PART II.

THE GEOLOGY

OF

LOWER MICHIGAN

WITH REFERENCE TO

DEEP BORINGS

EDITED FROM NOTES OF

C. E. WRIGHT, LATE STATE GEOLOGIST

BY

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WITH AN INTRODUCTION ON THE

ORIGIN OF SALT, GYPSUM AND PETROLEUM

BY

LUCIUS L. HUBBARD

AND ACCOMPANIED BY SEVENTY-THREE PLATES AND A MAP

OFFICE OF THE STATE GEOLOGICAL SURVEY,
Houghton, Michigan, August 28, 1893.

To the Honorable,
The Board of Geological Survey of Michigan:

GENTLEMEN—In accordance with your request, I have the honor to transmit herewith a paper, prepared during the administration of my immediate predecessor, by Dr. Alfred C. Lane, on the Geology of Lower Michigan, with Reference to Deep Borings.

With great respect, I am your obedient servant,

LUCIUS L. HUBBARD,
State Geologist.

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Pages 26 and 35, 3d and 15th lines, respectively, for "Petrolea" read "Petrolia."

Page 26, 11th line, for "Mason" read "Macon."

" 61, 6th line, for "R. R." read "R'w'y."

" 69, 12th line, for "900" read "400."

" 69, 23d line, for "H. W. Daw" read "H. H. Dow."

" 71, for "Newberg," wherever it occurs, read "Newburg."

" 71, 7th and 8th lines, "203" and "305" refer to wells Nos. 1 and 2 respectively.

" 71, 17th line, for "1130-1200" read "1180-1280."

" 78, 7th line from bottom, for "dips" read "depths."

" 79, between 9th and 10th lines, insert, as first group in Hamilton, "230-250, Limestone."

The cross-references from one well-record to another, giving equivalent depths, are meant for guides only, and the reader must not depend on them for minute accuracy, which is in fact often impossible to attain. There are some minor inaccuracies which are not here noted, because they are less than the probable error inherent in the record, e. g., on Plate II, the reference "L. R., 1300" should perhaps more precisely be "L. R., 1293."

INTRODUCTION.

THE ORIGIN OF SALT, GYPSUM AND PETROLEUM.

The material from which were derived, in great part, the data used in the preparation of this paper, was gathered by Charles E. Wright, deceased, late State Geologist, and consisted of a large number of samples from borings; of about sixty diagrams of salt wells, mainly complete; and of Mr. Wright's note books.

To these data Dr. Lane has added a few records, and has prepared six new sections, a map, and other illustrative matter. It is due both to the reader and to Dr. Lane to say that the latter is not personally familiar with the surface geology of the lower peninsula of Michigan. This paper, the credit for whose preparation belongs to the administration of my predecessor, Dr. M. E. Wadsworth, embodies what few facts the Geological Survey possesses on the deep borings of Michigan. No geological report on a subject of this kind can be expected to be final, and although the facts may be meagre, it has been thought wiser to lay them before the people and to try to point out their significance, in the hope that by so doing we shall furnish an incentive to further researches, as well as, to a certain extent, a guide to their successful prosecution.

These facts have been gathered from many sources during the search for deposits of salt, gypsum, oil, and other useful products. Before proceeding to their consideration, however, it may be worth while to give a resumé of the principal theories that have been advanced to explain the origin of the vast deposits of salt and gypsum that occur in different parts of the world, and of petroleum, which is often found in more or less intimate association with salt in one form or another. This resumé aims to give a simple account of the supposed processes of Nature. We shall see that the same facts may lead to conclusions that in some respects are diametrically opposite. It would be foreign to our purpose, nor would space and time permit us, to attempt to discuss at any length the different theories, or to weigh critically their relative merits, even if we were disposed to do so. The incompleteness of human knowledge makes progress toward the goal of truth very slow, and what may seem plausible today, may to-morrow, in the light of new evidence seem improbable, or even absurd. The duty of the investigator is to record observed facts and to wait patiently until enough of them are gathered to explain the phenomena about him. This is at least safer than to theorize on insufficient data. When the geologist can account rationally for the cause and method of deposition of substances that are of economic value, he may be able to predict where deposits of similar substances are likely to be found.

The primitive ocean of our globe is considered by some writers to have been as pure as rain water, by others to have been salty. Indeed, Schleiden says the ocean was originally a saturated brine with 33 % of salts. The water of the ocean at present contains in solution about 3.6 % of solid matter (2.5 % salt). As pointed out by Ochsenius,* if we allow the ocean an average depth of 3,600 meters, to restore it to a condition of saturation (25 % salt) would require a crust of salt 300 meters thick for the entire surface of the earth. G. Bischoff thought that the ocean was a million years in attaining its present degree of saltiness, and that it was the ancient, or crystalline rocks that were the principal source of the different salts that now make up this percentage. According to another writer, salt originated in animals and organic growths; according to a third, it was originally distributed over the earth in the form of rain as a saturated brine, which, beside enriching the ocean water, permeated many of the rock formations. That smaller quantities were brought by winds in moisture from the ocean and precipitated on the land is a much more common and a better grounded belief. By some, a salt-creating force in the atmosphere was supposed to produce superficial deposits of salt—certainly not a very scientific theory, if we are to understand by it that something came out of nothing. A deluge of brine in the early stages of the earth's history would have made the early formations salty to a greater degree than we commonly find them, and, unless speedily

*Chem. Zeitung 1887, 11, No. 56 et seq.

carried off, or diluted by fresh water, would have been likely to prevent the development of organic life. Salt, it is true, occurs in formations as old as the Silurian, but nowhere in beds of enormous thickness until we come down to Permian times. The vaster deposits of salt appear in the Trias and from there up to the Tertiary, and salt beds are in process of formation even at the present day. Different topographic conditions must have prevailed in different stages of the earth's development. Agassiz says that the types of mollusks from the Devonian to the Cretaceous belong almost exclusively to the ocean. Fresh water fauna are subordinate until we pass into the Cretaceous. By this time with the growth of sedimentary deposits and of volcanic flows, the crumpling of the earth's crust, and the re-arrangement of rock material, there were more basins inland for the accumulation of fresh water and others on the border of the ocean that may have been filled with salt water, or alternately with fresh water and with salt water.

We see from the foregoing that, however and from whatever source salt may originally have been derived, the ocean has been one of its great repositories since the time when the sedimentary deposits began to be laid down, and while some of the theories already quoted may account for small or sporadic deposits of salt in the older Paleozoic formations, no one of them accounts satisfactorily for deposits of such magnitude as, for example, that of Stassfurt, Germany, where the salt formation has been bored into vertically to a thickness of 325 meters without reaching its foot-wall, or of Sperenberg where, although less pure than at Stassfurt, the salt has been found to be 1,194 meters thick. The ocean alone gives us a safe starting point as a source of the salt deposits of more recent geological ages.

The principal associates of salt in its solid form are gypsum and anhydrite, the hydrous and anhydrous sulphates of lime; dolomite, the carbonate of lime and magnesia; the more soluble potash salts; as well as sulphur and petroleum. When we come to consider the two principal theories that have been advanced to account for the great salt deposits and their associated rocks, it may be well to bear in mind that in sea water we find the same elements that enter into the composition of the above bodies. From sea water we can obtain rock salt (chloride of sodium, $NaCl$), the very soluble potash salts (KCl, etc.), limestone (carbonate of lime, $Ca\,Co_3$), gypsum and anhydrite (the hydrous and anhydrous sulphates of lime, $Ca\,So_4\,(+2aq)$), sulphate and chloride of magnesia ($Mg\,So_4$, $Mg\,Cl_2$), together with bromine, iodine, double salts of some of the foregoing, and organic substances. In the laboratory we can get only a mechanical mixture of $Ca\,Co_3$ and $Mg\,Co_3$, but never a chemical mixture of the two that corresponds to dolomite $(Ca, Mg)\,CO_3$.

The two theories just referred to are the *volcanic* and the *aqueous*. According to the one, dolomite, salt and gypsum were brought up from the inner parts of the earth, either (1) as molten masses, accompanied by great heat and the development of gases, and with or without a display of violence, just like our basalts, porphyries and other volcanic rocks; or (2), they formed by the action of gases, either by sublimation or by the alteration of bodies already in place, or (3), they formed in concentrated solution in hollows down in the earth's crust, and either solidified there after the manner of granite, or were exuded to the surface through cracks and fissures, after the manner of porphyries; or (4), they (gypsum and salt) were ejected with violence in the form of slime, a phenomenon familiar to us in mud volcanoes.

The agency of gas in these deposits—its action on rocks previously existing—was a favorite theory. Hydrogen sulphide (H_2S), or fumes charged with sulphur acted directly on limestone, or they decomposed water, forming sulphuric acid gas (hydrous or anhydrous); the latter drove out the carbon dioxide (CO_2) in limestone and formed gypsum or anhydrite. Salt was formed by the action of $Na\,Cl$ gas, and dolomite by that of $Mg\,Co_3$ gas; these gases were concomitants of "black porphyry," the intrusion of which followed fissures by which they gained access to the different rock strata above their place of origin.

The thick lenticular masses of dolomite and gypsum often met with are the masses to which the theory of a sub-surface formation was particularly applied. Hollow places below the surface of the earth become filled with liquids, heated and concentrated to the consistency of a paste. Sulphur fumes entering caused the chemical changes above pointed out, and the formation of gypsum which often remained of the consistency of a paste. Salt separated out of the paste, and according to the amount of impurity with it, formed rock salt or salt clay. The various

mixtures were often ejected with violence, but as insufficient heat was developed to melt, this phenomenon is more closely allied to that of explosion- or mud-volcanoes.

The broad theory that salt deposits are formed by precipitation from sea water in basins connected with the ocean, was advanced as long ago as the last century, but not until recent years has it been taken up in detail, by Dr. C. Ochsenius,* who by means of some important modifications seems to have reconciled several weighty objections formerly urged against it, and to have made out a strong case in its behalf. This theory is particularly applicable to deposits like that of Stassfurt.

