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OF
THE MICHIGAN ACADEMY OF SCIENCE

CONTAINING AN ACCOUNT OF THE ANNUAL MEETING

HELD AT

ANN ARBOR, MARCH 27, 28, 29, 1907.

PREPARED UNDER THE DIRECTION OF THE COUNCIL

BY
E. E. BOGUE
SECRETARY

AND

WALTER G SACKETT
ASSISTANT SECRETARY

BY AUTHORITY

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LETTER OF TRANSMITTAL.

TO HON. FRED M. WARNER, *Governor of the State of Michigan:*

SIR—I have the honor to submit herewith the Ninth 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.
WALTER G. SACKETT,
Assistant Secretary of the Michigan Academy of Science.
Agricultural College, Aug. 31, 1907.

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COUNCIL.

The Council is composed of the above named officers and all Resident Past-Presidents.

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*Deceased.

ISRAEL COOK RUSSELL.

Since the last meeting of the Academy there has passed from among us one who had always been a leading and interested participant in the discussions concerning the welfare of our organization and its activities since its foundation.

Israel Cook Russell, the subject of this brief memorial, was not only known to the circle here, but as well, and possibly better, beyond these circumscribed limits, as a writer of great ability and authority upon his chosen subjects, as a scientific, thorough and careful student, as a daring explorer, and as a teacher who was constantly striving to give his students the best results of his own and others' work in geology and kindred subjects.

He was born near Garratsville, N. Y, on December 10, 1852, and was the son of Barnabas and Louisa Sherman (Cook) Russell, who were of New England descent, and moved with his parents when twelve years of age to Plainfield, N. J. His education followed the usual course; preparation for college, first, at a high school, near his home in New York State, and afterwards at the Hasbrook Institute, Jersey City, and a college course at the University of the city of New York, from which he was graduated with the degrees of A. B. and C. E., in 1872, after which he took a graduate course at the Columbia School of Mines.

His first scientific work after his college course was finished, was done in 1874, while he was attached to the U. S. Transit of Venus Expedition to New Zealand and Kerguelen Island, as photographer, acting, however, in the capacity of naturalist as well. It was doubtless on this expedition that he gained the experience in the art of photography which enabled him to do so much most excellent photographic work in his later explorations.

In 1876 he was appointed assistant professor of geology in the Columbia School of Mines, resigning in 1878 to accept a position with the U. S. Geographical survey west of the 100th meridian, and for a year, or more, was engaged in geological work in New Mexico. In 1880, after returning from a trip to Europe, he entered the United States Geological Survey and was assigned to the Division of the Great Basin, in which his special work eventually became the investigation of the Quarternary history of a series of desert basins in Northern Nevada, and adjacent parts of California and Oregon, and as the result of this work, he prepared a series of papers which are classics, and secured for him high praise in this country arid in Europe.

After completion of this work he was assigned the investigation and mapping of portions of the Paleozoic formations in the southern Appalachian region, and later prepared a report upon the Newark formation. In 1889 he made his first trip to Alaska, ascending the Yukon River, and crossed the mountains southward to the Lynn Canal during the early part of winter. This work was done under the auspices of the U. S. Geological Survey in connection with the work of the U. S. Coast and Geodetic Survey, which was then surveying a portion of the eastern boundary of Alaska.

The next two summers were also spent in Alaska, exploring Mt. St. Elias and the adjacent region, and as a result of his studies upon the Malaspina glacier; his very valuable contributions to glacial geology were made. In 1892 he was elected Professor of Geology in the University of Michigan, in which position we learned to know and honor him. In 1886 he was married to Miss J. Augusta Olmstead, who, with three daughters and a son, survive him.

As compiled by Librarian Koch, of the University of Michigan, his list of published writings contains 124 numbers, and there were five unpublished, but completed, or nearly finished, manuscripts upon his desk at the time of his death, two at least of which will be published. Seven of his published productions are books, and of his remaining publications 30 may be classed as extensive reports of investigations, or major scientific papers, and 50 as brief discussions and minor contributions to our knowledge of the subjects in which he was interested. The rest of the list is made up of miscellaneous papers, a considerable proportion of which may be termed educational and philosophic.

Among the books already mentioned, there are several valuable works which were in part, at least, the outgrowth of his work as a teacher. These are what he modestly termed "Reading Books," but in reality they are monographic manuals adapted to the needs of the general reader, or student, in which not only all the data collected by others have been brought together in a single volume, but the results of the wide personal investigations and observations of the writer are given, and the light of his analysis of facts and theories is added. This makes these works useful to the expert, as well as valuable and available to the beginner, and they are not infrequently quoted as standard authority.

In these works his style is simple, direct and pleasing, a statement equally applicable to all of his publications; there is very little technical language used, and such as there is, is not difficult to grasp. These writings also abound in illustrative matter and descriptions of actual localities which are considered typical, enliven and enrich the text with word, pictures which take the reader to the place described, and point out the salient features to be observed, and explain their meaning.

This habit of making his writings clear and interesting was a fixed one, and pervaded his more technical works as well as the group under discussion. One instance in point, is to be found in the monographic study of the Mono Lake region of California. This region has recently been made accessible by rail, and a demand came from the people living in the county in which the lake lies to the Director of the U. S. Geological Survey for a new edition of the report, to be paid for by the residents, who were to use it in attracting the attention of tourists and others to the wonders of the lake and the surrounding country. The request of the committee in charge of the matter explicitly stated that the attractive style in which the report was written made it very desirable for their purpose. It was to revise his work of twenty years ago in that region that the summer of 1906 was to be devoted. In passing it may be said that this pleasing and attractive style in no way detracted from the *scientific* value of his work, and was cultivated with the express hope that it might make it of more use to a larger number of people—a hope which in this case was undoubtedly realized.

Of a slightly different class from the "Reading Books," is the book entitled "North America in 1900," published in the series "The world in 1900." This is a popular resume of the Physical Geography of the North American Continent and its condition at the beginning of the 20th century, and is an excellent reference work on the subject.

Among other works which are of a distinctly educational type are two "Geographic Monographs," a part of a series, written to aid teachers and furnish collateral reading for students of geology and physical geography in secondary schools. With these also should be placed a paper on the Topographic Atlas of the U. S., which shows the uses which may be made of this magnificent series of maps by various classes. Along this same line also is the address delivered before the Michigan Academy of Science as its President in 1894, upon the topographic survey of Michigan, in obtaining which he was greatly instrumental, by making a strong plea showing how generally useful such a survey with its resulting maps would be to all classes, pointing out especially the educational value of the completed work.

His major contributions to the sum of human knowledge are along the lines of Physical Geography, Descriptive Geology and Dynamic Geology, and, although much of his work of investigation was of reconnaisance or exploratory character, it was done thoroughly and so well that those who follow him will find little that is new.

His observations were carefully made, and fully and clearly described, and, since he was a tireless worker in his study as well as in the field, promptly published. It was his habit to begin writing the account of his season's field work immediately upon his return home, while the details were still fresh in mind, and it was this industry which gave us the last two works which he finished, his report of the surface geology of the Menominee region in the Northern Peninsula, and the paper which he was to have read before the Geological Society of America.

A very few of his briefer papers are reviews, and he seems to have indulged in controversial writings to but a slight extent. Two things stand out prominently in all of his written work, first, thoroughness and careful attention to important details, and second, clearness of statement, accompanied by abundant illustration both by verbal and by actual pictures, so that even laymen could find much of interest in the most technical of his papers.

While Professor Russell was a deep thinker upon the problems pertaining to many of the lines of research in his chosen field of work, there is little of the purely speculative in his published writings, and apparently he kept his imagination well in hand in developing hypotheses to account for observed facts, working out those which were reasonable and probable. He was persistent and patient in gathering facts, and his statement of them may be relied upon, as he made little, if any, use of hearsay statements; his mind was flexible and active, when he was making observations, and he was quick to see the bearings of *new* observations, and to place them in their proper categories and did not hesitate to discard an old theory when it did riot fitly explain newly-observed facts.

Little has been said of his work as a geographer, but this was fully as important as his geological work. His love for penetrating the unknown and difficult parts of the continent was well known to all of his intimate friends, and it was a cherished hope that he might again have the opportunity to go to Alaska to explore some of the more inaccessible portions of its mountain, fastnesses.

In all of his field work after his connection with the University of Michigan he was constantly on the lookout for illustrative material, with which to enrich his lecture courses, and a large number of unique specimens were added to the geological collections as the result of this activity, as well as many photographs and lantern slides, which could not have been obtained in any other way. His skill as a photographer was unusual, and he possessed rare ability in choosing proper subjects, and the right light and angle to show these in order to make the most attractive pictures, as well as to illustrate the point under consideration. He not only had the skill which conies from long practice, but a love for the beautiful and the artistic instinct as well.

He was a member of several scientific and professional societies, and had served this Academy as President and as Vice President of the Section of Geology, and in many ways less formally. In the broader fields, he had been Vice President of the American Association for the Advancement of Science, and was President of the Geological Society of America when he died, and his last completed writing was a paper entitled "Concentration as a Geological Principle," intended to be used as his presidential address to the society at the annual meeting. He held the honorary degree of Doctor of Laws, given him both by his alma mater and the University of Wisconsin.

The writer had the pleasure and good fortune to be associated with Professor Russell during his field work in the Menominee region in 1905, the last of his life, and thus had a chance to become somewhat closely acquainted with his methods of work, and to strengthen a bond of friendship already formed. In the intimate associations of camp life his steadfastness of purpose, his simplicity of character, serenity of spirit, his goodness of heart and consideration for his associates were deeply impressed upon the writer's mind. It is entirely characteristic of the man that while he was a delightful story-teller, he rarely volunteered to tell of his experiences, and when urged to describe some of his adventures, declared that he had never had any, "for nothing had really ever happened to him." His love of home and his family was also a marked characteristic, and it was apparent from, chance remarks that they were never absent from his mind during the entire season.

In person he was slightly below medium height, and of rather slender frame, so that he seemed almost frail, but really possessed great strength, agility and endurance, as must be apparent if his work as explorer is considered.

As a man, he was upright, generous, industrious, and always ready to do his whole duty as he saw it; and as a citizen, when called upon, was willing to give liberally and without cost of his time, energy and knowledge for the benefit of the community. This is exemplified in his voluntary services to the city of Ann Arbor as a member of the committee to investigate the city water supply, and his report on the subject is a most valuable one to the city.

Truly, a good man has gone from our midst, in the prime of a busy and useful life.

CHAS. A. DAVIS.
University of Michigan, Ann Arbor, Michigan.

EARTHQUAKES VIEWED IN A NEW LIGHT.*

WILLIAM HERBERT HOBBS.

Mr. President, Members of the Michigan Academy of Science, Ladies and Gentlemen:

It is safe to say that the last twelve years have registered an advance of our knowledge of earthquakes not paralleled by that of any earlier period of the same length, if it is, indeed, by that of all earlier time. The collection of data essential to so grand an achievement has necessarily extended over a somewhat longer period and has been made in earthquake countries, more especially, however, in Italy, Austria and Japan. Nowhere else has earthquake study attained to such well-planned refinement as in Japan. It may seem, therefore, somewhat remarkable that the two men to whom more than to any others we owe the recent advance of seismology, are residents of countries within which earthquakes belong to the rare and curious, rather than to the most common of natural phenomena. The Count de Montessus de Ballore, who has given us the new science of seismic geography and who has discovered a law to connect earthquakes with the relief of the country, is a major of artillery in the French Army. Professor John Milne, to whom more than to any one else we owe the so-called "new seismology," or the study of "unfelt earthquakes," now resides near the little station of Shide, upon the Isle of Wight. Both these distinguished seismologists have made earthquakes the study of a lifetime, and each was formerly a resident in provinces which, to use the picturesque continental expression, have been tormented by earthquakes.

The grander results of recent earthquake study may be summed up in a few words. Perhaps most important of all, the long supposed genetic connection of earthquakes and volcanoes has been shown to be without a basis of fact. Speaking broadly, the earth provinces where volcanoes are found are generally those of important earthquakes, and light earth shocks are an accompaniment of all grander volcanic eruptions, as they are likewise of explosions in mines or of the passage of a railway train; but as regards the great earthquakes, it is found that the show no quick sympathetic relation to volcanic outbursts within the same province. Further, it has been found by the Count de Montessus as the result of the analysis of no less than 170,000 separate earthquake shocks, that a law connects the seismicity (which we may translate the "earthquakeness") of a province with its topographic relief. Other things .being equal, the steeper the slope, the greater the danger from earthquake shocks.

