate XI). On the other hand, the maple seems to need more light for successful germination, and abundance of maple seedlings is a common characteristic of the greater light supply produced by the fall of a large tree, and the consequent opening up of the forest crown.

3. Persistence in the open. When forest trees are left to grow in the open, or are planted in isolated positions, the maples seem to be the most successful. It is a popular saying that the hemlock will not grow where people walk over its roots, which apparently indicates that it .needs the undisturbed conditions of the forest. The beech also is not a tree of the open, and seems to die readily where

exposed on the edges of clearings. From these considerations it would seem as if the hemlock on the whole was the more shade tolerant, and therefore likely to become the final member of the climax forest, if left long enough in undisturbed conditions.

University of Chicago.

LEGENDS.

Plate VI. Fig. 1. Fossil Beach, north of Pt. Betsie lighthouse.
Fig. 2. Shore bluffs with "crater" dunes perched on glacial plateau.
Plate VII. Pt. Betsie Dune Complex, showing typical blow-out on right; relic forest patches in background, and lighthouse and coast guard station.
Plate VIII. Beech-Maple Hemlock Forest on fixed dunes.
Plate IX. Interior view of Border-Zone formation.
Plate X. Exterior of relic forest patch on Pt. Betsie Dune Complex.
Plate XI. Interior of Climax Forest, showing hemlock seedlings on decaying log.

With the exception of Plate VII, the originals of the above are by Dr. George D. Fuller of the University of Chicago.

MICHIGAN ACADEMY OF SCIENCE. PLATE VI.

Figure 1.

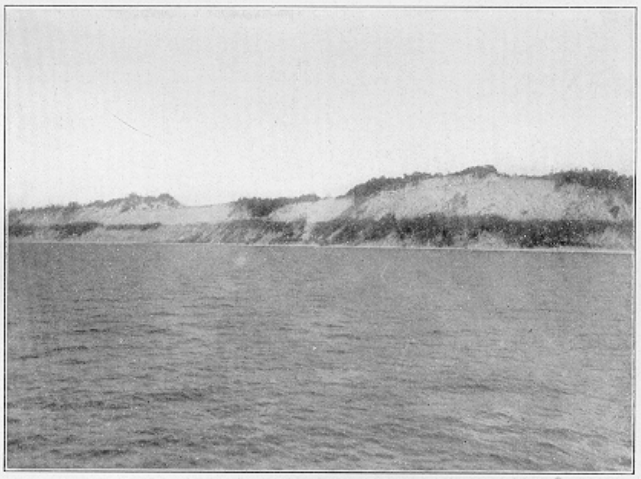
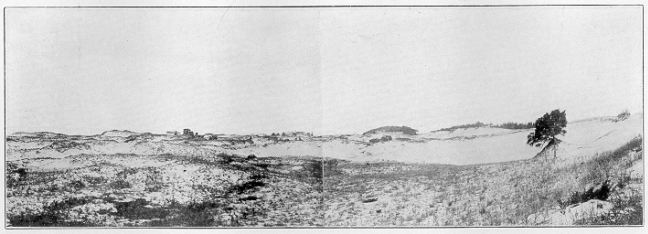


Figure 2.

MICHIGAN ACADEMY OF SCIENCE. PLATE VII.



MICHIGAN ACADEMY OF SCIENCE. PLATE VIII.

MICHIGAN ACADEMY OF SCIENCE. PLATE IX.

MICHIGAN ACADEMY OF SCIENCE. PLATE X.

MICHIGAN ACADEMY OF SCIENCE. PLATE XI.