The evaporation of sea water in the laboratory precipitated, according to Usiglio, first (Sp. G. 1.0506, 1.1304), small quantities of carbonate of lime ($Ca\,CO_3$) and of hydrous oxide of iron; then 83.82 % of all its sulphate of lime ($Ca\,SO_4$) (Sp. G. 1.13–1.22); then 54.17 % of all its rock salt ($Na\,Cl$) at the same time that 16.18 %,† the balance of its $Ca\,So_4$ was being precipitated; then 8.5 % of its salt ($Na\,Cl$) without any admixture of $Ca\,SO_4$. The remainder of its $Na\,Cl$, together with the more soluble salts of magnesia, potash, bromine, and iodine, which compose the bitterns, finally crystallized in various combinations.

If the same process takes place in nature, undisturbed by local influences, such as inflowing rivers and rainfall, we can imagine a basin of sea water shut off temporarily by some catastrophe from connection with the ocean, its water evaporating under the influence of tropical heat. This will correspond to what is called a "salt-garden." The bottoms and sides of the basin will be coated with carbonate of lime, more or less colored by iron, on which will be a layer of sulphate of lime, gypsum. The concentrated brine retreating to the lower parts of the basin, salt will soon begin to precipitate with the gypsum until the latter is all thrown down, and the final or upper salt strata will be approximately pure. The bitterns retreating to the hollows of the basin, their very soluble salts will be the last to crystallize, in part as a thin skim on the sides of the basin, and if the basin receives a slight access of water from inflow or atmospheric moisture they

* See Die Bildung der Steinsalzlager und ihrer Mutterlaugensalze. Halle, 1877; Nova Acta der Ksl. Leop.—Carol. d. Akad. der Naturforscher. Bd. XL, No. 4; and Chem. Zeit., 1887, 11, No. 56, which also contain references not cited here.

† The total $Na\,Cl$ being to the total $Ca\,SO_4 = 27.11 : 1.75$, this amount is relatively small. Almost all analyses of rock salt show at least traces of $Ca\,SO_4$.

will quickly redissolve, perhaps with a small portion of salt, and may or may not eventually be removed. The alternation of winter and summer, or even of night and day, might have the same effect, and the bitterns would then seek the lowest parts of the basin, where they might recrystallize in a more contracted space. Animal life in the basin when the barrier formed between the latter and the ocean, would soon be unable to exist in the concentrated waters. Vegetable matter in the water would be imbedded with the deposits as they formed, its position depending, of course, upon its specific gravity relatively to that of the concentrating waters. The desert of Sahara and the eastern coast of the Red Sea furnish good examples of the processes described above.

In a case of this kind the amount of solid salts cannot, of course, exceed the amount of salts in solution in the basin at the time its barrier formed, supposing it receives in the mean time no salts from other sources. This amount is only 1-60 of the cubic contents of the basin. We can, of course, imagine a disruption of the barrier, or the irruption of the sea at regular intervals. The new supplies of sea water thus introduced into the basin might on evaporation give us a repetition of the first deposits, but not an immense uninterrupted deposit of any one substance. Deposits like that of Stassfurt can therefore not be accounted for, says Ochsenius, by supposing them to have formed in a closed basin. We must presuppose a basin of sufficient depth, an *almost horizontal channel connecting it with the ocean*, and the ability to evaporate the inflowing water as rapidly as it is received.

The continuous connection of the basin with the ocean is the principal point in the argument for the formation of the very thick deposits of salt, but is not necessary in order to explain all salt deposits.

Under the above named conditions, the upper layers of water in the basin become heavier, as evaporation proceeds, and sink. They come in contact with layers differently charged. Chemical changes take place, which result finally in the deposition of various salts, principally of sulphate of lime and chloride of sodium, according to the varying specific gravity of the solution, as already noted, and to other factors that will be mentioned subsequently; while in solution, the chloride of sodium (rock

salt) will tend to lie in the lower strata, and the magnesia salts between these and the surface. As the water concentrates, the fish will seek the highest and freshest parts of the basin, and will finally pass out of it. We find comparatively few remains of fish in great salt beds. In the Caspian Sea, which has no outlet, and in a great basin of which, the Adschi-Darja, salt is continually forming, fewer fish are found in those parts that are richer in magnesia salts than are found in the highest, less salty layers, and fewer fish in the Adschi-Darja than in other parts of the Caspian Sea.

The bottom of the Straits of Gibraltar forms an imperfect bar between the Atlantic Ocean and the Mediterranean Sea. An under-current flows out of the latter into the former, while a current from the Atlantic flows in at the surface. The water of the Mediterranean contains in proportion to its salt ($NaCl$) 2½ times as much sulphate of magnesia ($MgSO_4$) as the water of the Atlantic, and the excess of this $MgSO_4$ is supposed to lie in the higher layers, between the surface layers and the level of the top of the bar. The water below the bar is relatively stagnant and of a relatively uniform temperature and chemical composition. The temperature of the water under those layers that are affected by the sun is equal to the mean of the winter temperature of the Mediterranean Sea at the surface, 12.8°. It follows, therefore, that none of the upper layers on concentration can attain a density that will enable them to penetrate below the level of the bar. They will therefore, as it were, glide over the lower zone, and giving way to the "feed water" from the Atlantic, will pass out under it into the latter body. It is a similar action that Ochsenius applies to the salt basins.

The layers of water that are rich in magnesia salts set up a counter-current and flow out of the basin under the incoming current of sea water. Thus there are constantly introduced fresh supplies of gypsum, salt, etc., while the more soluble salts are being carried away. It is evident that upon the rapidity of evaporation and the consequent varying specific gravity of the water will depend the salts, in kind and amount, that are precipitated in the basin. If the inflow and distribution over the basin were constant and uniform for long periods, and the specific gravity were maintained steadily between 1.0506 and 1.1304 we should have a deposit of nearly pure limestone. With the specific gravity between 1.1304 and 1.22, we should have sulphate of lime (gypsum), and beyond the latter point salt would form rapidly. Under favorable conditions this process might continue until the basin was filled with precipitates, or until the barrier was closed, when the salts of the bitterns would be precipitated and lastly the anhydrite cap would form over them all. The magnesian and potash salts, owing to their easy solubility, might be carried off later in solution.

The occurrence of absolutely pure rock salt is therefore possible only after fresh accessions of sea water are rendered impossible, *i. e.*, after all the gypsum is deposited. A recurrence of pure salt in different strata would point to the periodical closing of the bar.

Salt and gypsum deposits are frequently impure from the presence of sand and clay. Both of these substances might be brought in from the sea, or the latter might come largely from the surrounding lands, being brought by the winds and scattered uniformly over the whole basin. In the last stages of desiccation, the basin would be a "bitter lake," and under its influence the shores would be likely to become barren of vegetation and be without protection from the erosive force of the wind. Hence we should expect to find layers of clay or of sandstone over salt deposits, some of them perhaps saturated with the more soluble potash salts.

The *annual rings* at Stassfurt, to which reference is made on page 9 of the following text, are by Ochsenius ascribed to local causes. According to Usiglio, sea water concentrated to one-half of its volume (*i. e.*, specific gravity = 1.0506) deposits a large part of its $CaCO_3$, but between this point and a further concentration to 19 % of its original volume only traces of $CaCO_3$ fall down. At the latter point, however (specific gravity = 1.1304), another large precipitation of $CaCO_3$ takes place ($\frac{53}{64}$ of first precipitation). The first precipitation begins gradually and ends abruptly, the second begins abruptly and ends gradually. This is supposed to be due to the mutual decomposition of $NaCO_3$ and $CaSO_4$ and the formation of Na_2SO_4 and $CaCO_3$. Therefore if there be any substance in the solution, that falls down when the specific gravity of the liquid varies between 1.0506 and 1.1304, it will lie between two layers of $CaCO_3$, against which it will be quite sharply delimited. Ochsenius thinks that from the known greater

solubility of gypsum in salt water than in fresh, and from the probable formation, on concentration of the sea water, of double salts, or perhaps of the four salts, $NaCl$, $CaCl_2$, $NaSO_4$ and $CaSO_4$, sudden and well marked deposits of $CaSO_4$ might be caused by a sudden dilution of the concentrated water, or by the addition to it of Na_2SO_4 or $CaCl_2$. So also $CaSO_4$ is insoluble in a saturated solution of $MgSO_4$. The outflowing magnesian and other salts with the incoming sea water might produce these salts or others like them, and the return to the basin of the resulting salts might be caused by certain periodic winds. Hence the direction of the mouth of the basin with reference to these winds would be the principal local factor. The fact that only one other locality, near Dieuze, shows annual rings, while others near Stassfurt do not show them, is an argument against the theory that these rings of anhydrite are due solely to a change from a summer to a winter climate, for in the latter case they should be more general, in the same locality at least. These periodic winds, however, may be due to a recurrence of seasons.

The presence of anhydrite in connection with salt deposits, where gypsum might be expected, especially as a cap to the principal salt deposit, has been explained by Ochsenius as due to the fact that the hydrous sulphate of lime in solution with some potash salts exchanges part of its water for sulphate of potash, in the formation of polyhalite and other salts, and this exchange results in the formation of the anhydrous sulphate, anhydrite ($CaSO_4$). Dr. Lane has observed that many occurrences in Michigan borings, generally taken for gypsum, are in reality anhydrite. Unless this form of the sulphate occurs with other salts in a solid state, it is of course impossible to verify or disprove the accuracy of the above explanation.