The most sensational of the newer revelations in siesmology has resulted from the "distant" study of earthquakes at properly equipped earthquake stations. In the year 1883 Professor Milne wrote, "it is not unlikely that every large earthquake might, with proper appliances be recorded at any point on the land surface of the globe." The fulfillment of this cautious prophecy was assured when, six years later, von Rebeur-Paschwitz found in the records of a horizontal pendulum certain abnormal movements which he traced to earthquakes at great distances from the observing station. The great Indian earthquake of 1897 was the first to be studied at distant stations, namely, in Italy, Germany and England; but today the globe is dotted with earthquake stations well distributed over its surface. Every heavily shaken district whether accessible upon the land areas or upon the bottom of the sea, has its shocks recorded not at one but at many stations; and from these earthquake watch-towers it may be quite accurately located through a very simple calculation. Thus, for example, an earthquake in New Zealand telegraphs its own report to Professor Milne at his station in the Isle of Wight, though this is almost exactly upon the opposite side of the planet; and it occupies, moreover, but a little more than twenty minutes in transmission. This first report is dispatched through the body of the earth, but other and slower messages are sent along the surface with velocities only one-third as great, and these arrive over the longer route some hours after the first intelligence. Still later come the telegraphic reports of the disaster, though these may be delayed for days as a consequence of ruptured cables.

The distant study of "unfelt" quakes has revealed to us facts of the first order of importance. Of "world-shaking" earthquakes, comparable in intensity to the one which visited California last April, we know that no less than 70 occur each year, 90% of which are fortunately upon the floor of the ocean. Each of these disturbances throws into agitation the entire earth's crust, the surface movement being transmitted as a slow swell which even at the most distant points has sufficient intensity to raise the surface of the ground a number of inches, and would be perceived were it not so slow. The waves which first arrive at the earthquake station come by the direct route through the earth's mass, and these have told us that the substance of the earth's core is about 11/2 times as elastic as the best tool steel. To have discovered a direct method of studying, upon the one hand, the interior of our planet, and upon the other, geological changes which take place at the bottom of the sea, will hardly be considered small contributions to the sum of human knowledge.

Fascinating as is this distant study of unfelt quakes, it is to the no less interesting and more purely geological phases of our subject to which I wish to draw your attention this evening. The supposed dependence of earthquakes upon volcanic sources of energy in its more concrete form has assumed that gases are imprisoned at some place within the crust—a locus or center— and in their struggles to free themselves they send out sharp

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*Address delivered by invitation at the annual meeting of the Michigan Academy of Science.

seismic waves. This focus or centrum idea has come down to us from the Greek philosophy, and was common enough in the Middle Ages. When in Henry IV Glendower boasts that the heavens were on fire and the earth was shaken at his birth, Hotspur is made to say:

> "O, then the earth shook to see the heavens on fire,
> And not in fear of your nativity.
> Diseaséd nature oftentimes breaks forth;
> In strange eruptions; oft the teeming earth
> Is with a kind of colic, pinch'd and vex'd
> By the imprisoning of unruly wind
> Within her womb; which for enlargement striving
> Shakes the old beldame earth and topples down
> Steeples and moss-grown towers."

As a modern scientific theory the earthquake centrum dates from the elaborate description by Mallet of the great Neapolitan earthquake of 1857. How firmly the idea was then implanted is shown by the fact that Mallet made no attempt to prove the existence of a centrum, but devoted all his energies to fix its location. By methods which are now known to be wholly unreliable he obtained a great number of results ranging with noteworthy uniformity from depths of 10,000 to 45,000 feet, and it is significant of his state of mind in respect to the certainty of a centrum, that he adopted the average depth for its exact position. His assumption was, in short, that within this subterranean "focal cavity" gases were imprisoned and their struggles to liberate themselves sent waves in all directions with equal velocities. These waves would reach the surface of the earth first at a point immediately above the centrum—the epicentrum—and at later instants the disturbed points would be situated upon lines roughly circular in outline and surrounding the epicentrum with successively larger and larger diameters. This conception of the cause of earthquakes rendered it manifestly impossible to establish relations between earthquake shocks and the geological structure of the country, and thus the field of seismology came to be yielded by geologists to a group of applied mathematicians now generally referred to as elasticians for nearly half a century the centrum theory has now been orthodox doctrine, and an elaborate superstructure of ingenious mathematical deduction has been raised upon it as a foundation.

The revelation that large earthquakes and volcanic eruptions within the same province are not sympathetically related, has removed at one stroke the *raison d'etre* of the centrum idea. It is also a significant fact that the great achievements in seismology during the past twelve years have been reached by studies which have largely ignored the orthodox faith of the science.

The history of science has furnished many examples of theories which have contained a small element only of truth, but yet enough to suggest experimentation and to widen the field of study. Such theories have evolved through enlargement of the true and elimination of the false. The centrum earthquake theory illustrates a false though quite plausible assumption, the effect of which has been like a bandage before the eyes shutting out the light and involving in deep mystery even the simplest of natural phenomena. It will be my endeavor in the brief time that I may claim your attention to present earthquakes in a new light, or, in other words, as geological phenomena to be studied in relation to the changes in the earth's surface by which they are accompanied, and upon which they appear to depend.

In order to bring before our minds the more important of earthquake phenomena we may profitably consider for a few moments the great Indian earthquake of 1897, which deserves to rank with the greatest in history. No earthquake has been more fully or more ably studied, and the results, well illustrated, completely fill a bulky volume of the Memoirs of the Geological Survey of India. Almost the total damage which resulted from this earthquake was the result of the initial shock, and all destruction occurred within the first fifteen seconds of the disturbance. Before two and a half minutes had elapsed all of the heavy shocks had passed, but in this brief interval of time an area of one and three-quarters millions of square miles had been shaken, and one hundred and fifty thousand square miles had been laid in ruins.

A member of the staff of the Geological Survey of India, who wag in the town of Shillong at the time of the earthquake, has stated that a rumbling sound like near thunder preceded the shock by a second or two of time, and increased in intensity so that the falling of heavy masonry buildings a few rods away was not audible. Unable to keep his feet he sat down upon the ground, and not only felt but distinctly saw the ground thrown into violent waves, "as though composed of soft jelly." These waves appeared to advance along the ground, and induced in him a feeling of nausea akin to seasickness. When the shocks had passed all masonry structures had been leveled to the ground, and over each hung a cloud of pink plaster particles and dust. Above the town in the park a horseman noticed that a peculiar rustling of the leaves upon the trees preceded the first sounds by a brief interval of time as though resulting from an earlier tremor.

By many the shocks were described as in places gyratory or twisting in their nature, and monuments which were built up of sections revealed an increasing amount of rotation for those higher blocks in the structure which had not been completely detached.

Over large areas the surface of the ground was rent by numerous fissures, large or small, and some of these had great extent. It was noticed that these fissures followed in their direction the lines of the ranges of hills. Sometimes they gave the impression of having opened and later closed under great pressure, as the ground was raised in a furrow. If sandy, the ground ap-appeared as though a steam plow had passed over it, tearing up the surface and throwing heavy clods in every direction. Posts were sunk deeper into the ground and were surrounded by a cup-shaped depression. In many instances monuments and even houses were similarly projected into the sandy ground so that only the tops and roofs remained visible.

In addition to the numerous cracks, crater-like pits appeared in the ground. These were usually about six feet across, though sometimes more, and through them jets of sand and water were thrown to a height of seven or eight feet, and probably much higher. Mixed with the sand were fragments of peat, coal, resin, half-petrified pieces of timber, and a black earth at the time unknown in the district. The same materials also welled up through some of the fissures. The large amount of sand thus brought to the surface was spread around the orifices in flat domes, and where these were most numerous the entire face of the country was flooded, and after an interval blanketed with a layer of quicksand in which cattle-floundered and were held fast. The local streams were swollen suddenly and raised from two to ten feet, though they settled back to their former levels shortly after. The Brahmaputra advanced as a wall of water ten feet in height.

In the Garo and Khasi hills the numerous land slips within the weathered sandstone rocks developed wide spread fans of sand at their bases. The rivers of this section are ordinarily a series of deep pools separated by rocky rapids, though in flood-time they changed to raging torrents. Following the rains after the earthquake of 1897, the pools were found to be filled up with sand, the rapids obliterated, and the streams flowed over the sandy floor of a broad and shallow channel. In this hill country were found the most interesting of the geological changes. Although only a single zig-zag journey was made through the country, three large earthquake faults, hundreds of great fissures and no less than thirty lakes were found to have resulted from the earthquake. One of these lakes was more than a mile across.

The largest of the earthquake faults, known as the Chedrang fault, adhered to the course of a meandering but otherwise straight river, and was thus followed for a distance of twelve miles. The vertical displacement or throw revealed by the walls of this fissure was in one place no less than 33 feet, but it changed most abruptly and frequently. Where the upthrown side of the fault cut the course of the river on the down stream side, the waters were impounded into a lake, but otherwise a waterfall resulted. Sometimes the fault was double, and examination of a ledge of rock 200 feet distant from it showed that adjustments amounting to several inches had occurred on many of the vertical fissures by which it was intersected. Throughout movements appeared to have been upon essentially vertical planes of fissure.

At places along the course of the Chedrang fault the ground was tilted for a considerable distance in the direction of the course of the fault, and in some cases small lakes resulted from this cause. A roughly cubical block of granite 40 feet long, 30 feet wide, and 30 feet high, which had lain across the course of the fault, had by the movement upon it been completely overturned. Elsewhere in the vicinity large boulders were seen to have been lifted out of their hollows, projected for a considerable distance, and left in some instances overturned with the dirt still adhering to them.

In the report upon the district the name fracture is given to the numerous visible fissure planes on which no observable vertical displacement, or at most a very small one, could be made out. Of these there were hundreds observed, the largest of which became known as the Bordwar fracture. This fissure was followed for about 7 miles in a straight line as a crack in the hard gneiss rock, and showed in places a few inches of displacement. Its course could, however, be easily followed by overturned trees, broken bamboos, land slips, or as a small ditch in the surface of the ground.

Important changes of level of great blocks of country were clearly shown by the alterations in the aspect of the landscape. Ranges of hills which before had not been visible from certain points, now for the first time came into view, while others had disappeared. In at least one instance some measurement of these changes was carried out. So soon as it was noted that the changes had taken place, lines of sight to definite points in the landscape were determined through the nailing of boards to stout posts. Later observations along the same lines gave some measure of the subsequent changes in level. Shortly before the earthquake, a primary triangulation of the district had been carried out, and a resurvey made subsequent to the disturbance revealed changes in elevation of stations by as much as twelve feet, and of location by about the same figure.

Though the most destructive shocks arrived during the first few seconds of the disturbance, those which immediately followed were heavy enough to have caused great damage had not all structures been already leveled. Shocks of lesser intensity were felt for more than a week, but these gradually faded away. At a point located near the great Chedrang fault, it was noticed that the surface of a glass of water did not come to a rest for more than a week after the disturbance. Observations proved, however, that after shocks were less numerous in the vicinity of the faults than elsewhere within the affected region. When the shocks had ceased to be felt as waves they continued to be perceived as low rumbling sounds. In this period observations extending over twenty-three hours furnished a record of 48 separate disturbances, only 7 of which were accompanied by sensible shocks.

The description of this earthquake has placed before us the more important characteristics of large earthquakes. A great earthquake affecting especially the floor of the ocean would have differed by producing a great wave, such as has generally been erroneously designated a tidal wave. Such was the great Lisbon earthquake of 1755, the wave from which traveled throughout the surface of the globe, or the Japanese earthquake of 1896. Earthquakes which occur upon a coast line also furnish us with a better indication of the changes in level of the surface of the ground, since the sea level is here a datum plane for measurement. Not only do earthquakes bring new lakes into existence, as was the case in the lower Mississippi in 1811 and in India in 1897, but lakes and swamps already in existence are frequently drained. Such changes were particularly well illustrated by the great earthquake in the lower Mississippi valley in 1811. The bottoms of the drained lakes thus exposed to view, showed the ground divided into strips with funnel shaped holes along them down which the water had been sucked in vortices. Sometimes the water which wells up to the surface gushes riot only from crater-like pits but throughout the length and breadth of long fissures, only to be the next instant sucked down again. In other cases the water of swamps is first drawn away, to be as suddenly returned through the newly formed fissures.