A glance at a geological map of Michigan and neighboring territory will show a series of sedimentary formations, one of the lowest of which, the Huronian, rests on the northwest, north and northeast on Laurentian rocks, forming a great basin. The different formations from the Huronian, or more strikingly from the Cambrian (Potsdam sandstone) up to the Coal Measures (Jackson Coal Group) outcrop around the edges of this basin, dipping gently toward a point, which for the later of the formations is the center of the basin, which lies near the middle of the lower peninsula. These formations, consisting of limestone, dolomite, sandstone, and rocks nearly related to these, form approximately concentric shells that were laid down in past geologic times, the lowest of them, up to and including the Monroe beds (Upper Silurian) as parts of a wide basin that extended from Wisconsin to the east, as far as the Appalachian mountains in New York, and south into Ohio, where it connected with the ocean which then covered the lower Mississippi valley. From the Monroe beds and up to and including the Coldwater shales the basin seems to have been more intimately connected with western Ohio and Indiana. The east side of the Michigan basin shows signs of having been elevated at the time the Berea was forming. This lies just below the Coldwater. Beginning with the Grand Rapids group, the great gypsum-bearing horizon, the basin seems to have contracted still more, to have shifted its center westerly, and to have been confined more nearly within the present land limits of the lower peninsula of Michigan. To explain the presence in the Michigan strata of deposits of gypsum, of rock salt and of other salts commonly associated with the latter, we are justified in assuming conditions that correspond with the more probable of the two theories above considered, that of an aqueous origin. In fact the "eruptive theory" has long since been pretty generally discarded. The records show deposits (30 to more than 100 feet thick) of rock salt in or below the Monroe beds, which probably correspond with the salt-bearing strata of western New York. Below these salt beds there should be expected a very general deposit of gypsum. In the southwestern part of Michigan, and in Ohio, this gypsum has been found, but as yet no salt has been found with it, so far as we know. The latter thinned out towards the edge of the basin and may also have suffered some erosion. The salt beds under Monroe county appear to be underlain by limestone. To account for the deposit of the salt of Michigan, in all four of the salt horizons, the assumption of an uninterrupted connection of this basin with the sea, for a long period of time, does not seem, so far as the evidence goes, to be required. Indeed the intervening formations between the different horizons, and the relatively small amount of the salt deposits point to the repeated interruption of this connection and to changes in the earlier conditions, among which the contraction and disturbance of the basin by epeirogenic

or continental movements were not the least important. Our chief concern is to ascertain, if possible, what parts of the basin were deepest during the deposition of the gypsum in the Grand Rapids epoch. In those deep parts we might expect to find equally thick deposits of gypsum throughout the basin. In like manner we might confidently look for the deposits of rock salt around the basin, that occur in the Monroe beds at Wyandotte, Royal Oak, and along the St. Clair River, at least if we knew where to locate the deeper parts of the basin as it existed during the epoch of the Monroe beds. The cross-sections accompanying this report are meant to be of aid in this connection. With additional information derived from the boring of new wells, we may expect in time to be better able to define the various flexures and irregularities of our rock strata, so that deposits of the more insoluble salts can be located with greater precision. Folds in the formation and subterranean percolation would be likely to disturb the original position of the deposits of the more soluble salts, whose present position would then depend in a measure on their specific gravity, on hydrostatic pressure and on factors of a complicated nature.

Petroleum, a mixture of hydrocarbon compounds in varieties of different appearance and chemical composition occurs, in a state of nature, in small quantities on the surface of the earth, and in different formations from the Silurian up to the Tertiary.

It occurs often in regions where salt deposits are found and, with gas, not infrequently comes up with the brines of salt wells, sometimes preceding and sometimes following the brine. It is most frequently found in sandstones or other porous rocks, where it may occupy a space equal to one-tenth of the bulk of the rock. It collects usually under an anticlinal, *i. e.*, under strata that are wavy, or slope downward from a crest in two opposite directions, where, if it lies between two impervious strata it is kept together in the same zone until released by an opening, natural or artificial, in the strata that cap it.

In Pennsylvania the oil belt is fifteen to twenty miles wide, and extends from southern New York to northern Tennessee, in gently undulating strata of the Hamilton and Chemung, along the edge of the Allegheny mountains parallel with and fifty miles west of the latter. The productive parts appear to have no connection with one another, although they probably belong to the same geological period. Miles of unproductive territory lie between the rich intervals. The coal and oil of Pennsylvania are widely separated in depth, the coal being above the oil. In the Caspian district the oil deposits lie in Cretaceous strata that extend on each side of the Caucasus mountains and along their prolongation southeastwards beyond the Caspian Sea. In Galicia, petroleum products are found in Tertiary strata along the line of the Carpathians; in South America and in California on the western mountain slope next to the Pacific Ocean. In the latter case the oil is in Tertiary strata which, unlike the Pennsylvania oil-bearing strata, are highly tilted.

In Pennsylvania and in Ontario the oil occurs principally in the Hamilton group of the Devonian age and in the Corniferous just below it. In Michigan what may be taken approximately as the equivalent in age of the former of these groups embraces the St. Clair shales and the Traverse below them, which have thus far not shown oil and gas in paying quantities, although traces of these substances are frequent in each of them. The Dundee in Michigan, the probable equivalent of the Corniferous, has also shown more or less gas and oil.

So far as we are informed, no drill hole in Lower Michigan has yet pierced the Trenton, the oil horizon of Ohio and Indiana, except at or near Monroe, where some gas was observed.

The beds in which the great deposits of oil are now found are most of them supposed not to be the place of origin of the oil. The uncertainty as to which are the mother beds deprives us of positive evidence that might go far towards a satisfactory explanation of the origin of oil, and geologists and chemists, especially the latter, are forced to offer their theories in a tentative way rather than as conclusions that can be accepted as final.

A theory that once found favor was that petroleum was a product of distillation derived from vegetable substance during the formation of anthracite. Again, it was thought to be the product of dry distillation of vegetable matter with bituminous schists. These views have been pretty generally abandoned, so far, at least, as the vaster deposits of oil are concerned, because petroleum is rarely if ever found in coal beds or near them, unless animal remains are also present. Oil occurs in beds of marine origin, where comparatively few plant remains are found. In these beds, on the contrary, are often found many remains of animal matter, and in close connection with them salt solutions of various composition. The water of the coal deposits, on the other hand belongs to the class of hard waters, and cannot as a rule be called salty.

Some investigators have thought that petroleum was the product of water vapor, carbon dioxide, and sulphuric acid or hydrogen sulphide, acting on iron. This theory seems to be based purely on the facts that these substances occur in the earth's interior, and that an oil resembling petroleum can be artificially produced by their combined action. Similarly, carbon dioxide acting on alkali metals forms acetylides, these, in turn, with hydrogen form acetylenes, from which petroleum might result.

Mendelejeff rejected the organic theory; because petroleum is often found near the surface of the earth, having been brought there by circulating water, than which it is lighter; because it is found chiefly in sandstones and other porous rocks where there are no carbonized organic remains; because it is found in nearly straight lines or arcs of great circles rather than scattered irregularly through different strata, as would be the case if it had formed in place. Therefore, he says, it must have been formed in some lower strata. These reasons, it may be pointed out, do not conflict with the organic theory and are in fact generally accepted by advocates of the latter. That the vaster bodies of oil are found in strata so low in the geological horizon, as for example, in the Hamilton in Pennsylvania, that sufficient organic remains for their production cannot be expected to have existed in strata below them, is an objection of weight, but for a reason already stated is not conclusive. Mendelejeff assumes an accumulation of metals in the earth's interior, especially of iron, as well as of carbon compounds of the metals. Water penetrates to the latter, and under pressure and a high temperature acts on them, forming metal oxides and hydrocarbons. These rise in the form of vapors, are condensed in the colder strata to oil, which collects wherever it finds a suitable receptacle. It has been objected against this theory that, if oil formed at such great depths in the earth, we should find more evidences of its occurrence in volcanic rocks and in those rocks of the earth's crust that lie nearest the supposed seat of generation of the oil. Besides, as already stated, we know that remains of animal matter do occur in petroleum beds, and we may safely infer that not all petroleum deposits are necessarily removed from their place of origin.

The distillation of train oil produces nearly all the compounds of petroleum and a gas that contains much marsh gas (CH_4). A dry distillation of muscles and sea-fish shows a large amount of ammonia and of nitrogenous organic bases, from which it appears that the flesh of animal bodies is nitrogen-bearing, while the fat is nitrogen-free. The former is subject to rapid decomposition, and in the earth's strata its constituents may to a great extent be carried off by percolating waters, while the fat remains as a source of petroleum.

Ochsenius* cites the decomposing action on one another of marine sulphates in contact with organic detritus and the formation of sulphur therefrom; the occurrence of bromine and iodine in the residue of petroleum distillation; of sulphide of ammonia and carbon dioxide as products of the distillation of crude petroleum; in several oil regions, of tungsten which is supposed to be an ear-mark of mother liquors or bitterns; of hydrogen sulphide, and of sulphur in petroleum; and lastly of salt and other chlorides in petroleum water, and concludes that it is the mother liquors from salt basins, that have not only caused the death, in large masses, of marine animals, but have also been the principal factor in their conversion to petroleum.

Therefore the occurrence together of gypsum, salt, petroleum and sulphur suggests to Ochsenius the probability that the two former mark the birthplace of mother liquors, which on the one hand form petroleum from animal remains, and on the other furnish the material for sulphur deposits. The mother liquors here play the part of the great heat required for the artificial production of petroleum. He mentions a locality in Alsace described by A. Andreæ, where sandstone strata were found saturated with oil; salt water beneath them and marsh-gas above. The strata were brackish and contained fossils, snails and plants. In the higher strata were abundant foraminifera. The deposit of oil was surrounded by a zone rich in brown coal, and the sandstones bore impressions of the leaves of land plants. This occurrence, which Ochsenius considers as corroborative evidence of the correctness of his theory, does not seem to exclude vegetable remains from being at least co-agents in the production of petroleum, nor does

*Chemiker-Zeitung, 1891, 15, No. 53.

it satisfactorily prove that a mother liquor with its magnesia salts must be the chief agent in this process.

Whatever be the materials from which and the process by which petroleum is formed, we know that oil deposits occur very generally along some old shore line of a former ocean in intimate connection with sea water, in contrast with coal deposits, which, essentially a product of land or fresh water vegetation, are seldom found in intimate association with petroleum; that they occur in distinct and independent deposits for some distance throughout approximately the same stratigraphic zone, interrupted by unproductive intervals; that these scattered deposits may represent so many bays or basins which once formed receptacles for the deposition of salts from the water of the ocean from which they were fed; that the barren parts of these oil zones represent, either land that separated the bays from one another, basins that were not suited for the deposition of salt, or points that were stratigraphically unfit for the retention of oil. This is at once much more apparent in the cases above cited than in more inland localities, where the topography is flat, as in Ohio, for example, which however at one time was under the waters of a shallow bay connected with the ocean on the south. After the deposition of salt and, in some cases, of mechanical detritus above it, owing to the presence of salts of magnesia (mother liquors) or to some other cause, petroleum was formed by a process of slow distillation from organic remains, probably both vegetable and animal. Naturally seeking a higher level, either in the form of gas or of liquid according to the temperature of the surrounding rocks, to the pressure to which it was subjected, and to the circulation of currents of water near it, the petroleum lodged where it found porous rocks with an impervious dome-shaped or corrugated cap—an anticlinal reservoir—and a more or less compact stratum below it. If the impervious overlying stratum was tilted, the oil probably kept on its course upwards until it reached the outcrop of those strata. Where this outcrop was buried under hardpan or glacial drift, the oil might again be confined. Where the strata of the cap are broken or disturbed, the oil escapes upward and may finally be dissipated. That no oil belt is found on the east side of the Allegheny mountains is ascribed to this cause. That all deposits of petroleum in its different varieties were formed in the same way is not probable, nor is it impossible that some bituminous products may be of vegetable origin. When the oil is associated with gas and salt water, we naturally find the gas at the top and the water at the bottom, although the order of exit of these products from a hole penetrating their vicinity must depend upon the local structure and the relative position of the hole to the different substances in confinement.