Within an earthquake district wells and springs are nearly always affected by the shocks, and show either an increase or a decrease of flow. Wells which pierce the water table far below the surface often fill suddenly and flow over at the surface immediately after the first shock, after which they often fill up with sand, and perhaps then suddenly cease to flow.

The geysers of Iceland are many of them known to have been born during earthquakes within the province. The famous Strokkur, which had come into existence during the earthquake of 1789, ceased erupting during the earthquake of 1896, and has since appeared to be quite extinct. The whole subject of the derangement of the surface and underground flow of water during and after earthquake shocks, has not been susceptible of explanation upon the centrum theory, and on this account has been almost wholly neglected; yet there is no more constant feature or fascinating subject for study in the whole domain of seismology.

Earthquake faults such as were observed to have formed during the Indian earthquake of 1897, are likewise a no less constant phenomenon in connection with all great earthquakes. Faults of large dimensions have, however, in each case been relatively few in number. During the Mino-Owari earthquake in Japan in 1891, there was formed but one large fault, though this extended for nearly one hundred miles across the country, and in the Neo valley exposed a nearly vertical displacement wall in places as much as 18 feet in height. The ground upon one side of the fault was seen to have been raised bodily so as to form a high terrace where the land had before been level. This section of land was, however, in places, not only moved upward, but also shifted laterally in the direction of the fracture, so that highways severed by it no longer matched upon its two sides. Trees upon opposite sides of the fault which before had been in an east and west line were afterward aligned upon the meridian. At other points along the fault where the displacement had been less and the cover of soil more, its course was marked out not by a nearly vertical wall, but by a so-called "plowshare" appearance due to adjustments within the loose overlying material. The numerous rounded edges of this character which are nearly always formed in connection with Japanese earthquakes, are responsible for the belief prevalent in the country, that a giant cat-fish moves beneath the surface during an earthquake and by his movements gives rise to the shocks.

Only one large surface fault appears to have been formed at the time of the recent California earthquake, though this has been followed in a somewhat broken line for between 200 and 300 miles. Where this fault intersected roadways, fences and other artificial features, it was patent that the land upon the southwest side had been bodily shifted northward a maximum distance of about 21 feet. During the Japanese earthquake of 1896, as well as during the Sonora earthquake of 1887, two great faults opened upon opposite sides of mountain ranges and the entire included range was bodily uplifted between these fissures by several feet.

Smaller faults and fissures born during an earthquake are numbered by the hundreds or even thousands. When these appear in parallel groups the ground is sometimes actually sliced by them, as was the case in the recent Alaskan earthquake of 1899. Again, individual fissures may zig-zag across the country with gaping sides, or be detected only through the derangement of the surface drainage within the district.

With this introduction to my subject, I shall take the liberty of referring to certain observations which I made in Calabria about a year and a half ago, and directly after the heaviest earthquake of that region in more than a century. I was so fortunate as to reach the affected district while the work of succor was still only in part accomplished, and when the destruction wrought could be examined to the best advantage. In Monteleone, though the greater part of the city had escaped serious damage, one could look down the entire length of the Strada di Forgiari along a straight and narrow lane of destruction as clearly marked out as the track of a tornado. Going into the country upon either hand this line was found to be extended by ruined villages, yet nowhere was there a fissure in the ground. General Ferrario, who commanded the division of regular troops engaged in the work of succor, had established his headquarters at Monteleone, though his command had been largely dispersed through the province in order best to render assistance to the people. All reports from subordinate commands reached headquarters at Monteleone, and with commendable scientific spirit they had been entered upon a great maneuver map in such a way that communes which had suffered most appeared as reel spots upon the map. As soon as this map was exhibited, I remarked that the red spots fell within straight lines which were generally parallel either to the coast line or to the margins of the mountain masses, only to find that this observation had already impressed itself upon the staff.

Such a localization of special damage from earthquakes along a series of lines which sustained relationships to the relief of the land surface, obviously called for explanation; and as the borders of the mountain masses had here in most cases been recognized by geologists as fracture lines, it was at once suspected that the observed relationship was accounted for through an adjustment at the time of the earthquake between different sections of the earth's crust outlined by the fractures. It had been noticed, after the earthquake in Japan in 1896, that when the surface faults appeared to die out, their continuation could be followed over the loose soil which covered the rock in the lines of ruined villages. Should it be true that in Calabria the movements had taken place upon hidden planes within the crust, it seemed likely that these planes would have been the seat of movement not once only but many times when earthquake shocks had been felt within the district.

No country save perhaps Japan, can rival Calabria in the long and tragic record of its earthquakes. For purposes of study an additional advantage favors Calabria, since an Italian seismologist of reputation has recently compiled and carefully edited the scattered records in a work of nearly one thousand pages. My field work completed, I repaired to Rome and devoted the winter months of 1905-06 to a survey of Calabrian earthquake records for the last three centuries, and for purposes of comparison large scale maps were prepared to show the distribution of damage from each earthquake individually. The result has been a confirmation of the working hypothesis, for the lines of damage indicated by one earthquake have been found to be those of the others as well, save only that the heavier disturbances have corresponded to movement also on certain additional fracture lines. It was with considerable satisfaction that I found in the records of the great earthquake of 1783 a statement that the initial shock had leveled the buildings along the Strada di Forgiari in Monteleone but had not affected the other buildings of the city. Unlike strokes of lightning, therefore, earthquakes appear to search out the same places for their repeated attacks. From these Calabrian studies we may conclude that at the time of earthquake shocks opportunities for learning important facts are afforded which at other times are denied to us. The earth's surface is at the time of an earthquake, so to speak, sensitized to reveal its hidden architecture, much as are our bodies under the influence of the x-rays or the fluorescent screen.

An additional fact of importance foreshadowed upon the staff map of Gen. Ferrario was that the points of intersection of the lines of special damage had received much the heaviest shocks. Without appreciating its significance this fact has been unconsciously recognized in Italy by those officers whose duty it has been to receive and classify the reports of damage from earthquakes. When an earthquake has been announced in a definite province of the Italian peninsula, men familiar with the earthquake history of the district can tell in advance what communes will probably report damage and what others will have been immune. It is, in fact, wholly possible upon the basis of reports now upon record to derive numerical figures which, in a relative scale, set forth the danger from earthquake shocks of each commune in Italy.

The lines of special damage from earthquakes—the so-called seismotectonic lines—are found to be in most cases the generally rectilinear features upon the surface, as, for example the borders of plateaus, the bluffs along the coast, the boundaries of geological formations, the sharp lines of drainage, or, perhaps, the line joining waterfalls in neighboring streams; but in any event lines relatively straight and technically described as lineaments.

When the Calabrian studies just referred to had been completed there appeared the great work of the Count de Montessus upon Seismic Geography. By a method of compiling and standardizing, so to speak, all the earthquake records within each earthquake province of the globe, de Montessus has prepared a series of maps which; speaking broadly, show the distribution of danger from earthquakes within each of these provinces. The results are the more reliable in those provinces where careful records have been longest preserved, but collectively they possess a value which, in view of the painstaking statistical researches upon which they are based, it would be difficult to overestimate. Examining now these maps with reference to the lineaments of the surface, it was a special satisfaction to End that with hardly an exception they show the special danger spots to lie at intersections of the prominent features within each district. Two maps may be chosen by way of illustration—the northern section of the British Islands and the Greater Antilles. In both these cases the earthquake danger spots are ranged upon the lineaments, with the places of special seismic prominence located at their intersections.

We may now come nearer home and survey for a moment an earthquake map of the Atlantic coast states. The more prominent lineaments are here brought out in dotted lines, and it will be noted that upon them are ranged the spots which indicate earthquake damage in the past and presumable earthquake danger in the future, with the largest of the spots at lineament intersection. Note, for example, the "northern fall line," on which are ranged Washington, Baltimore, Wilmington, Philadelphia, Trenton, New York, New Haven, East Haddam (Conn.), and Boston. This line marks a well known fracture in the earth's crust at which formations of widely different geological age have been joined and where slight falls in rivers have determined the head of navigation, and with it the location of the port cities.

The largest spot upon the map is East Haddam, Connecticut, where the fall line intersects the straight gorge-of the lower Connecticut. From the earliest colonial days this town has been shaken by light earthquakes which have generally not affected the surrounding country and which have been accompanied by subterranean rumblings. Upon its site stood the ancient Indian Village of Morehemoodus, or the "Place of Noises." Almost as noteworthy for its earthquakes as the northern fall line is the central New England coast line, the Boston-Augusta line, upon which are the prominent earthquake towns of Newburyport and

Boston, as well as Pt. Judith, Greenwich, Portsmouth and Portland. Upon the southern fall line are similarly aligned the earthquake towns of Macon, Clinton, Milledgeville, Saundersville, Augusta, Aiken and Columbia. Like the northern fall line this lineament is a boundary between geological formations and is marked by rapids in the rivers which fix the head of navigation.

It appears from this map of the Atlantic coast region that the lines of special danger from earthquakes may not be lines of relief in the surface; and hence in a more elaborate analysis of earthquake shocks the law of the steepest slope is not verified. Yet in many, perhaps in most cases, each seismotectonic line is either in some part of its course or in its extension, a line of considerable slope upon the earth's surface. Thus, for example, the northern fall line is to the southwest of Washington in coincidence with the steep southeastern base of the Appalachian mountain system, the steepest slope within the province studied. The central New England coast line, which at first sight might appear to constitute an exception to the rule, if extended southwest-ward across the continental shelf, is found to correspond in position to that remarkable escarpment which is the border of the continental shelf and on which, for a distance of more than 500 miles the ocean suddenly deepens from less than 1000 to more than 9000 feet. Yet, whether a line of relief or not, each seismotectonic line is throughout distinctly marked in some way, whether as a geological boundary, a straight line of drainage, a fall line, or otherwise.

De Montessus's law that earthquake shocks are heaviest upon the steepest slopes must therefore be revised, and may be expressed as follows: *Earthquakes are localized upon earth lineaments—faults—and especially at their intersections.*

Thus we have learned that earthquakes exercise a selective property by searching out upon the earth's surface the lines of fracture within the district, and, it would appear, also, that the heaviest shocks are transmitted in the directions of these fractures. Thus the earthquake of October 20, 1870, appears to have been caused by vibrations which were sent out from and transmitted along the principal lineaments of the New England province. The earthquakes of May 18, 1729, Aug. 10, 1884, and Aug. 31, 1886, have all been especially marked in the chain of great cities upon the northern fall line. No one of these earthquakes was of catastrophic violence, but we should not on this account delude ourselves by any false hopes that this condition will continue. The so-called "Charleston" earthquake came as a complete surprise, perhaps even to many geologists, but data were in existence upon the basis of which it might have been predicted, though without even a guess as to the time of its arrival. The devastating earthquake which will sometime visit the cities upon the fall line, may not befall in our generation or that of our children or grandchildren, but come it will eventually. When the blow has fallen the cities will be safer because they will know their danger and may, perhaps, rebuild with some reference to it. Despite their disastrous consequences earthquakes have served a useful purpose by revealing the lines of special movement where they pass beneath the cities, and as soon as possible after the shocks have passed, a detailed map should be prepared setting forth the distribution of their intensity within each city upon the basis of the damage sustained by its artificial structures. Over the positions of greatest damage public parks, or wide streets should be laid out in the rebuilding of the city, and on no account should structures be again reared above them. To proceed in any other manner is to court destruction.

To one who has followed me in this address, I think it is not necessary to say that, in my view, earthquakes result from mutual adjustments of the blocks which compose the earth's crust and are outlined by a system of fractures. Such fractures, large and small, we have seen are actually in view at the surface after any great earthquake and may be counted by the hundreds, or even thousands. A still larger number, upon which the amplitude of the movement has presumably been less, do not appear at the surface as fractures, though their course is marked out by the lines of special destruction.

It is not necessary to assume that these fractures have originated through the action of those forces which engendered the earthquake; indeed, it is far more likely that most of them existed before, and that the earthquake is the consequence of displacements which have occurred upon them. We have only to look about us in those places where ledges of rock are exposed at the surface to note that when undisturbed from their original position these rocks are everywhere intersected by a network of fissures generlly perpendicular to the earth's surface and arranged in a number of intersecting but parallel series. By these fissures the rocky crust is divided into an immense number of vertical prismatic blocks, which grouped together, make up masses of any size or outline whatever, though always bounded by a vertical wall and capable of being moved *en bloc* upward or downward, laterally past each other, or, even when crushed to some extent, tilted from their position of horizontality. Such movements are the ones actually indicated upon the earthquake faults which are open to our inspection.

I shall not consider myself called upon to give here the reasons which have led geologists in recent years to regard the outermost portion of the earth's crust in which are the fractures above described, as resting, and potentially floated upon a lower rock zone within which a flow of material is the only way in which adjustments may occur. It is enough to say that the view is based upon a consideration of gravitation and the strength of rock material, and confirmation for it is found in the observed behavior of the earth's surface.

It is a fact well known that while some seacoasts, like those of Maine and Norway, have been sinking, others, like that of Florida, have been rising. Upon the continents mountain ranges continue to push up their heads, while the tireless forces of erosion and transportation are as steadily planing off the elevated areas and depositing their waste upon the seashore in the neighborhood of the land. Such changes inevitably involve a new distribution of the load pressing upon the rocks within the zone of flow, and no argument is needed to show that somewhere beneath the surface a new distribution of material by lateral movements must take place in order, in part at least, to bring about adjustment to the new and ever changing conditions. At any moment places can be found where a strong tendency exists for the withdrawal of some of the material and the supply of a corresponding need elsewhere. A tendency towards withdrawal of material is at the surface above a tendency towards subsidence or settlement; whereas a tendency toward elevation must exist over those districts toward which the material tends to be transferred.

So long as the transfer is delayed, the downward acting forces within the region about to be depressed are met and balanced by equal upward forces due to the rigidity of the rock prisms in the zone of fracture under the strong compression which results from earth contraction. Within the areas about to be elevated, the upward tending forces are similarly met, and the blocks are held rigidly as though between the jaws of a vice. We may illustrate these conditions by a very simple experiment. Within a long narrow tank, of which one side is formed of strong plate glass, is fitted loosely near one of the ends a wall which is hinged upon the bottom. An iron rod of length sufficient to project beyond the wall when fastened in a horizontal position to the opposite end of the tank, is supplied with screw-thread and nut so as to be used as a vice in compressing any bodies within the tank and large enough to occupy most of its area. The tank is partially filled with water, upon which are supported rectangular prismatic wooden blocks which loosely fill the space. Through varying the height of the blocks they are made to float and project by different amounts above the water surface. When the vice has been tightened they may, however, be made to retain other than their natural positions of flotation.

If, now, a board of such size as to fit loosely over the blocks in the tank be allowed to rest its weight lightly upon them, all may be brought to the same surface level, and if the vice be properly adjusted, may be retained in that position when the board is removed. (See Fig. 1.) Tightly compressed in the vice, the bridge of blocks is held in place against forces tending to elevate it throughout those areas where blocks have greatest depth, and to depress it where the block depth is least. If the compression upon the blocks be now gradually removed, a point will at last be reached when the rigidity of the bridge of blocks regarded as a beam is insufficient to hold it in its present attitude, and adjustment will take place. (See Fig. 2.) This adjustment occurs by certain blocks being forced upward and others downward, and when a transfer of water goes on from beneath the latter to the former. Such adjustments of level among the blocks in the bridge correspond to adjustments of crust blocks at the time of earthquakes, and to the formation of earthquake faults upon the block margins.

The water which ascends between the blocks, owing to the fact that they are not perfectly fitted to each other, represents in the experiment the underground water which fills the fissures in all rock masses from very moderate depths down to the zone of flow. As we have seen, the underground water flow is thoroughly deranged at the time of earthquakes, so that within one portion of the affected district the springs flow with unusual volume and bring large quantities of sand and mud to the surface, and in other parts of the same district the water of ponds and swamps is as suddenly sucked down and disappears. The first mentioned condition is represented in the experiment by those portions of the bridge where blocks are shallowest, and where in consequence they are suddenly dropped when the compression is relieved. If the entire bridge be depressed in such a manner that the water overflows it before the experiment, the opposite condition may be locally illustrated.

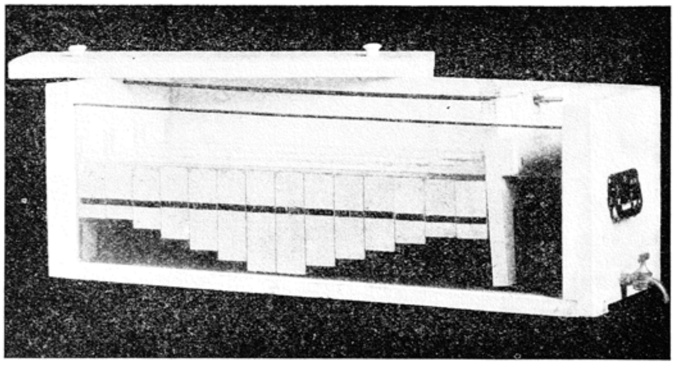

FIGURE 1.

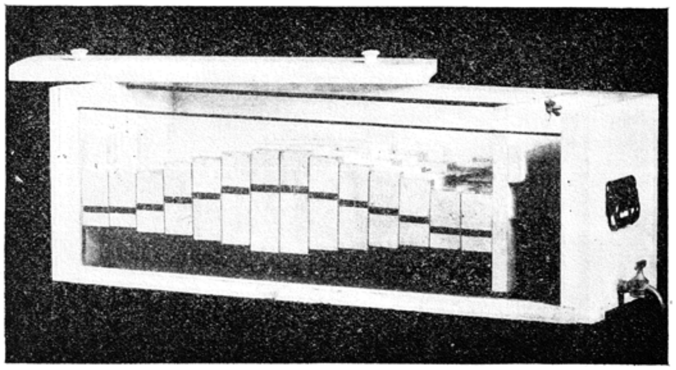

FIGURE 2.

Whenever two surfaces slide over each other under pressure they tend to assume a more or less interrupted but progressive movement as a result of friction; and this alternation of quicker and slower motion is transmitted outward in all directions as elastic vibrations or waves, whenever the moving bodies are in contact with an elastic medium. The waves will be of the greater intensity according as the slips are the larger—have greater amplitude—and according as they take place the more rapidly. The surface of a violin bow slips over the strings of a violin, and the elastic air medium transmits the movement as waves of sound, which will be the louder the more rosin is upon the bow—the greater the friction—the farther it is moved over the string and the more rapidly. The motion of adjustment at the margin of blocks produces a fault accompanied by vibrations which are transmitted as earthquake waves by the elastic rock medium. These waves will be of at least two types, one yielding successive shocks which cause damage, the other relatively quick and feeble and perceived as sounds only. Experience has taught that the slips upon earthquake faults are accomplished within a few seconds at most, and often within the fraction of a second; and, further, that a definite relation appears to exist between the size of the faults produced and the intensity of the successional earthquake shocks.

Shocks must be transmitted from every fissure upon which a slip has taken place. The distance to which these waves are carried is much less than has generally been supposed for the reason that the cumulative effect of the slipping on many planes often widely separated from each other, has been erroneously traced to a disturbance supposed to emanate from a single focus near the center of the affected district. It appears that the waves travel with the least loss of intensity along the fissure planes themselves, but in directions at right angles to these fissures their intensity is rapidly dissipated, so that at relative short distances they are impotent against well built structures. Thus may be explained the mysterious and repeated immunity of certain villages from earthquake damage even though situated in the heart of an earthquake district; as well as the hitherto equally unaccountable shocks which have been felt in villages located far outside the so-called destructive zone of the great earthquakes. In far too many instances wholly reliable reports of so-called "freak" shocks which have been felt at great distances from an earthquake "centrum" have been wholly disregarded because in conflict with an accepted explanation.

An oft observed result of earthquake disturbance is the rotation upon their bases of the higher blocks in heavy monuments. A recent illustration has been furnished by the twisting of Queen Victoria's statue in the square at Kingston during the recent Jamaican earthquake. It has long been realized that heavy shocks have reached the same point of an earthquake district from different directions. This has often been illustrated by the throwing of objects first in one direction and later in another. The late Professor Sikiya of the University of Tokyo prepared with much care a twisted wire model which recorded in its changing direction the sequence of the shocks and the exact direction of each for the Japanese earthquake of January 15, 1897. Three complicated snarls of wire were necessary to record in this manner the variation in direction of shocks arriving at a single point for an earthquake which lasted about a minute. These models, which have hitherto been given no satisfactory explanation, we may now interpret as due to the shocks which have reached the station from the numerous fissure planes of the district upon which the movement has occurred. Such waves should reach the station at different times, in different surface directions or azimuths, and with different angles of elevation. Should two or more shocks reach the station at the same instant from different directions, the result must be a rotatory movement, such as would explain the long and gradual curves in the wire as well as the twisted monuments.

I am painfully conscious that it has been possible to touch but lightly upon the interesting problems which earthquakes offer for solution, and my story has already developed a likeness to the oldtime novel with its prolongation of agony into the third volume. I must not forget that even the "three-decker" has an end, and in Kipling's words:

> "She dwindles to a speck,
> With noise of pleasant music and dancing on her deck."

If the denouement has been harrowing and you have been shocked by disillusionment concerning the security of mother earth; if it is unpleasant to contemplate some of our great cities quite unprepared in the grip of a devastating earthquake, I can at least offer the assurance learned of our mothers in childhood, that the medicine is for our good. I have observed, too, that dangers which impend often seem less terrible when they threaten us not so much as they do our friends—and especially our more distant ones. I can offer no earthquake insurance, and it is much easier as well as much better for one's reputation, to predict where earthquakes *will* strike than where they *will not;* but it may help you to a restful night, if as a parting word I say that the state of Michigan, as regards earthquakes, is apparently much more secure than either the Pacific or the Atlantic slopes, the Lower Valley of the St. Lawrence, or the Lower Mississippi.

University of Michigan.

SOME INTERESTING GLACIAL PHENOMENA IN THE MARQUETTE REGION.

Charles A. Davis.

(By permission of Alfred C. Lane, State Geologist.)

ABSTRACT.

(A full account will be published in a forthcoming report of the Michigan Geol. Survey.)

During the field season of 1906 the writer was assigned by the State Geologist, Dr. A. C. Lane, the work of completing the soil survey of the Northern Peninsula of Michigan, begun two years before by Professor I. C. Russell, and continued by him and Mr. Frank Leverett of the U. S. G. S. during 1905. In addition to the soil survey, attention was given to mapping the glacial features and to other surface phenomena, and it is to some of the glacial records and their interpretation that attention is called by this paper.

The region unmapped lay to the west of a line south from Marquette and north of the south line of Tp. 43 N., and amounted to more than 200 townships, or, in round numbers, 7500 square miles, much of it in nearly primitive condition without roads or settlements except along the railroad lines, hence it is a difficult area to study in detail. The portion of this territory to which attention is called lies in Marquette and Baraga counties, and in this the following phenomena were noted and conclusions deduced:

(1) Very light glaciation, especially light erosion, in all parts of the area, and practically none in the high parts of the Laurentian highland in the north half of Marquette county above 1800 feet a. t. In the vicinity of Marquette there are excellent examples of glacial erosion imposed upon pre-or inter-glacial weathering, without erasing it, while in the highlands north of Michigamme, and both east and west of that point, recently uncovered rock surfaces show no glacial smoothing or erosion.

(2) On the north side of the Laurentian highland are three or four great morainal terraces, made up of moraines and their accompanying out wash plains. The latter rise quite to the level of the tops of the moraines, filling in the space between the rock highland and moraines and giving the terrace form to the whole deposit. Above these, on the ancient rock peneplain the till deposits are practically all in the form of valley moraines of very small extent, or are wanting, while rock hills and valleys constitute the chief topographic features. The valleys contain gravel deposits or are partly filled with great deposits of uneroded talus from the cliffs.