LUCIUS L. HUBBARD.

CHAPTER I.

GENERAL CONSIDERATIONS.

§ 1. The Geology of Lower Michigan is well worthy of careful study from a practical as well as from a theoretical standpoint. For underneath its fields and forests are buried treasures of coal, salt and plaster, which are known to be of great value, and it is more than likely that greater quantities of these, and of building stone, lime, cement, marbles, gas and oil still await development. But while this is true, the surface of the country is so covered with gravels left by the great ice age, and is so gentle in its relief, that outcrops of rock are very scarce, and it is only by a careful comparison of facts that we can form a true idea of the structure beneath our feet.

§ 2. The mode of arrangement of the rocks is fortunately very simple, and was long ago made out by Bela Hubbard,* and has been since more carefully studied and explained by Alexander Winchell and after him by Carl Rominger. I say fortunately, for were it otherwise the geologist's lot had indeed been hard, as there are serious difficulties in the way of the investigator. Some of them have just been mentioned, and others, which have only gradually been realized, are the change in character, and the great increase in thickness of the rock beds, in passing from south to north.

Successive reports show a steady increase in the estimates of the thickness ascribed to the beds of rock lying between the Trenton and the Coal Measures, so that while the geological column (Plate LXXIII) shows almost the *minimum* thickness of the beds in the state, the thickness thus given is quite as great as that given by any previous writers.

* 4th Rep. State Geologist, Sen. Doc. No. 16, 1841, p. 137.
See A. Winchell, Proc. A. A. A. S., 1875, Pt. II, p. 27.

For the causes of this misapprehension of the thickness, we have not far to seek. The states south of us, Ohio and Indiana, which, according to the law just mentioned, have much thinner beds than the corresponding formations in Michigan, were earlier and more carefully studied by geologists, in spite of the fact that our mineral resources are more varied than theirs. The published results of geological work done in these states are, at least, more complete than ours; the Michigan State Survey has been twice interrupted, and thus much material has been lost or buried.

The geologist has therefore always been tempted to use the records of the aforesaid states as standards of comparison. Moreover, the lower part of the rock series, if we may judge by the exposures in the Upper Peninsula, does not seem from all accounts to be very thick. Yet we are undoubtedly nearing old shore lines in moving north, and for a part of the time Michigan belonged geologically, as we shall see, rather with Ontario and New York than with the states south of it.

Under these circumstances it is easy to imagine how much light may be given by the records of deep borings and how eagerly it would be welcomed by the geologist.

§ 3. Before we go on to describe these records and the results we obtain from them, it behooves us to consider to what errors they are liable, that we may know how far we can depend upon our deductions from them.

A perfect well-record would show us exactly what kinds of rock there were below a definite point at all depths.

We do not find the same kind of rock at the same depth in different wells for some of the following reasons: (1) Because, while the rocks remain the same and unaltered, and are horizontal, the points from which we bore are not at the same altitude, or (2) because the bed, though it remains horizontal, has changed its character, having, for example, become more sandy, or (3) because the beds themselves have a dip, which may be due to a tilting or folding of the rock series as a whole, or merely to the thickening and thinning of one or more beds lying between the bed under consideration and the surface. Any lack of information which hinders our judgment, or any misinformation which causes us to misjudge as to the matters aforesaid, tends to spoil or render inaccurate our work.

Among the points, at which many records fail, are the following:

(*a*) First, the point at which the well is sunk is often not exactly known. "At such a town" or "near such a town" leaves a probable range for the location, of a couple of miles each way and a possible range of much more. Even location by streets, while of course more exact, is not satisfactory, because local maps or authorities must be referred to before the true place on the state map can be determined. Much the better way is to refer to the section, township and range of the original land survey. If we know in which "forty," or quarter of a quarter section the point lies, that is often at present as near as we can get. But decidedly the best method of reference is to the southeast corner of the section, with the statement as to how many feet, steps or paces (2,000 paces = one mile) north and west of that location the boring is. Of course to determine that, it is necessary only to walk to the nearest point whose position in the section is definitely known.

The nearer the wells are to each other, the more important it is to have their exact location given, that the full benefit of their records may be obtained. For if we can have the exact locations, altitudes and depths of three adjacent wells, we can thence derive the dip of the beds in the neighborhood and find the rate of rise and fall of the beds in any direction.*

(*b*) Secondly, the exact altitude of the well-head, *i. e.*, of the point from which the measurements are taken, *is not known for a single one* of the records transmitted to me from Mr. Wright. Yet, obviously, if we wish to get the dip of a bed, it is necessary that its depths at different points be referred to a datum plane, and the altitude of the well-head nearly enough for practical purposes can be obtained by a hand-level or even by a barometer.

Borings are not often made far from railroads or other means

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* See Green's Physical Geology, p. 463, whence we take the following easy graphical construction:

Let A, B and C be the position on a map, of three wells that cut a certain bed, A being the well in which the bed is deepest, and the elevation of the bed in all the wells being referred to a common level, *i. e.*, to tide level. Lay off along the direction AB a measured distance AZ. Along AC lay off AY, so that AZ:AY as the difference in depth above or below tide level, of the same bed respectively in A and B, and A and C. Then Z and Y should be vertically over points of the bed that are at the same distance above or below the level of reference, and ZY will be the line of strike. Notice that AZ is determined by the depth of the bed in C and AY by the depth of the bed in B. A perpendicular from ZY to A,—the line DA—will have the direction of the dip, and moreover AD:AY:AZ inversely as the true dip is to the dips (as measured in feet per mile) in the directions YA or ZA.

of transportation, and the elevations and profiles of railroads are taken carefully and are referred to lake level or sea level. Moreover in the "Dictionary of Altitudes in the United States," by Henry Gannett,* the altitudes of the railway tracks at most of the important stations through the state are given, and to connect these with the head of the boring will ordinarily be but little trouble. In fact, even without direct connection, inasmuch as the state is generally flat, and neither well-borers nor railroads are liable to choose the tops of hills, by substituting the altitude of the nearest station, which I have given with each well,† we are not likely to make a mistake of over twenty feet. At the same time, when wells are near together, this error becomes important and hinders decidedly the finding out of these minor flexures, which have great practical importance as accumulators of gas.

(*c*) A third error is in inexact measurements,—a positive error, whereas the previous ones were merely omissions. For a description of the manner in which measurements are made, we may refer to the Ohio report on Economic Geology,‡ merely remarking that there are several chances of error in the way that running measurements are taken, and there is evidence that errors do occur. For example, Mr. Charles L. Davis reports that when the Niles well was finished, it was supposed to be 1,140 feet deep, but proved on actual measurement to be only 1,099 feet. Numerous discrepancies may be noticed in the depths of other wells, when the measurements are derived from different sources or when the sum of the thickness of the beds passed through does not correspond with the total depth given for the boring,—discrepancies which are doubtless in part due to this cause. The records do not however give data to enable us to eliminate, allow for, or know definitely the size of this error. From various indications I judge that the percentage of error at Niles (4%) was not commonly exceeded, but was often approached elsewhere; the drillers are not likely to underestimate the depth of the well. This error is probably large enough entirely to disguise the other, made by taking the elevation of the railway track for that of the well-head, and seriously to affect our representation

* Bull. No. 76. U. S. Geological Survey.
† These altitudes are due mainly to Mr. Gannett, being taken either from his dictionary or from unpublished material kindly furnished by him.
‡ Geological Survey of Ohio, VI, 497.

of the beds, when the beds are close together. However, it is usual to take accurately with the steel tape the depths at important points, *e. g.*, where brines are struck.

(*d*) Another source of error consists in inexact descriptions. Of many of the borings no samples have been kept, and we have to depend upon the descriptions of those who attended the boring. Now, it is not always an easy matter even for an expert geologist to make much out of the ground-up particles brought up from the boring,* and it is not surprising if the drillers' records are very deficient.

I instance a few of the common mistakes:

Dolomite, [non effervescent (Ca, Mg) CO_3], is classed sometimes under limestone, sometimes under sandstone, but is rarely, if ever, recognized as dolomite. Anhydrite is never called anything but gypsum, is often overlooked entirely and called marl, etc. Anhydrite (or gypsum) in nature is always found where salt is. Not so in the records. Even geologists are apt to confound gypsum and anhydrite, the hydrous and anhydrous sulphates of lime. It is a noteworthy fact that at great depths in Michigan borings the anhydrous form occurs almost if not quite exclusively.

"Soapstone" is a loosely used term for calcareous shales and argillaceous limestones. It is a favorite term to apply to the Hamilton or Traverse Group.

Coal and black shale are sometimes confounded.

The term "sulphur" (as well as "sulphur water") is applied to water containing H_2S and smelling of rotten eggs, as well as to water that deposits sulphur, and to pyrite. Then there are other terms, such as freestone (by which sandstone is meant, although the material so called is not always sandstone), soaprock, flint rock, oil sand, oil rock, etc., whose meanings depend upon circumstances. Only those wells have trustworthy records where the fact is noted that samples have been deposited with the Survey.