(3) The south side of the highland westward from just west of Ishpeming, along the D. S. S. and A. R. R., is marked by high, often precipitous cliffs', banked against which is generally a thin deposit of till, covering, in some cases at least, talus material. From this low bank, extending always southeastward, branch off a number of low moraines, which in places are so covered by forests and so closely related to lines of rock hills that it is often hard to trace them for any distance. As one proceeds westward there is a series of moraines to the south of the highland, which trend almost east and west, nearly parallel with its southern border, which are stronger than the one mentioned above.

(4) The series of terraces lying along the north side of the highland extends westward to the valley of the Sturgeon river, where the highland practically ends, and from thence westward they are replaced by a heavy moraine with terraces on the north side, which apparently is continuous with the moraines lying against the Copper Range, forming the back-bone of the Keweenaw Peninsula. The till in this deposit is red, clayey, with numerous red sandstone fragments, etc., while that of the lower ridges on the south side of it, is gray and sandy with an abundance of slates and some little granite.

(5) The glacial drainage is well marked and significant. The main lines of drainage when the ice was at its highest, after the highland became bare, were southward across the highland, through the rock valleys in which the Peshekeme river and its tributaries now run, and then east along the edge of the highland, and then southeast. The best defined of the channels for this position of the ice, was one which ran in the shallow valley now occupied by the west branch of the Escanaba river, but at earlier stages the water seems to have been forced against the cliffs much farther east, and may have flowed even as far as Negaunee before finding an outlet to the south..

A second line of drainage at this time, or a little later, was in the valley now occupied by the head-waters of the Sturgeon, near Nestoria. There was a strong stream from this outlet, following the edge of the highland eastward for several miles, which formed a sand-plain of considerable size at Three Lakes, and then probably at one time entered the Michigamme basin, and later, flowed to the southwest of it. The Peshemeke gravel plain is very extensive and contains great quantities of sandstone pebbles, which get more numerous and larger to the northward. There is no divide between the waters of the present stream flowing into Lake Michigamme and southward, and the headwaters of the Escanaba, which follow the glacial drainage lines to the southeast, and there are channels in the plain which permit the Peshekeme by a rise of four feet to flow into the Escanaba.

(6) In this whole region west and southwest of Ishpeming, there is a strong slope of the land southward, despite the southeasterly flow of the streams, which lie almost wholly in sand valleys.

(7) There are some good examples of boulders deposited to the northward of the known outcrops of the same kind of rock, but granite is the prevailing boulder material and is most widely distributed in the entire region as the bedrock.

(8) The striæ from Ishpeming west are chiefly north 75° east, and near Clarksburg, seven miles west of Ispheming, is a line example of knob-and-train structure in the form of a rock hill, which is bare on the west side, but has a till ridge extending out for several hundred feet on the northeast side, the axis of which lies N. 75° E.

(9) In the vicinity of Ishpeming and Negaunee there are a number of small valley moraines with independent outwash plains on the south sides. The glaciation, as represented by striae and rock erosion, is light in this vicinity, as in other places,

(10) In the extensive sand-plain which lies along the valley of the Escanaba river fifteen miles southwest of Ishpeming, there is an exceedingly broad erosion valley, more than a mile wide and with a forty foot bank on the north side, in the middle of which the present insignificant stream now runs in its own rather deep, narrow valley. There are at least two small, partly buried moraines across this sand-plain, and the plain ends abruptly on the south side in a steep descent to the south, which is boulder-covered and has all the characteristics of the ice-side of a moraine, while the

north side is so level that it is difficult to see where the sand-plain ends until the edge of the southward slope is reached.

The conclusions reached from a study of these facts are:

(1) That there exists in northern Marquette county an area of several townships extent which is almost without glaciation. This land rises to nearly or quite 2000 feet above tide in the higher parts, and is 100 or 200 feet lower in the valleys.

(2) From the fact that the drainage was across this highland and followed pre-glacial rock valleys, while the ice was piled up around its outer margin, it is evident that this area must have been early abandoned by the local ice-cap which covered it.

(3) From the position of the moraines, and the drainage lines, it seems evident that the ice lying south of the uncovered area was moving in from the west and not from the east, and while this is not yet established, it seems probable that the direct movement of the ice from the northeast was practically checked by the Marquette highland and by the Copper Range.

(4) The region to the south of this was covered by ice which pushed in on the west side of the Keweenaw Range, with a generally southeasterly movement, which spread out on the slope lying south of the highland, up to, but not over, the cliffs bounding this, and formed weak moraines as far east as Clarksburg, and possibly as far as the complicated region about Ishpeming and Negaunee, which has some characteristics of an interlobate area. This southeastward movement is indicated especially by the present stream valleys which follow lines of ice drainage diagonally across the general slope of the land, and by the fact that the clayey red till characteristic of the high moraine assumed to limit the movement of ice from the northeast, ends abruptly with this moraine, and is replaced in the adjacent lower moraines to the south of it, assumed to be formed by western ice, by gray till of a much more sandy structure.

(5) The presence of strong moraines running east and west to the south of the highland, which have drainage lines along their northern sides, indicate that the axis of movement lay to the south, and adds to the probability that the ice forming them was moving from the westward down the land-slope, rather than from the east up the slope. In the latter case it would seem as if the chief moraines would have been formed about northeast and southwest, since the thicker ice and more rapid movement would have been in the low lands to the south. In case the ice had pushed through the relatively narrow passage at the head of the Keweenaw embayment and spread out to the southeast, the main axis of movement would have been southward, and it would seem that the moraines would have been more or less concentric at right angles to this line, and the thin, more remote ones would have run northeast and southwest on the eastern side of the axis. As there is no evidence that the ice pushed in from the northeast over the Laurentian highland and much that it did not, but a word need be said regarding this possibility. In case a movement is assumed from this direction, it is impossible to explain the presence of the morainal bank against the foot of the bounding cliff, and the marginal drainage, which evidently was on the present land surface and not in the ice.

It is apparent, therefore, that the chief contentions are, that the glacial ice from the northeast did not move across the higher parts of the Laurentian highland, but lay banked around it in a nearly stagnant condition, hence there was little glacial erosion, even on the lower slopes along the shores of Lake Superior, and practically no glaciation of any sort in the highlands, while above the highest moraines the country is nearly driftless. The same stagnation apparently prevailed in the ice-field as far west as the axis of Keweenaw point, and this ice was further prevented from penetrating inland, south of the highland, by a strong ice-stream pushing in from the northwest on the west side of the Keweenaw peninsula.

Ann Arbor, Mich., March, 1907.

GEOLOGY AND PHYSICAL GEOGRAPHY OF MICHIGAN.

W. F. COOPER, Michigan Geological Survey.

CONTENTS.

INTRODUCTION. GEOLOGY AND PHYSICAL GEOGRAPHY DEFINED. CORRELATIONS.

Geology has been variously defined as the physical history of the earth and its inhabitants, as recorded in its structure. It includes an account of the changes through which they have passed, the laws of these changes, and their causes. In a word, it is the history of the evolution of the earth and its inhabitants[1]. In a later work we have geology defined as that science which treats of the structure of the earth, of the various stages through which it has passed, and of the living beings that have dwelt upon it, together with the agencies and processes involved in the changes it has undergone. Geology is essentially a history of the earth and its inhabitants."[2]

On the other hand physical geography is defined as that "branch of geography that treats of the physical features of the earth, more especially those of its surface, including the operation of existing physical agencies, the distribution and flow of water, and the distribution of the forms of animal and plant life."[3] Again in this connection we have the subject of physiographic geology, "a general study of the existing features of the earth's surface, as contours of continents and systems of surface relief, partially synonymous with physical geography, but dealing with .general physical features as resultants of past dynamical agencies, while physical geography deals with details, chiefly as existing under recent or present dynamical forces."[4] As treated in this paper I will combine certain phases of both subjects as given in this and the former definition, eliminating any consideration of the distribution of the forms of plant and animal life.

The principal departments of the science of geology may be divided into structural geology, historical geology or the treatment of the succession of events, while stratigraphic geology deals with the succession of beds laid down in the progress of the ages, dynamical geology "the treatment of causes, agencies and processes."[1]

The factors embraced in the study of physical geography are mainly the atmospheric temperature, the effect of meteoric water, with the resultants of topographic forms, denudation and aggradation. As we have just seen dynamics treats of causes, agencies and processes, which therefore furnishes the nearest correlative in geological science, and it is believed that these two branches are mutually complimentary.

As a science physical geography antedates that of geology, and was formerly understood as "embracing two equally important and closely related subjects—the interior structure of the globe and its external form."[2] James Hutton "started with the grand conception that the past history of our globe must be explained by what can be seen to be happening now, or to have happened only recently. The dominant idea in his philosophy is that the present is the key to the past. The pudding stones were in his eyes only compacted gravels, the sandstones were indurated sands, the limestones were in great part derived from the accumulation of the remains of marine calcareous organisms, the shales from the consolidation of mud and silt."[3] It is with certain of these agents and resultants that we have here to deal. In this connection I am indebted to Wm. M. Davis, professor of physical geology at Harvard University, for a communication on the subject:

"I will only say in brief that I regard physical geography, or physiography, as a sub-heading of geography, and treating of all the inorganic content of geography, namely, everything concerning the earth as a globe—the oceans, the air and the lands which go to make up the inorganic environment of organic inhabitants of the earth. Geography as a whole I look upon as simply the geology of today; as I have sometimes expressed it, geography is only today's issue of a world's record, the complete files of which would constitute geology; or, in other words, geography is the top member of a series of strata horizontally arranged with respect to the vertical time line. There has always been a geography, and geology is nothing but a summation of all geographies of the past, up to and including the present. The chief reason that has separated geography from geology so long, and so much to its disadvantage is that the facts of geography are open to immediate observation as existing phenomena. The facts of past geographies, which make up geology, are determined only by inference and are known very incompletely. In their essence, however, they would surely be very much like the observable facts of today's geography. It is for this reason that the whole tendency of my work has been to bring out a closer association of geology and geography than has been customary in the past. A great deal that is taught in geology, concerning processes now going on, is good physical geography. The bulk of historical geology is (fragmentary) geography of past ages—partly physical, partly organic (ontographic.)"

"In a sense physical geography is to geology as physiology is to anatomy, the essential element being activity in its effect on geological deposits, as embodied in dynamic agencies. The agents as far as will be considered here, are the water, precipitation, the results and changes of temperature, with certain topographic features. These factors and the dynamic resultants of earlier geological conditions enter largely into the relief of the surface of Michigan."[1]

"Physical geography is the geology of the present, while one branch of geology is the physical geography of the past."[2]

MICHIGAN GEOLOGICAL SURVEY.

In the reports of the Michigan Geological Survey dealing with Monroe, Sanilac, Huron and Bay counties the topics chiefly dealt with relate to climate, configuration, elevations, surface and underground drainage, shore lines, contours, elevation of the great lake basin and subordinately related subjects.

WINCHELL'S DIAGONAL SYSTEM.

Dr. Alexander Winchell in 1873 read a paper before the American Association for the Advancement of Science entitled "The Diagonal System of the Physical Features of Michigan."[3]

"The actual topographical and hydrographical axes of Michigan and the whole lake region, are the resultant of two forces—a glacial acting from the N. E. and a stratigraphical acting along the lines of strike of the rock

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[1] Joseph Le Conte, "Elements of Geology", 1896, p. 1.

[2] Chamberlin & Salisbury, "Geology", Volumn I, p. 1.

[3] Standard Dictionary.

[4] Standard Dictionary.

[1] Chamberlin & Salisbury, Geology, Volumn I, p. 1.

[2] "The Principles of Geology", Volume I. A. Geikie, 1901, p. 74.

[3] Idem. p. 168.

formation. As a corollary we should find that where the rocky formations are most consolidated, the resultant lies nearest the lines of the stratigraphical force, and where the resultant approximates the line of the glacial force. As a second corollary physical features determined by causes which have obliterated the glacial and stratigraphical trends, do not, necessarily, express relations to either force. Of this kind are the small streams whose courses over the diluvial beds have been determined by post-glacial erosions, and river courses, like the St. Clair and Detroit, marked out across lacustrine or other post-glacial deposits which have concealed the surface features due to geological structure or glacial erosion."[4]

ORIGIN OF THE GREAT LAKE BASINS.

Michigan being a peninsular state the question is pertinent as to the causes which produced the basins forming the adjacent great lakes. "It is to be observed that concave tracts border the continents very generally. They are connected with the descent from the continental shelf to the abysmal basins and are unsymmetrical. Notable concavities are found in some of the great valleys on the continental platforms. The basins of Lakes Superior, Michigan and Huron are in part concave. When to the weakness of the crust, as computed under ideal conditions, there is added the weakness inherent in these concave and warped tracts, the conclusion seems imperative that while the crust is the pliant subjects of minor and nearly constant warpings, such as are everywhere implied in the stratigraphic series, it is wholly incompetent to be the medium of those great deformations which occur at long intervals and mark off the great eras of geologic history."[5] The Lake Superior basin as thus stated is an early crustal warping which antedates Paleozoic time. The basins of Lake Michigan and Huron occupy lateral parts of a considerable earth concavity existant during early Paleozoic time, built up by median and later succeeding formations, not unlike saucers laid moon each other, the latest bed rock formation, the Coal Measures, being at a later time relatively elevated, in conformity with the law established by James Hall of the greatest accumulation of sediment, forming areas of uplift and consequent highest elevation. In this manner it can be seen that the physiography of Michigan as seen in its present development has very early geological antecedents.

AREA AND ELEVATION OF MICHIGAN.
PRE-GLACIAL DRAINAGE.

According to the statement furnished by Mr. H. M. Wilson, Geographer for the U. S. Geological Survey, the area of Michigan is now accepted as 57,480 square miles. By planimeter measurement of Plate II of Water Supply Paper No. 183, issued by the government, I make the area of the Lower Peninsula 41,452 square miles. Newaygo county was taken as the unit of comparison and area. Computations based on Farmer's "Michigan Book" give an area of 16,560 square miles for the Upper Peninsula. By difference I would make this area 16,628 square miles.

Mr. Henry M. Gannett has issued the fourth edition of his Dictionary of Altitudes, this publication being Bulletin No. 274 issued by the U. S. Geological Survey. An average of 1457 altitudes, the greater part being railroad stations, determined with as much accuracy as possible, gives Michigan an average elevation of 840 feet above sea level. Lake Erie is 572 feet above tide and lake Superior 602 feet above the level of the sea. This determination is very likely somewhat below the true elevation, but is based upon the only complete information at present available.

The average elevation of the Lower Peninsula of Michigan is 854 feet above sea level as determined from a 100-foot surface contour map prepared by Frank Leverett and forming Plate II of Water-Supply Paper 183, issued by the U. S. Geological Survey. In making this determination "the first step was to measure, by means of the planimeter, the areas lying between different contours. Then each such area may be assigned an elevation half way between the two limiting contours, and multiplied by that number of feet. The sum of these products divided by the area give an approximation of the average height."[1]

The percentage of area in Lower Michigan between the different contours is shown in the following table:

600– 700 feet above sea level = 23%
700– 800 " " " " 26
800– 900 " " " " 21
900–1000 " " " " 14
1000–1100 " " " " 6
1100–1200 " " " " 8
1200–1300 " " " " 2
1300–1400 " " " " .03
1400–1710 " " " " .002

The line of 44° latitude extends from just north of Standish, Arenac county, west to just north of Ludington on the Lake Michigan shore and includes in latitude the northern 5-12 of the state. Within this area is the highest elevation in Lower Michigan. The following percentages apply to this area:

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[1] Bay county, W. F. Cooper, Ann. Rep. of the Mich. Geol. Surv., 1905, p. 355.

[2] A. C. Lane, Mich. Geol. Surv., Vol. VII, Pt. 2, p. 31.

[3] W. H. Sherzer, Monroe Co., Geol. Surv. of Mich., Vol. VII, part I, p. 118.

[4] Tackabury's Atlas, A. Winchell, 1883.

[5] Chamberlin & Salisbury, Geology, Volume I, pp. 558-562, 1904.

600– 700	feet above sea level =	24.2%
700– 800	“ “ “ “	15.
800– 900	“ “ “ “	12.
900–1000	“ “ “ “	9.
1000–1100	“ “ “ “	8.
1100–1200	“ “ “ “	25.
1200–1300	“ “ “ “	6.
1300–1400	“ “ “ “	.08
1400-1710	“ “ “ “	.006

The most remarkable feature indicated by this table is the plateau formation above the 1100-foot contour line which embraces the greatest part of the upper portion of the Lower Peninsula.

The average elevation for bed rock of Lower Michigan as determined from Plate II of the report referred to above is 554 feet above sea level, making the average thickness of the soil and subsoil formation, properly known as the drift, approximately 300 feet for Lower Michigan. There is considerable margin for error here, but all knowledge is progressive and beginnings are to be taken in the proper spirit. In Bay county we have an average thickness of the drift of 97 feet as determined from 460 drill holes for coal and 126 well records.[1]

Probably the highest elevation in Upper Michigan is Mt. Whitney in the Porcupine Mountains, and not far from Ontonagon, which has a height of 2023 feet above sea level, and this is probably the highest altitude in the state.

In the Lower Peninsula we have two areas of topographic development, which are clearly the result of former geological conditions. In the central part of the state we have the Saginaw-Maple-Grand valley. South of this in the Hillsdale uplands we have the highest elevation south of the latitude of Saginaw Bay, this portion of the state culminating at Bunday Hill, where the elevation is 1284 feet above tide. North of this area, southeast of Cadillac, and in the north central part of Osceola county, the land reaches an altitude of 1710 feet above sea level, which I am told is the highest elevation in Lower Michigan. It is, moreover, worthy of note that both the elevation of the bed rock and the present land surface vary approximately 1100 feet in extremes of elevation in this portion of Michigan, indicating a certain amount of uniformity in topographic developments and the resultants of agencies during glacial and earlier geological periods.

In the report on the "Geology of Bay County," the former drainage system of the state, which was in the course of development after the elevation of Michigan above the sea at about the close of the Paleozoic, was given specific designations in the same manner that our present drainage system is designated.[2] The advantage of this plan is in convenience and definiteness of arrangement and designation, while on the other hand we are able to reconstruct the former physical geography of the Lower Peninsula, in a manner consistent with the present, thereby giving life and unity to long bygone times.

During this former age of topographic development during Mesozoic and Cenozoic times the drainage in central Michigan was westward, probably through the southern part of Bay and Midland counties, the northern part of Gratiot and Montcalm and thence northwestward towards Manistee and Ludington where the former drainage was not far from sea level, there being a drop of not less than 400 feet in its course westward from Saginaw Bay. I would suggest the name of Alma channel for this former drainage course as the upper reaches of this channel passes underneath that town where the depth has been obtained. It will be observed that this former drainage channel is more or less parallel and just north of the present Saginaw-Maple river valley, and a portion of the Grand river to which the Maple is tributary. It seems not impossible that the very large amount of glacial debris which would be required to fill the former Alma channel resulted in a lack of material further south, the result being the depression forming the present area of the Saginaw-Maple-Grand valley, across which a ship canal was at one time projected. The present depressed topographic feature was also very likely considerably lowered during the lacustrine period toward the close of the Pleistocene, when the drainage of a portion of the former glacial lake series had an outlet near Pewamo and thence drained westward into the basin of the Grand river. In Bay county we have coming into this Alma channel the Beaver, Auburn, Amelith and Souwest conning channels, all the drainage being westward and southwest ward. They have there been designated washouts in deference to the usage among the miners, which is moreover appropriate and perhaps worthy of continuance, but on the other hand it is well to have all the unity compatible with scientific accuracy. Within the 400-foot above tide rock contour line the Alma channel has an area of about 2,751 square miles and an average depth of 162 feet. To this, however, should perhaps be added a depth of 300 feet for erosion during the glacial period, which figure represents the possible average depth of glacial and glacio-fluvial deposits and therefore since a greater part of the glacial drift, soils and subsoils, was probably only carried a comparatively short distance, the amount of erosion in the peneplain through which the Alma channel worked its way. Consequently we have an average depth of 462 feet if not more for this buried channel in its theoretical restoration.

This does not, however, take into account a certain amount of erosion of the Alma basin during Mesozoic and Cenozoic times, beyond the limits of the apparent valley, and I do not know of any way in which this amount of erosion can be determined. Since very nearly all streams have their outlets either into lakes, gulfs, seas or oceans, it is necessary to infer that the Alma channel either emptied its burden of sediment into a former lake in the area occupied by at least a portion of

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1 Communication, Henry Gannett, Feb. 8, 1907.

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[1] W. F. Cooper, Bay Co., Ann. Rep. Geol. Surv. of Mich. for 1905, p. 339.

[2] Geology, Bay Co,; Ann. Rep. Mich. Geol. Sury., 1905, pp. 162-165 and 333-339.

the present body of Lake Michigan, or on the other hand the channel may have been continued onward. Since stream development is both progressively downward in cutting its channel, and also away from its outlet by head erosion it is necessary to add to the approximate vertical depth near its apparent outlet above Ludington, a later development of this same channel as in its upper reaches near Bay county. As near as I can calculate this would give an erosive record of some 400 feet to which will be added 300 feet of erosion as represented by the record obliterated during the glacial period. This entire estimate is at least a portion of the erosion which took place during Mesozoic and Cenozoic times. This combined record, therefore, may represent a vertical equivalent of 700 feet.

PRE-GLACIAL RAINFALL.

My object in going into some detail regarding the Alma channel is to gather such information as is obtainable concerning the amount of rainfall subsequent to Paleozoic time and antecedent to the glacial epoch when beds of soils and subsoils were in process of formation. That precipitation took place at very early geological times is indicated by the beds of glacial deposits formed (luring Cambrian time at the base of the Paleozoic formation and in Permian beds at the close of the Paleozoic. Only recently Mr. A. P. Coleman has described in the March number of the "American Journal of Science” boulder bearing rocks in the Huronian formation of Canada which may represent glacial deposits of very early age.

Calculating as nearly as possible the amount of rock removed by erosion in the Alma channel, the amount of water which is necessary to remove a cubic foot of rock material, the relation of rainfall to rim-off by means of which erosion was accomplished, the relative area in which precipitation and active erosion took place, and the uncertain duration of time during which erosion was acting, we have the factors by means of which the amount of annual rainfall may be uncertainly estimated during the period subsequent to the elevation of Lower Michigan above the sea at about the close of the Paleozoic and previous to the glacial epoch. Without going into all the calculations the result arrived at amounted to about 29 or 30 inches annually for one square mile for Mesozoic and Cenozoic times. I believe that the present amount of rainfall is given as 32 inches for Lower Michigan. The factors used are: 2611 cubic feet of water is required to remove one cubic foot of sediment over a drainage-erosion area of 1,244,000 square miles or less; 16,355,339,000 cubic feet of sediment in one square mile 700 feet deep; the runoff varies to the rainfall as from 33 to 56%, the average of 12 streams being 46%; the period of time is 2,450,000 years, more or less. The most uncertain factors in this calculation are the amount of rock removed by erosion, the relation of rainfall to run-off at that time, the duration of time, and the relation of active erosion to the entire basin of the Mississippi, which is one of the essential elements in this calculation. This last subject is worthy of additional investigation on the part of physical geographers and geologists. While these speculations might arouse the envy of the amalgamated nerve of E. H. Harriman and a certain proportion of the Wall Street organization of metaphorical quadrapeds I trust that it will lead to further investigations and results that will give material for comparison and more accurate information.

TILTING OF THE GREAT LAKE BASINS, SHORE LINES, WILLOWY DRAINAGE.

This subject of tilting of the Great Lake basin was first discussed by G. K. Gilbert in the 18th annual report of the U. S. Geological Survey, the result being that if a line is drawn N. 10° E., 100 miles long, that at the end of 100 years the north end of this line would rise .4 of a foot relative to the south end. The nodal line of stability is calculated-to pass from Port Huron to Saginaw and thence northwest towards Manistee, the land rising to the north of that line and sinking towards the south. For further information of the details of this interesting subject the reader is referred to the reports on the geology of Huron and Bay counties of the Michigan Geological Survey.