(*e*) A final source of error is in the intermixture of the samples. This may be in two forms, either through accidental enclosures from the caving of an entirely different part of the column, or, if samples are taken but seldom, through the averaging up of perhaps a hundred feet of beds. In this latter case, if there

* See Rominger. Geol. Survey of Mich., III. 30, 117.

appear to be two distinct varieties of rock, their mutual relations, *i. e.*, whether they are interbedded in thick or in thin layers, may be quite obscure.

Considering all these errors together, it is probable that hitherto they have sufficed to render valueless any determination of dip from borings in the same immediate neighborhood; that they render the depth of a bed uncertain by more than 50 feet, but that they do not obscure the larger features revealed by the present borings as hereinafter described.

§ 4. Inasmuch as the material is thus imperfect, the only proper course to pursue is to put on record the data thus far obtained, quite apart from the conclusions that I have drawn, so that future workers with more and better data can draw further and more exact conclusions. Even as I write this report I am expecting well-records which promise to shed some much needed light.

But on a subject like this, where new facts are constantly being accumulated, a report must needs be journalistic rather than final, showing merely the state of knowledge up to some date; having for a main object, to point out where further work promises reward, and thus to lead to discoveries. Thus the more useful it is, the sooner will it become behind the times.

If those who are connected with well-sinking will see that samples are taken and kept on file (in the office of the Survey or elsewhere), that the depth of the well is accurately measured (at least when the boring is ended) and compared with the running measurements, and the location and altitude of the well-head are known, for the determination of which pacing and a barometric reference to the nearest railway are enough, we shall soon be able to prepare a much better report than this. And if ever the time comes that the drilling is done so as to bring out cores, and we have also a record of the temperatures of the rocks and of streams encountered by the drilling, such records will be of far greater value. Blanks for records and bottles for keeping samples have been furnished gratis by the Survey.

I have arranged near the close of this report an alphabetical list of all the towns in Michigan (and of a few of special importance in adjacent states), from which we have boring-records. This arrangement is the simplest, admits the insertion of new wells most readily, and makes it easy to look up what there

may be from a given town. In seeking to group by districts, one is sure to encounter some wells that belong as properly in one district as in another. Moreover one may see at a glance by reference to our map, whereon every town mentioned in the list is underlined, under just what town-names he will find the borings of a given district, which is convenient when wells are as numerous as they are about the Saginaw and St. Clair rivers.

Referring to this part for details, we begin then a general account of the rock series which will be pierced by the drill, and we naturally take them in the order in which they will be met, *i. e.*, the uppermost first. But of course the drill will strike in at different points of the series in different parts of the state. Accordingly, on the map (Plate LXXIV) are placed lines which show in general what I suppose would be the outcrop of some of the important division lines between different kinds of rock, if the soil and gravel and similar glacial or recent deposits were stripped away. Thus by noticing between which of these lines a given place lies, one can obtain an idea as to where in the geological scale he will begin, if he starts a boring. The same divisions are made, with some others, in the engraving of the geological column, which is mainly compiled from the wells at Jackson and at Monroe. We place by the side of our divisions those made by previous writers, and we shall discuss the differences as they come up. There are, however, two different principles of classification, the paleontological and the lithological, or classification by the remains of life in the rock and classification by the chemical and structural character of the rock itself, concerning which we wish to say something at the outset.

§ 5. The first step in the study of the earth's history, as it is written on tables of stone, was taken by Werner, or about his time, under the idea that different epochs of the earth's history were marked by the formation of peculiar kinds of rocks. Thus we get such names as Old Red Sandstone, Carboniferous, New Red Sandstone, Cretaceous, to denote periods of geologic time.

The second step was taken under the idea that by a series of creations, rocks formed during a given epoch, were characterized by remains of a life peculiar to that epoch, a life that was swept away by some terrible upheaval or cataclysm at the end of the epoch.

The third step in advance was taken when geologists began to realize that even as now in different places different kinds of deposits are forming,—in swamps, peat; at the mouth of the Mississippi, mud; on the coral reefs, limestone;—so it has always been. Hence the Old Red Sandstone in one place may correspond to a limestone elsewhere.

The fourth step in advance has just been taken in the realization by the paleontologists that, as now, so always, the kinds of animals and plants found in a given place or buried in a particular epoch vary, and depend not only upon their environment,—whether fresh water or salt, warm water or cold, muddy water or clear, shallow water or deep,—but also on more remote causes. Thus there are and have been zoölogical provinces, in which, under like conditions, very different assemblages of living beings have existed at the same time. Australia, South America and South Africa may serve as a present instance.

Thus we can rely blindly neither on the physical character of the rocks nor on fossil-lists. In either case we must also have an eye to what we may call paleogeography, and any classification we make will apply first and foremost only to a certain district. A final and universal classification and correlation of rocks according to time of deposit we can expect only from the use of both kinds of data, linked, if possible, to a chain of astronomical cycles.

It is certain that the zoölogical or paleontological provinces are much larger and more permanent than those districts for which there is a likeness in deposits. Yet within its confined district a classification by this method is as legitimate as one by that. Now, we shall find that the Lower Peninsula not only now belongs, but always has belonged mainly together in one basin, and that a distinct parallelism can be traced in the sections on the north, south, east and west sides of the basin, although, as has already been said, there is a great difference in these sections, due to an approach to a shore line on the northerly side. Of these sections we shall use as our type that farthest from the shore, for deposits along shore vary rapidly from time to time and from point to point, whereas any change that affects the deposits further from shore is likely to be wider-spread, and to mark a more sweeping geological or climatic

change. Moreover, among the changes which may take place in the character of the rocks, some will be found in practice to be farther-reaching than others and may also in theory be expected to be so. Conglomerates are notoriously local and variable, whereas the change from a clear sea-deposit to that of a sea supplied with the silt of a large river like the Mississippi, may be expected to affect an extensive area.

So too the contrasts between deposits of fresh water, of salt water and of very salt water will extend over the whole basin affected. It can hardly be expected as a rule that one part of a sea basin will be permanently quite fresh and the other part near saturation with salt. So that if there are marks of deposit from very salt seas, such as the scarcity of organic remains, and the prevalence of dolomite over limestone, or of precipitated limestone, siderite, anhydrite, salt, etc., these will be widespread. At the same time we must remember that there may be local exceptions at the mouths of unimportant rivers bringing in fresh water, and that while the condition of being concentrated to near precipitation may characterize a sea for a long time, very slight causes, such as the cold of winter or the spring freshets, the heat of summer, a series of dry years or some slight current, may suffice to check or to start actual deposition. The great deposits of salt at Stassfurt in Germany are divided by a series of lines of anhydrite into beds from 3 to 16 cm. thick, each supposed to represent a year's growth. We find at any rate in the basin we are considering, that while the general assemblage of non-fossiliferous (?) dolomites, marls, anhydrite and salt, forms a well marked series all over our district, we are not as yet able to trace any close parallels between different beds.

We notice finally another thing. In general, a new assemblage of living forms will work their way into a district in the wake of some geographic or climatic change that gives them a chance to replace the previous occupants. This geographic or climatic change will often leave its impress on the physical character of the beds and will thus mark a division line on both systems of classification. Often, however, the change takes the form of a prolonged battle between the old conditions and the old life, and the new conditions and the new life, first one side, then the other victorious at a given point. Thus we may find beds of the new physical character containing the new life, alternating with beds containing the old physical character and the old life. Again, we may find several incursions of the new physical conditions before the old life gives way to the new, or, on the other hand, we may find the new life entering with the first occurrence of the new physical conditions, and persisting in spite of partial relapses to the old state of affairs. Such phenomena give rise to very complex problems, that may puzzle both the stratigrapher and the paleontologist, and may lead them with equal justification to draw their dividing lines at different points. We find, for example, at Goderich and Monroe (*q. v.*) an inroad of the Upper Helderberg conditions and fossils before the final disappearance of the Lower Helderberg dolomites. We find again, in the Traverse or Hamilton Group an era of struggle between the conditions of the limestone formation below and of the shale above, and in the Berea shale above the Berea or Richmondville sandstone we may perhaps see the last expiring effort of the Black shale to maintain its once extended dominion. In fact, the whole Waverly (in Rominger's sense) is a transition series between two periods, which, at their highest development, are easily contrasted. It is natural to find, as we do find, that these epochs of strife show the greatest variety of conditions at different points, provokingly enough, just where we wish to run our lines of division. A good illustration is the variation of the Richmondville or Berea sandstones in various wells. It should therefore be remembered, that while the great body of the formation above a given correlation line may quite certainly correspond throughout a given cross-section, there is quite a chance for error in the beds that immediately overlie it.

It may also happen that minor physical differences may occur quite independently of the general conditions of life and deposit. We find, for example, in the Silurian series beds of sand or sandy limestone or dolomite, like those of Sylvania, Ohio, or Ida, Michigan, composed of angular grains of pure silica, very free from alkalies, and hence admirably adapted for glass-making and of considerable practical value. This sand does not seem to have been rolled along, but actually transported by ocean currents. Now it is quite conceivable that a current like the Gulf Stream might slowly shift its course so as to deposit a sandy layer in the Atlantic, now on the American side, and

now toward the European side, while other changes of life and deposit were spreading from Europe toward America. If we look at the sandstones recorded in the Silurian, either from the wells between South Bend, Indiana, and Kalamazoo, Michigan, or from various points in Monroe county, we must assume for them some such origin.

If such a bed proves continuous from point to point, as it seems to be in Monroe county, it is proper and of practical importance to correlate it, even though this correlation line may cross some other. The two correlation lines will mark geographic changes that inverted the order of occurrence of the beds in different parts of the basin.

Mr. Winslow, State Geologist of Missouri, has recently,* in a valuable paper, to which I shall have occasion to refer again, dwelt on a similar phenomenon in coal formations, which we may also expect to find in our Coal Measures. The coal is liable to be built out as a swamp from the land, and to follow the horizontal upper level of the water, while a varied alternation of shale and limestone is deposited on the bottom and partakes of its gentle curvature. Thus the coal beds will appear to transgress the others slowly.

Inasmuch as the economic character, or practical value of a rock will depend more on its physical character than on the fossils contained in it, we feel quite justified in adopting a purely stratigraphical† division of the series; but as divisions may have only a local value, we should not lay too much stress upon them and should use for them only local names. This I have done in the geological column which is given herewith (Plate LXXIII), putting, however, in parallel columns, what I conceive to be the corresponding names and divisions of previous writers, and throughout the text, for the greater ease of the reader, often appending the older, more or less nearly equivalent names.