The south shore of Lake Superior is apparently sinking in the Porcupines.

It is an obvious corollary from this; that the river valleys would have comparatively rapid descents into Lakes Michigan and Huron above the places named, while to the south of this diagonal line the outlets of river valleys would be drowned. Thus we have along the south shore of Lake Michigan what might be termed river-lakes at the outlets of the Grand, Muskegon and Marquette rivers, where these river reaches have been drowned by relative sinking and encroachment of the lake. Further northward stream channels have a relatively rapid descent into the lake.

The cause and effect of glacial-geologic action and resultant drainage, has in many cases produced a striking form of drainage.[1] In the Saginaw Bay basin the Tittabawassee and Cass rivers are deflected by the Saginaw-Port Huron moraine toward the south until meeting in the Saginaw river, the concave area opening to the north. This type of river flow has very appropriately been styled willowy drainage, in this case the Saginaw river forming the trunk of the tree, the Cass and Tittabawassee lateral branches. On the west coast the St. Joseph river forms a bow into northern Indiana. There are, however, numerous streams which follow a more direct course, the simplest type is where there is a smooth even sloping plain, the water courses following nearly parallel and independent drainage lines, as in Bay county.[2] However, in the same county we have this willowy type of drainage characteristically developed. It is also characteristic of this type of drainage that the main tributary streams come in from the south of the trunk stream. In Bay county this is at least due to the more abrupt descent of the front of the moraine last deserted.

[1] A. C. Lane, Water-Supply Paper No. 30, U. S. G. S., p. 62.

[2] W. F. Cooper, Bay Co., Ann. Rep. Mich. Goel. Surv. for 1905, p. 373.

TERRACES.

These originate in various ways.

1. Due to inequalities of hardness, the upper surface of the hard layer marks the lower limit of the terrace.

2. Due to flood plain deposition along the sides of a stream, and subsequent down cutting of the channels by various operations as follows:

a. The head advancing up stream may on reaching the head of the valley plain lose so much of its load as to be able to sink its channel farther down, forming cycles of erosion with alternate deposition, cutting and deposition again.

b. By the exchange of load dropping the course near the head of its valley plain and taking up fine material, thus degrading its channel into the flood-plain which the earlier and perhaps smaller stream had developed.

c. As erosion and transportation vary accordingly to the grade of the stream the flood-plain may be subsequently deepened due to stream development which permits material to be removed which is temporarily left on the flood plain.

d. Any stream reaching the flood plain stage is apt to meander, the meanders tend to migrate down stream and become relatively lower and more capacious so as to hold the water of ordinary floods. At this stage or even before, such parts of the earlier flood plain as remain are terraces. Other causes are the uplifts in a region where the rivers are flats, the streams are rejuvenated, and the remnants of their former flood plains become terraces. Again if an alluvial flood plain has been built as the result of excessive sediment, the exhaustion or withdrawal of the excessive supply would leave the stream free to erode it where it had been depositing. An increase in the volume of a stream, without increasing its load, as by stream capture may occasion the development of terraces by allowing the stream to deepen its channel. Barriers may cause flood plains, their removal will cause the stream to cut more or less deeply into the plain above, leaving terraces. The recession of a falls through a floodplain convert such parts of it as remain, into terraces.[1] Prof. I. C. Russell has described terrace formation lateral to the Menominee river by cutting down through broad alluvial plains, the highest terrace being the plain itself, the lower terraces were eroded in subsequent flood plains. Again he describes terrace formations adjacent to Green Bay which are due to subsequent lowering of the lake and down cutting of the stream channel.[2]

TEMPERATURE.

Finally I would like to be permitted to digress a minute and call attention to the very favorable opportunity of studying the effect of water temperatures on the insular climate of Lower Michigan. The prevailing wind in Lower Michigan is from the southwest, so that members of the Academy living on the Lake Michigan shore can have an opportunity of determining the results and relationship of the exact effect of water temperature on that of the land. An average of the isothermal lines shows the same temperature averages extending 46 miles farther northward on the west side of the Lower Peninsula as compared to the east side. Comparing the results on the east and west sides of Lake Michigan we have an average of 36 miles farther north than on the east coast of Wisconsin in crossing the lake. During the latter part of August the average water temperature is about 4° greater than that of the air. Also during this time the ratio of change of water temperature relative to that of the air temperature is less than 34.4%. In this factor taking into account the prevailing southwesterly winds, we find a partial explanation of the insular climate of Lower Michigan. Moreover the temperature of the water, as a rule, being greater than that of the air from about 7 p. m. until about 9 a. m. the following day, the tendency would be to increase the temperature of the adjacent windward shores. On the other hand, the air temperature being greater during the remainder of the day, the water would tend to establish an equilibrium by reducing the air temperature the mean range probably approaching the mean of the average ranges of air and water temperatures. The more prolonged period of average higher water temperature is doubtless the greater factor in this question.[3]

Observations of this character to be of general value should be taken at least once a week throughout the year and should be continuous for 24 hours, readings being taken every hour beginning at say 6 p. m. Readings of the air temperature on the land and of the surface water temperature at the end of a pier where there is 15-20 feet of water should be taken as nearly together as possible. As to the proper way in which this work can be carried on information from C. F. Schneider, head of the State Weather Bureau, at Grand Rapids could be obtained, and perhaps the use of an accurate thermometer suitable for the purpose. The results would be of very considerable scientific value.

Lansing, Michigan, March 26, 1907.

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[1] Chamberlin & Salisbury, Geology, Vol. I, p. 193-198.

[2] I. C. Russell, Ann. Rep. Mich. Geol. Surv., 1906, pp. 77-78.

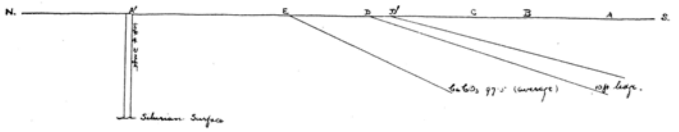
[3] Michigan Academy of Science, 7th annual report, p. 40-43, and Monthly Weather Review, Washington, D. C., Dec. 1905.

THE GEOLOGICAL CONTINUITY OF ESSEX AND KENT COUNTIES, ONTARIO, AND MONROE AND WAYNE COUNTIES, MICHIGAN.

REV. THOMAS NATTRESS.

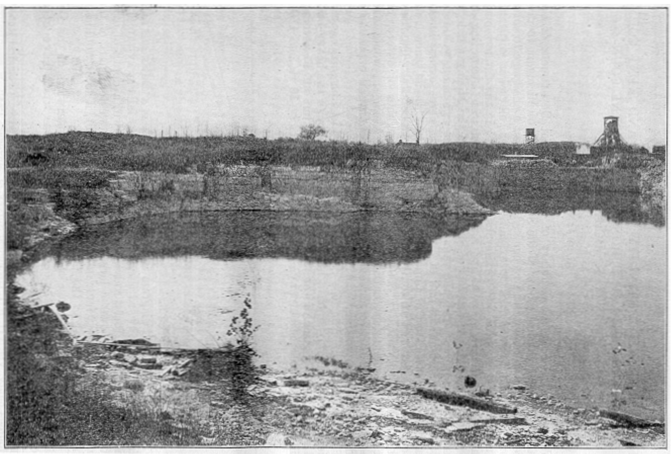
When requested by the secretary of the Geological Department of the Academy, and at the instigation of the State Geologist of Michigan, to prepare a paper to be read here, I recognized in the request a challenge to solve a problem. That problem is to explain the presence, elevation, dip, and nature of the outcrop of the Corniferous (*or Dundee) in the Amherstburg Quarries, in Anderdon Township, Essex county, Ontario. According to the ascertained lines of outcrop of Silurian strata on the Michigan side of Detroit river at its mouth, the same Silurian surface extension would be looked for in the Southern half of Essex. But it isn't there—except in the river bed, and northward of Lime Kiln Crossing ashore. In its place is an outcrop of Corniferous, with southwesterly dip at the Amherstburg Quarries, and maximum elevation of 609 feet. The successive lines of outcrop in Ontario and Michigan, concentric in the coal area of Michigan, would lead one to expect a north to northwesterly dip. But the natural expectation is denied by the contrary fact.

The several strata, from the bottom of the high grade limestone deposit which lies immediately upon a brown dolomite, up through the heavy-bedded rock, to the surface of the thin-bedded limestone, thin out to nothing, as illustrated in the accompanying diagram by the heavy 10 ft. bed DD^1.



From A to B in the diagram is drift. From B to E is a Devonian rock surface. From E northward the rock (which is Silurian) falls away rapidly, until at A^1, less than forty rods away, it is 50 feet down, a depth of drift that is fairly uniform over a large area of the middle western part of the county. There may be a fault in the Silurian here. But, if so, it would ex plain nothing in regard to the Devonian outcrop.

The evidence goes to prove a Silurian anticlinal, northward of the Devonian deposit in Anderdon, upon which the Corniferous strata have been deposited with south to southwesterly dip.



High grade limestone quarry, at the Amherstburg Quarries, in spring-time, showing dip of strata. Essex County.

Were there sufficient exposure of the rock surface to facilitate observation, the dip of the overlying formation would doubtless be seen to circle round the anticlinal as this falls away eastward, until the north to northwesterly dip would be found again on the north side of the anticline, the same clip as on the opposite side of Detroit river.

Let it be noted that there is a Silurian surface extension immediately northward of the Amherstburg Quarries. The log of the Sucker Creek Oil and Gas Company's test well, lot 7, con. 6, in Anderdon Township (some six miles northeast from the point A^1 in the diagram), shows dolomite from the surface down, 350 feet of it over the Sylvania.

The Rock Surface of Essex County falls away eastward from an elevation of 609 feet at the quarries in Anderdon, to 533 feet at Essex town near the center of the county. There is a further fall to 476 feet at Comber, and to something less than this at the Kent county line. (This is a medial line, both territorially and with reference to surface drainage.) From the same starting point of 609 feet elevation, eastward through the southern part of the county, there is the same falling away, but less pronounced. At Marshfield, southeast from the highest point of rock elevation in the county, at the Amherstburg Quarries, and southwest from Essex town, the rock elevation is 521 feet. At Leamington, southeast of Essex town and south of Comber, it is 502 feet; and at the county line less than 500 feet. In the northern part of the county the elevation of the rock surface is 492 feet at Belle River; and there is evidence that it is lowest at the northeast corner of the county, at the mouth of the Thames river.

Were the analyses forthcoming they would, therefore, doubtless show, not only that the Corniferous extends into Essex county along the ascertained lines of outcrop in Monroe and Wayne counties, overlain northward by the Hamilton and Genesee, in order; but also that it circles round as above suggested to where it has the southward dip as exposed in the Amherstburg Quarries.

I make the statement on the authority of Mr. Eugene

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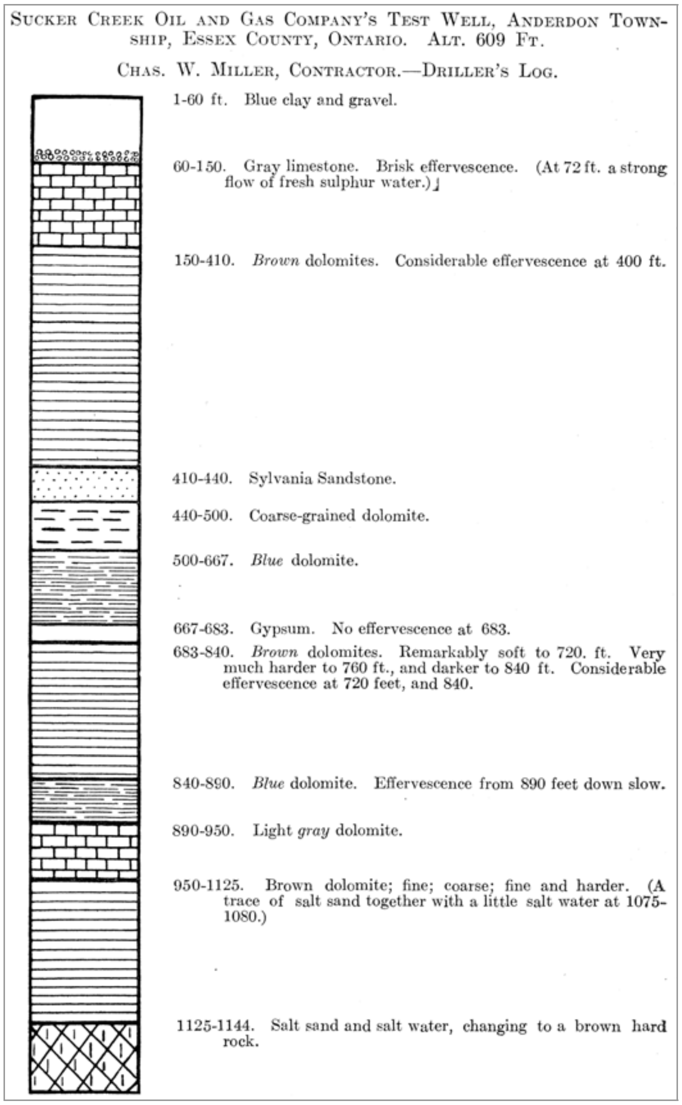
*The Dundee of Monroe county, as described by Professor Sherzer (Geological Report on Monroe County, Vol. VII, p. 1, Geological Survey of Michigan, 1900), is essentially a high grade limestone; whereas, in the Amherstburg quarries there are three several deposits, the lower averaging 97.5 Ca Co3, the middle about 60.9, and the upper 80.+ (See Bureau of Mines, Ontario, 1904, Vol. II, "The Limestones of Ontario.)