In my geological column, the column before the woodcut shows the local names that I use for the formations, with figures indicating their probable maximum and minimum thick-

* Bull. Geol. Soc. Am., 1892, III. 114-121.

† This we must do, in fact, in dealing with drillers' records, for without samples no paleontological evidence is possible, and even where samples have been saved, fossils are often absent, scanty, or interpretable only by an expert.

ness. The next column after the woodcut shows the names used by the Ohio Survey and largely by C. E. Wright. The third column shows those used by Rominger and the fourth those used by A. Winchell, and the fifth the probable grouping into systems.

CHAPTER II.

THE GEOLOGICAL FORMATIONS OF THE LOWER PENINSULA AND THEIR ECONOMIC PRODUCTS.

(*a*) THE QUATERNARY.

§ 1. The surface of the Lower Peninsula is, under the soil, covered with a layer of unconsolidated deposits that is commonly known in drill records as "drift" or "surface." This layer is composed of gravel of various degrees of fineness, mixed with boulders, and at times replaced by sand, marl, clay, etc. It is the product of the latest geological action, and is scarcely ever preserved in samples, so that it is useless to try to separate the parts belonging to the glacial, and those belonging to the terrace epochs. Nor are there data for discussing whether there are more glacial periods than one represented. The fact, however, that from a boring near Vassar, chips of beech-wood came up, and that wood was also found in a boring near Paw Paw, may be mentioned in this connection.

This layer of drift is entirely unconformable with the rocks beneath, and hence it is not possible to tell how far one must go to strike solid rock. This renders the exact position of the outcrops of the underlying rocks more or less uncertain. Take the Allegan well, for example. If there were only ten feet of earth to begin with, instead of over two hundred, it is quite possible that in the upper part of the well we might pass through the Marshall sandstone, which would thus extend somewhat further south than we are now justified in representing it.

Generally speaking, the drift is rarely over a hundred feet thick in the south and southeastern part of the state, but, as we go north toward Manistee, Frankfort, and Ludington, we find it much thicker.

It is often more or less stratified, and then the coarser layers are liable to yield good supplies of water.

At the very bottom there is often a layer of clay known as "hard-pan." As the drift lies unconformably on the other formations, this layer, where it occurs, will form an impervious covering on the edges of the beds beneath it. Hence it is, that often on striking through the drift to the rock beneath, especially if that rock be a black shale, we encounter flows of gas, which have been slowly oozing out of the bituminous rock and accumulating in any dome-shaped reservoirs that may be made by this impervious sheet.

Before leaving the group of unconsolidated deposits we may recount the different kinds of deposits known to be present, even although we cannot separate them in the well-records.

On top we have the alluvial deposits recently laid down by rivers, or by the wash of rains, or, in the southwest part of the state especially, the dunes of sand accumulated by the wind. We have also beds of marl and peat formed in small ponds. Then we have widespread terraces or beaches left by the great lakes when they stood at a higher level. Then there are gravel plains, kames, etc., left by the ice in retreat, as well as clays of about the same age deposited in lakes, and finally the moraine material, unassorted and often coarse and full of boulders, deposited at the front of or under the ice.

(b) THE COAL MEASURES—THE JACKSON COAL GROUP.

The most recent beds, below the unconsolidated surface materials, that will be met by the driller, will be found in the center of the state, as might be inferred by what we have said of its basin-like structure. They are the Coal Measures, in which small beds of coal rarely if ever over four feet thick are found. Very likely they never extended over the whole length of the state. They certainly were formed in very shallow water, not far from shore, and in consequence the exact order of beds varies rapidly from point to point, as Rominger remarks.* Not only that, but being so near the water level any slight lowering of the latter would bring them within reach of erosion, or if we imagine them an old delta deposit, the erosion might be accomplished by the main channel of the river, which from time to

* Geol. Survey of Mich. III, 126, 131.

time might have changed its course. Thus we get old river channels filled with sand cutting out the coal, such as are so clearly described in the report of the Commissioner of Mineral Statistics for 1881.* Obviously a boring striking such a river channel might present a section of beds entirely different from that 200 feet away, and entirely misleading. The section given from Corunna may be of such a nature. These river-channel sandstones are of common occurrence in coal measures.†

Besides the coal beds another rock of practical importance is fire-clay. Coal underlain by fire-clay, then by black, coaly shales and limestones, or beds of siderite (carbonate of iron), lighter colored shales and sandstones, with these makes up a set of beds separated by numerous unconformities. The common character of these beds lies in the abundant traces of vegetable matter in them and in the generally rapid variation in their composition, though they remain black or gray, not red colored, and always keep the marks of a shore deposit.

The series begins and ends with a sandstone often enough to justify, as it seems to me, the separation of these from the main group into an overlying Woodville and an underlying Parma sandstone. This has been done by Winchell, although Rominger doubts its propriety.‡ The imperfections of the records, of which I have already spoken, are far too great to permit any definite decision on this point as yet.

It has been suggested by certain authors, that as swamps would occur along the edge of a sea, so coal beds would occur most often near the margin of the coal basin. The positions of Jackson, Grand Ledge and Sebewaing rather favor this view, and point to a belt a few miles in from the margin of the coal basin indicated by the innermost line on the map, as most suitable for coal explorations. Corunna, however, where coal has been mined, is nearer the center of the basin, and there is also a report of five or six feet of soft coal in the well at Midland, only a hundred feet down. I hardly think that this could have been more than coaly shale, however, or steps would have been taken to develop it. Midland is near the center of the basin,

* Page 24. C. D. Lawton, under C. E. Wright.

† See Winslow's paper above cited, Geol. Soc. Am. 1892. III. 114. for cases in Missouri, and also Geikie's Text book of Geology, 1885. p. 467. for a well worked out system in the Forest of Dean.

‡ Geol. Survey of Mich., III, 128, 129.

and it will be seen that the coal of Michigan never lies far below the surface. In fact one of the serious difficulties of mining, one in which the center of the basin would have an advantage over the margin, is the lack of a roof strong enough to sustain itself and impervious enough to keep the water out.

The bottom sandstone of this series, *i. e.*, the Parma sandstone, is charged with a brine at many points, *e. g.*, at Bay City, where the brine the sandstone carries is distinguished from the next lower brine by a higher per cent of $CaSO_4$, etc., and a less per cent of the earthy chlorides (probably also bromides).*

There is no reason to believe that the Parma sandstone itself contains rock salt, and the brine may be supposed either to be the original salt water in which the sandstone was deposited or to have percolated up from the underlying saline beds, as the outcrop of these beds to the southeast is at a noteworthy elevation, and the water in the beds at the outcrop appears to be fresh. It is thus the first-met or uppermost salt horizon of the many which underlie Michigan. It varies rapidly in thickness and probably is bounded above and below, at least at many points, by unconformities due to erosion. It makes a transition from marine, intensely salt water deposits, to brackish or fresh water formations.

The character of the change would be fully accounted for by supposing the adjacent land to have been elevated so that it would condense more moisture and pour it into the sea out of the mouths of sand-laden rivers. Such a change would also account for the shoal-water deposits and rank vegetation of the Coal Measures. It should be said, however, that in comparing the well-records of Portsmouth and other points around Bay City, it seems likely that the "upper salt-rock" is not exactly equivalent to the sandstone in the deep Bay City well. At Portsmouth the upper salt-rock appears to have nearly the same position as the gypsum of the deep Bay City well.

(*c*) THE GRAND RAPIDS GROUP.

We pass next into a group of rocks composed of dolomite and limestone, and of gypsum beds with accompanying green shales, which indicate a shallow basin, from which the water was often evaporated faster than it was received. I do not know, however,

* Geol. Survey of Mich., III, 182, 183.

that rock salt beds have been found in this group, and by their absence it differs from the lower gypsiferous (Salina) formation.

Like most gypsiferous series, it does not appear to be at all uniform in character and thickness. On Rominger's map the breadth of outcrop varies widely, but that map is certainly inaccurate in some respects, as according to the coloring Sebewaing is on this formation, whereas it really belongs to the coal basin.

The shallowness of the basin is shown, not only by the great prevalence of ripple marks, but also by minor unconformities, such as one noted by Rominger on the Charity Islands.* It is probably unconformably overlain by the Parma sandstone, and perhaps in some places eroded away altogether. The following, however, appears as a common arrangement of the beds, beginning at the top:

First, Brown, veined dolomites.

Second, Light colored sandy limestones or calcareous sandstones, often flinty, often veined.

Third, Rapid alternations of sandstone, gypsum and shales, mostly light colored, which make up the lower part of the formation and were separated by Winchell into the Michigan Salt Group. The objections to retaining this name and group are, that no rock salt is known to occur in the beds; that the brines, which he associated with it, are really from overlying and underlying sandstones; and that, as Winchell himself remarks:† "This group is a mere local condition of the lower portion of the carboniferous limestone." Possibly Winchell grants too much in this, but at any rate in the well-records it does not yet seem practicable to separate the upper, more limey, and the lower, more shaly, part by a steadfast line.

(*d*) THE MARSHALL SANDSTONE.

Next beneath the group just described, which in its upper calcareous and lower gypsiferous beds is so well exposed near Grand Rapids, occurs a series of sandstones, very widespread and usually very easy to recognize in a general way, that have been the object of more detailed study than any other group in the state. The lower part of the formation, and the

* Geol. Survey of Mich., III. 119.

† "Michigan," 1873, p. 69.

beds immediately underlying it, in the sense in which we use the term, are rich in fossils and their casts, and have been the subject of detailed paleontological and stratigraphical investigation by Prof. Winchell. Prof. Winchell originally speaks of two groups,* an upper, Napoleon group, and a lower, Marshall group, the two lithologically not distinguishable, but the upper group non-fossiliferous. He seems later to have abandoned the subdivision and in his description and map made for Walling's Atlas, in 1873, as well as in the "Geological Studies" and in the chapter prepared for the American Geological Railway Guide (1878-1890), the Marshall group is given as the sole division. Romingert† considers Winchell to have overestimated the group by an error in the stratigraphy about Point aux Barques, denies that the presence or absence of fossils is a characteristic feature, and maintains that in fossils, *i. e.*, paleontologically, the beds under consideration are one with those of the group below, next to be mentioned, and hence refuses to recognize this group at all. How far this is justified from a paleontological point of view we shall not pretend to decide. It is a fact, however, in which all really agree, that the gypsiferous formation or carboniferous limestone (that is to say, what we call the Grand Rapids group), is underlain by sandstone, which often graduates into the shales beneath. If this were not admitted, the evidence from the borings would be quite sufficient. Its thickness varies, but it is generally from 50 to 100 feet. In the only two wells from which we have samples (Charlotte and Jackson) it is fine grained,—so that the individual rounded grains of sand and scales of mica can be seen only with the aid of a lens,—calcareous, friable, and gray, slightly greenish in hue, and, in contrast with the Parma sandstone, finer-grained and darker. This appears to be its common character, but at Napoleon, Stony Point and elsewhere, it is thicker and coarser. Winchell speaks of it as yellow and brown. This is probably an effect of oxidation.

The upper boundary of this sandstone is generally sharper than the lower.

Economically it is of importance, not only in outcrop, where it furnishes building stone, flagstone, and the Huron grindstones,

* Geol. Survey of Mich., 1860, pp. 80, 88, 138-141.
† Geol. Survey of Mich., III. 70-76, 86.

but also in being under cover the source of the Saginaw valley brines of Bay City, Saginaw, Midland and other places. It is thus the second salt horizon.

From a scientific point of view it marks the time at which the geological history of Michigan switches off from that of adjacent states and pursues its individual and peculiar course, so that any parallels drawn must be paleontological rather than stratigraphical. The Coldwater shales lying below the Marshall, and next to be mentioned, are stratigraphically continuous with and paleontologically (doubtless, at least in part temporally), equivalent to the Cuyahoga shales of Ohio. The Logan conglomerate, which caps the latter, corresponds, therefore, to the Marshall.

Thereafter, that is to say, for the rocks above this horizon, the basins were distinct, and we find in neighboring states no lithological parallels to the Grand Rapids gypsum beds.

In the beds next beneath the Marshall, there is a resemblance to the series found in Ohio. This continues through all the beds which come to the surface, down to those which outcrop in Monroe county, underneath which we find a closer likeness to the rocks of Ontario, except that the extreme southern part of Michigan belongs with the greater part of Ohio, and the extreme northeastern portion of Ohio with Ontario and with the rest of Michigan.

(*e*) THE COLDWATER SHALES.

This formation, which has numerous outcrops in Branch and Hillsdale counties, and is well exposed by the Coldwater River, from which I have named it, is a very bulky one, whose thickness geologists did not appreciate until it was revealed by borings. It consists of light colored, greenish or bluish, sometimes darker, shales, growing sandier toward the top and gradually passing into the Marshall. They are in zones more or less calcareous, and may have occasional bands of limestone, although nodules of kidney iron ore, of a brownish color, which in the well-samples appear as brown fragments mixed with the greenish shale, are more common, and are very liable to be mistaken for limestone or even, by drillers, for sandstone.

The Coldwater formation is never less than 600 feet thick, even if we exclude from it the Marshall at the top and the

Berea at the bottom. On account of its gradual transition into the Marshall sandstone Rominger has not separated them, but includes them both as Waverly, nor does he seem to have any definite line to separate the Coldwater shales from the Black shale beneath. That the top may be set at a brine-bearing sandstone, the Marshall, we have already seen. The Berea, the brine-bearing sandstone of Sand Beach, White Rock, Port Austin and Oscoda, which was long ago recognized by Garrigues as an independent horizon, furnishes an appropriate base, of which we shall treat in its place.

The succession of beds between these two horizons is in general quite monotonous. Traces of fossils are rarely if ever discernible in borings, but this may be due to the fact that the rock is very soft and friable, and so crumbles that the fossils are obliterated.

Toward the west and northwest this formation undergoes a change, which makes its lower boundary much less distinct. We find no distinct sandstone at the base, but at two horizons, one about 200 or 300 feet, the other about 500 feet, above the bottom of the Black shales we find red shales which represent sandstone, and are somewhat charged with gas, oil or brine, according to circumstances.

(*f*) THE RICHMONDVILLE SANDSTONE.

This formation, which may as well be called Berea, as it is much better developed in Ohio — at least so far as outcrops are concerned — is nevertheless of great practical importance in this state, as it supplies the salt wells of Tawas, Oscoda and of Huron county. It is also reached by deep wells at Bay City and Blackmar. It is thus the *third* salt horizon.

At Muskegon petroleum and gas are said to have been observed at about 500 feet above the bottom of the Black shale. This occurrence, however, is probably in the Coldwater proper, as one marked feature of the Berea is its disappearance toward the west of the state, where another zone some 200 feet above it, grows in importance; north and south the Berea is comparatively uniform. The cause of its origin and greatest development is evidently to be sought in the elevation of the east side of the basin, while the upper horizon may mark a slight elevation of the west side.

In the southeast part of the state it is a coarse, gray sandstone about 100 feet thick, and under Pontiac apparently thicker. It was first (?) recognized by Rominger at Ann Arbor (see Ann Arbor well-record), and according to Wright crops out at Richmondville on Lake Huron. This is the only outcrop recorded in the state that I know of, unless the outcrop at Brown's Station mentioned by Rominger* be such.

This is the horizon of one of the Pennsylvania oil sands, and, since at different points in Michigan, it is overlain and underlain by bituminous shale, it would surely be an oil or gas producer, if the right structure of upward flexures for accumulators or reservoirs could be found. As we have said, our records are too imperfect to enable us to determine this point with absolute certainty, but the sections suggest as favorable for experiment, a region near Tawas, one between Caseville and Romeo, and one southwest from Saginaw.

Small gas reservoirs, as previously mentioned, are sometimes formed where the line of outcrop of the formation is covered with glacial clay.

Along the west coast the red shale that marks the place of the Berea, is probably either the underlying Bedford shale, which is often reported red in northern Ohio, or the overlying formation stained this color by chemical action. Red shales are often associated with brines.

The Richmondville brine is at the greater depths, *e. g.*, Port Austin and Oscoda, strong and rich in $(Ca, Mg)(Cl, Br)_2$, their ratio to Na Cl being about 1:3. This brine nearer the outcrop at Sand Beach and White Rock is on the other hand exceptionally free from earthy chlorides, and forms an excellent salt brine.

(*g*) ST. CLAIR SHALES.

This group represents one of the most characteristic and most widespread formations of the Mississippi Valley.

The name Huron shale has often been applied to the same series of rocks, but, as the table shows, was used by Winchell in a much broader sense. The name Ohio shale also covers

* Geol. Survey of Mich. III, 83.

pretty much the same ground.* The group consists of a series of dark shales growing darker and more bituminous toward the bottom. The bottom layers generally burn with an aromatic smoke. Pyrite occurs and readily decomposes, frequently yielding sulphates of a puckery taste, like that of alum, and sour smell. This group is widespread not only within but without the state.

On the shore of Grand Traverse Bay and on Sulphur Island, in Thunder Bay, lying under the surface drift deposits of St. Clair County and River, and pierced by many borings there and all over the southern half of the state, it is easily recognizable and tolerably constant everywhere, although, as Canfield and Wheeler's boring at Manistee shows, it appears to be less black and bituminous towards the northwest, in which region also the Berea shale is absent. It seems as if the conditions that attended the immense luxuriance of vegetable matter which characterizes this formation began to prevail over the whole state at the same time, but lingered much longer in the southern part of the state, even till after the epoch marked by the Berea sandstone, and produced the black Berea shale, while in the northern part said conditions were relatively transitory, so that both the underlying and overlying shales gained at the expense of the bituminous. This formation, with the bituminous matter in it, is one of the great sources of gas and oil, which, if conditions are favorable, may accumulate in beds overlying and underlying it, and if the outcrop is covered with impervious clay, oil and gas may accumulate there, producing shallow wells. I copy from Mr. Wright's notes some entertaining accounts of the behavior of such gas wells near the St. Clair River.

On W. H. Stevens's farm one well was bored 250 feet deep, when a large flow of gas was struck. Mr. Stevens noticed something queer about the smell of the well, though he did not suspect that there was gas, as he was looking for water. As he struck a match to light a cigar he was immediately surrounded by flames. The workmen ran away and went into a barn. The gas from the well taking fire began to blow out sand and

* Brumell, Bull. G. S. Am., 1893, IV, 227, calls them Portage. This paper gives valuable details as to wells in Ontario, and announces a forthcoming publication of the Canada Survey, *q. v.* It has been published since this report was written. It contains descriptions of wells and formations harmonizing with ours from the Devonian down.

boulders, some of the latter as large as a man's two fists. As they came dashing through the roof of the barn they caused the men to leave it at once.

The stream of mud, sand, water and gas shot upward for a long distance, the water from 50 to 100 feet, where the gas seemed to separate and ignite in a solid column 30 to 40 feet in diameter, reaching upward for a long distance. A newspaper could be read a mile away even on a dark night.

After the boulders ceased to blow out, the men succeeded in driving a plug into the "casing pipe." On the end of a casing pipe was a T with a cock on the horizontal branch. After the vertical outlet was securely closed they opened this cock and permitted the gas to escape from the horizontal pipe and lighted it again. The flame shot out 200 feet, passing over the railroad track. In the evening the train came along and whistled "down brakes," and did not care to proceed until Mr. Stevens and the train men had walked along the track under the flame to see that it was perfectly safe. In the spring of 1885 the gas was shut off and securely fastened for fear that it might burn everything during the dry season.

Antoine Halin had a farm two and a half miles west of Marine City, and in 1877 or 1878 he struck gas, which did not smell of sulphuretted hydrogen, in a hole 130 feet deep. It blew with great force and formed a cavity 15 feet across, but after several weeks gradually weakened, and, though still yielding a little gas, is used as a fresh water well. The gas came from between the rock and the clay and blew out one stone eight inches in diameter, and made a pile of sand three feet deep for 20 feet around.

He burned it in his house for three or four years, although when one rock came through the roof of his house he was very much frightened and thought the devil was after him, and would have taken a very small price for his farm. The ground trembled for some distance around and the roar could be heard for two miles.