Coste, late mining engineer of the Geological Survey of Canada, who has done a great deal of exploring for gas and oil in both Essex and Kent counties, that "*the western limit of the black shale* is, roughly speaking, the Essex and Kent county line; and in places in Kent county these shales extend south as far as Lake Erie; although they are missing in Kent over a number of anticlinal folds." Thereby establishing two things: First, and incidentally, that the contour of the Antrim or Genesee shales, as figured in the 1903 report of the Michigan 'Geological Survey, errs by defect, as does also the outline mapped by the Dominion Government Survey, in showing the extent of these ^shales; and second, (and more to the purpose of the argument in hand to establish the fact of a Silurian anticlinal in the western part of Essex county), that anticlinals have interfered to displace later deposits in this southwestern .section of Ontario. A Silurian anticlinal is the solution of the problem offered. For that matter the Lime Kiln Crossing in the immediate neighborhood of the Amherstburg Quarries, in the Detroit River, known to sailormen as the danger spot of the lakes for deep draft boats, is part of a Silurian anticline.

The Geology of the Western End of Lake Erie does not appear to have been very well worked out by either Michigan, Ohio, or Ontario. It is therefore with some diffidence that I advance an opinion. I am, however, convinced that those forces which gave rise to unconformity between the Silurian and the Devonian strata, caused an expansion of the Devonian sea southward and southeastward. In proof of this let it be stated that the rock outcropping on Pelee Island, and (as I am told) on Middle Island and Kelley's Island, in Lake Erie, is the same as that in the Amherstburg Quarries in Anderdon Township. The approximate limit of deposit of the Devonian westward corresponds, very probably, as nearly as may be, with the international boundary line until it passes North Bass Island, thence curving southward till it passes the west side of Kelley's Island. If this be (as I believe it to be), the delimitation of the Devonian in this direction, it follows that the Corniferous strata rest unconformably upon the earlier deposits of the upper Silurian at the west end of Lake Erie.

The surface extension over the entire upland of Pelee Island is the same thin-bedded limestone as lies over the heavy bedded stone in the Amherstburg Quarries. At the north end of the island the rock has faulted, leaving a bluff, with north exposure of the thin and heavy bedded lime. About the middle of the island on the west side, is another similar elevation of 598 feet to 608 feet, or thereabout, breaking off eastward at an angle with the north and south faces of the ridge. But at no place on the Island is there an exposure deep enough to show the high grade limestone that underlies the heavy beds.



SUCKER CREEK OIL AND GAS COMPANY'S TEST WELL, ANDERDON TOWNSHIP, ESSEX COUNTY, ONTARIO. ALT. 609 FT.

CHAS. W. MILLER, CONTRACTOR.—DRILLER'S LOG.

1-60 ft. Blue clay and gravel.

60-150. Gray limestone. Brisk effervescence. (At 72 ft. a strong flow of fresh sulphur water.)

150-410. *Brown* dolomites. Considerable effervescence at 400 ft.

410-440. Sylvania Sandstone.

440-500. Coarse-grained dolomite.

500-667. *Blue* dolomite.

667-683. Gypsum. No effervescence at 683.

683-840. *Brown* dolomites. Remarkably soft to 720. ft. Very much harder to 760 ft., and darker to 840 ft. Considerable effervescence at 720 feet, and 840.

840-890. *Blue* dolomite. Effervescence from 890 feet down slow.

890-950. Light *gray* dolomite.

950-1125. Brown dolomite; fine; coarse; fine and harder. (A trace of salt sand together with a little salt water at 1075-1080.)

1125-1144. Salt sand and salt water, changing to a brown hard rock.

The siliceous strata occurring in the Sibley quarry, near Trenton, Wayne county, to which my attention was directed by Mr. K. J. Sundstrom, General Manager of the quarry, are of a later horizon than the thin-bedded strata in Anderdon and on Pelee Island. It would appear that the depositing of the same limestone beds has gone on for a long period in the Corniferous age; in Wayne county, after it had ceased in Essex county by reason of the elevation of the Devonian sea bottom. There is evidence of disturbing forces at work producing this uplift presented: (1) in the faulted and disturbed condition of the Lake Erie islands; (2) in the irregularly undulating surface of the Silurian rock in Detroit river bed and in Monroe county; and more particularly (3) in the fact of the absence of the later Corniferous beds on the Canadian side of the river which are present and exposed in the Sibley quarry.

It will riot be without interest to note *the varying elevation of the Sylvania sandstone* which forms a very considerable surface extension in Monroe county. At Amherstburg, in the bed of the river, opposite the D., B. I. & W. Ferry Company's dock on Bois Blanc Island, it forms a surface extension over a very small area, at an elevation of 552.5 feet. At the Sucker Creek Gas and Oil

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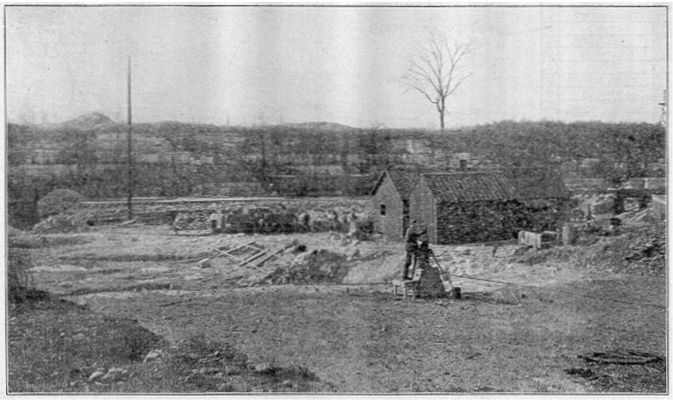
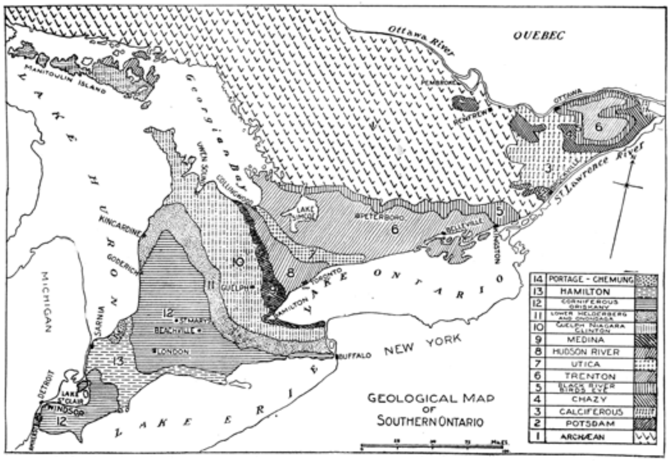
*Well records show a varying depth of these shales at the North side of Kent County from Dresden to Bothwell, of 180 feet, 146 feet, 98 feet, 200 feet, and 77 feet.

Company's test well in Anderdon Township it occurs at the elevation of 199 feet. At the Salt Shaft below Detroit the elevation is 155 feet. At Belle River, about half way along the south side of Lake St. Clair, one record shows a sand rock at an elevation of 312 feet. Almost due south of this on Pelee Island, in Lake Erie; the elevation is, approximately, 300 feet to 325 feet.

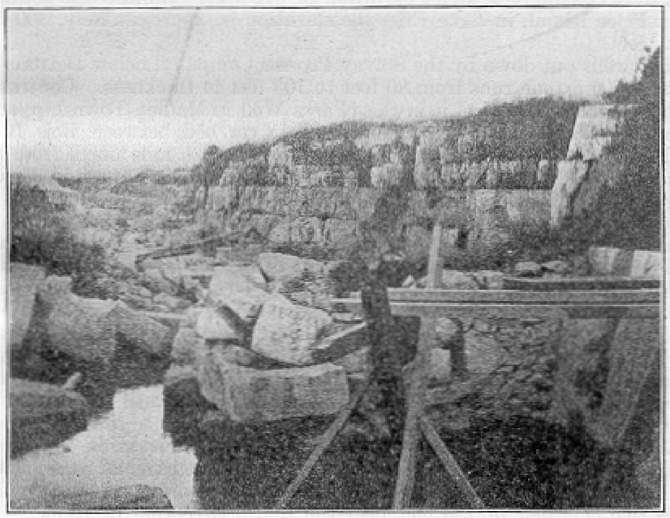


Quarry of gray dolomitic limestone, Anderdon, resting on high grade limestone floor; showing also (upper half of bluff), thin-bedded deposits. Essex County.



In five wells put down by the Solvay Process Company, below Detroit, the *Sylvania Sandstone runs from 80 feet to 103 feet in thickness. Contrasted with this there is 84 feet of it in the †Parks Well in Maiden Township, some two miles distant from the outcrop in the river bed between Bois Blanc Island and Amherstburg.† The Caldwell grove well a mile north from this shows 60 feet. In the ‡Anderdon well already referred to there is 30 feet. At Belle River, 25 feet. And ‖ on Pelee Island, 40 feet.

The Depth of Till over the western half of Essex county varies from 60 feet to 110 feet. Mr. Coste, whose name was mentioned in connection with the Genesee shales, says: "The depth of the drift over the east half of Essex and the west half of Kent seems to vary from 90 to 200 feet, being mostly from 100 to 150. Its character varies a great deal but it most often consists of about 100 feet of boulder clay, and from 20 to 30 feet of sand or gravel under that." At Bothwell, at the northeast corner of Kent county, where the surface §elevation is 691 feet, there is a maximum depth of till, 255 feet.



Showing the heavy beds from which the block stone was quarried for the Canadian Sault canal locks, and for the old locks at the American Sault. The same quality of stone was taken from Pelee Island to build the locks at Port Colborne, on the Welland canal.

The Point of Highest Elevation in Essex county is at Ruthven, on the old Talbot road, west of Leamington. Here there is a deposit of sand and gravel and boulders, of the Belmore Beach doubtless, with an elevation of 734 feet, the western limit of a ridge of the same material that extends parallel with Lake Erie almost its entire length, and which reaches a maximum elevation, for the two counties, of 736 feet near the southeast corner of Kent.

St. Andrew's Manse, Amherstburg, Ontario, March 8, 1907.

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*My Report on the Corniferous Exposure in Anderdon, Bureau of Mines, Ontario, 1902, page 123.

† Brummell's report on Natural Gas and Petroleum in Ontario, 1892, Geological Survey of Canada.

‡ Log of Sucker Creek Gas and Oil Company's well, Chas. W. Miller, drill contractor, 1905.

‖ Drillings examined by Dr. H. M. Ami, Ottawa, 1896.

§ Surface elevations quoted are as given in the Dictionary of Altitudes in Canada, by James White, F. R. G. S., Geographer to the Dominion Government Geological Survey. The rock elevations are from individual well records, except in the case of the Amherstburg Quarries and the Detroit River bed. These latter were ascertained by Mr. Charles Y. Dixon, of the U. S. War Department Office, Detroit.