So also four and a half miles west of Marine City, the same distance south of Port Huron, near Swan Creek, and in other places in the neighborhood, wells down to the rock have furnished gaseous fuel for some years.

Another similar well is at Norris, near Detroit.

(*h*) THE TRAVERSE GROUP.

This group of rocks may be said to form the transition between the St. Clair and the underlying limestone. The change from the black bituminous shales is generally well marked, especially as the upper part of the formation is more calcareous than the lower. Very frequently on striking through into this formation a flow of highly mineralized water is struck, which is too impure for a salt brine. A more markedly pervious horizon is at the base of the group. Lithologically the formation may, in fact, be considered very well marked and consists of bluish calcareous shales and limestones or dolomites, which lie below black bituminous shales and above a yellowish cherty limestone. While the formation as thus defined can be traced all over the state, it varies enormously in thickness and is very possibly not everywhere equivalent in time. It is perfectly conceivable that the conditions producing this group lasted longer in the north than in the south and that the black shale formation came in later. Such reasons make a local name preferable to that of Hamilton. Winchell used the name Little Traverse, but it seems to me that the prefix "Little" can be dropped, inasmuch as the outcrops of both the Little Traverse and the Grand Traverse, the names applied by the early voyagers to the short-cuts across the mouths of the two bays which indent the northwest coast of the peninsula, belong to this group. Its outcrops are unknown in the southern part of the state, so that Rominger on his map entirely omits it there. N. H. Winchell, in the Proc. of the Am. Assoc. for the Adv. of Science* gives an account of the different views as to the boundaries of the formations in that region.

We find no difficulty in recognizing in the well-borings, at least 80 feet of this group as defined above, and by the time we have got as far north as the St. Clair River we find it has thickened to over 300 feet and is subdivided as follows:

2 feet hard pyritiferous argillaceous limestone.
12 feet shale, "soapstone."
80 feet limestones, "top limestone," often gaseous.
150 feet shale, "top soapstone."
4 feet limestone, "middle limestone."

* 1875, II. 57.

65 feet shale, "lower soapstone."

Beneath the latter are light-colored limestones yielding gas.

The "middle" limestone is not always recognized, and the shales are calcareous, so that we may consider them as alternating calcareous shales and argillaceous marls or limestones. The 14 feet of transition beds on top often seem also either to have been overlooked or to be absent, but the division into a top of limestone and a bottom of shale we can trace throughout the state.

By the time we get as far north as Alpena, the formation appears to be nearly 600 feet thick.

This formation gives a case where, according to the accounts quoted by N. H. Winchell, hereinbefore mentioned, the life of the Hamilton period begins its continuous existence before the general conditions of the Corniferous time are finally routed.

(*i*) THE DUNDEE LIMESTONE.

This name is nearly equivalent to Corniferous or Upper Helderberg. Lithologically the upper limit of the formation is one of the sharpest lines we have, separating a great series of bluish grey or black, largely argillaceous rocks, from a great series of buff, yellow or almost white, largely calcareous ones. It probably marks some geographical change from a dry climate to a wet one and from a sea of clear water to one more or less tinged with mud and floating algæ. The paleontologists, however, as may be seen by N. H. Winchell's paper already referred to, are not agreed as to this upper limit and, as we shall see in a moment, there is a very serious difficulty in fixing its lower limit. We therefore prefer to take a local name, defining it as extending down from the bluish beds of the Hamilton so long as the formation continues to be limestone, stopping with the appearance of dolomite or of gypsiferous shales.

As thus defined, it is widespead, easy to recognize, and quite uniform in thickness and character. Its thickness remains not far from 100 feet, running up to 160 feet.

It is generally very light-colored, yellowish, effervesces very briskly in acid, and leaves a harsh, cherty residue. It is almost always saturated with a strong but impure brine. On penetrating it from the overlying Hamilton shales we encounter frequently oil or gas. It is supposed to yield the oil at Petrolea, Canada, and yields oil in Michigan wherever we find the proper structural conditions. In spite of the strength of the brine (*e. g.* at Charlotte it has a Sp. Wt. of 1.198) it is also so impure that in the presence of so many better ones, it has no commercial importance as a source of salt, but has importance from a medical standpoint, and as a source of chemical industries.

This formation is well known in the outcrop, not only in the Mason Creek quarries and elsewhere in Monroe County, but also skirting the northern end of the Lower Peninsula to Mackinaw City.

Winchell has distinguished an upper oölitic and a lower agatiferous and brecciated part, but this division is not marked in the borings. Winchell has also been corrected by Rominger in the assumption that this group appears in the extreme southwest part of the state, and the borings at Niles and at South Bend, Ind., show that this correction is just. Fragments of fossil brachiopods are common in samples from this formation (See Allegan well), and the samples are more characteristic than those from any other horizon except possibly the Black shale.

The line between this formation and the one below it, being one between limestone and dolomite, can be ascertained only by the use of acid. Hence it is commonly overlooked by drillers and cannot be determined in wells from which we have no samples. But it is very often marked in outcrop by a brecciated or conglomeratic zone. Generally we reach dolomite before the formation becomes gypsiferous, but, as in Morley's well at Marine City, and perhaps at Charlotte, this does not seem to be always the case. We may have gypsiferous limestones. In such a case to connect the gypsum is about as justifiable as to connect the tops of the dolomites.

(*j*) THE MONROE BEDS.

This name may well be taken to represent the oldest beds that come to the surface in the Lower Peninsula. Not more than 100 or 200 feet of these beds are exposed at the surface, but borings reveal a thickness of even more than 1,200 feet, which

we are not yet able to subdivide. It may be defined lithologically as extending from the limestones of the overlying Dundee down to the lowest gypsiferous beds, and to consist mainly of buff dolomites and of calcareous and argillaceous marls, associated with anhydrite and rock salt. Both of the latter are white when pure.

An interesting feature is the intercalation, in the upper part of this formation, both at Goderich and at Monroe, of a group of beds which lithologically and, according to Hunt, in fossils also, resemble group (*i*)—the Corniferous.

The period of the Monroe beds is that of the Salina and Lower Helderberg. At that time Michigan was covered by an excessively salt sea which stretched from Wisconsin to New York, was bounded by a continent on the north and east, on the west by low land in Wisconsin (the edge of the Helderberg is found barely extending to just north of Milwaukee), and on the south by a great bar, or reef, or flat in Ohio, which seems to have been just awash. This is indicated by the prevalence in the Ohio Helderberg, not only of ripple-marks, but also of mud cracks and of brecciated and conglomeratic layers. If we imagine tides like those of the Bay of Fundy rushing over this flat, producing this breccia and conglomerate and bringing fresh supplies of water to the enclosed sea, and furthermore that the sea was exposed to a hot sun and received but little accession of fresh water from rivers—this latter is shown to be true by the scarcity of mud and sand—we have the conditions of the Helderberg or Monroe deposits, conditions which are evidently favorable to the formation of a sea charged with salts.

The bed or beds of sand suitable for glass-making, already mentioned, seem sometimes to be derived as a residue from the dissolution of a siliceous dolomite. This sand shows by the frequency of perfect minute double ended crystals of quartz that recrystallization has gone on to a great extent. These sands mark the course of currents and perhaps also the result of rehandling and recrystallization of flint derived from siliceous organisms.

If a line be drawn, leaving Muskegon and Wyandotte on its northeast side, Monroe and Kalamazoo on the southwest, we may say that south of this line no rock salt has been discovered in this formation, although concentration proceeded far enough to lead to the deposition of sulphate of lime and the concentration of brines. This region then belongs with Ohio. But north of this line it is probable that this formation yields rock salt almost universally. The thickness of rock salt at Wyandotte and along the St. Clair River is over a hundred feet, and at Royal Oak it appears to be over a thousand.

These figures need excite no incredulity, as there are vastly thicker deposits in Germany. They only excite the query whether somewhere there may be found deposits of those salts which, being most soluble, are latest to crystallize, like those deposits which have made Stassfurt the storehouse of the world's chemical industries. Such analyses as those of Sand Beach indicate a concentration of sea water nearly to the point of precipitation of the Stassfurt salts. Such deposits, if they occurred, would be expected in the upper part of the formation.

These salt deposits should rise again proceeding to the north, and, in fact, just north of the Straits of Mackinac, gypsum beds do outcrop, while at St. Ignace a thin bed of salt is reported only 400 feet below the surface. At Alpena they are about 1,200 feet below the surface. Near Cheboygan they should be sooner reached. The salt industry will doubtless, in time, work north.

The upper beds outcropping in Monroe county are ash-colored and brecciated in some places, marked with acicular crystals (gypsum), which readily weather out and leave cavities.

Thick as this formation is, we cannot sharply subdivide it, although, as I have said, it doubtless includes the series called Salina in New York, as well as the Helderberg. However, in the section between Monroe and Goderich we may perhaps divide it as follows, in descending order:

At the top a series of dolomites or gypseous marls, marking a time of desiccation, underlain by limestone frequently passing into a calcareous sandstone; beneath this sandstone some more beds, gypseous or even salty, marking a second time of desiccation, and after two hundred feet or more of somewhat gypsiferous dolomites, a rapid succession of thick salt beds, marking the first and greatest period of desiccation. The boundary line between this formation and the Niagara underlying it is far from well marked.

(*k*) NIAGARA AND CLINTON.

These formations are struck in well borings only at the extreme south and north of the district under consideration. The most characteristic part probably belongs to the Guelph formation, being a dolomite or dolomitic limestone, very fine-grained and very light colored. In fact the powder is almost white. The description of this formation would answer well to that given by Orton*, and, in accord with what he says of the change in passing from southern to northern Ohio, we are not usually able to distinguish between the lower part of the Niagara limestone and the Niagara shale. The latter shale, however, we identify at Wyandotte. Generally toward the bottom of the series the limestones become more ferruginous. (I may remark just here that from all the samples of the borings the magnet will extract at least a small quantity of black magnetic oxide of iron which is, I imagine, derived from the drill.)

From the horizon just mentioned we have "red rock" at Wyandotte, but at Monroe it is very indistinct and at South Bend, Indiana, it is no plainer.

This formation is at the bottom of and marks the beginning of a great period of limestones and dolomites, formed in an era when the waters of the sea were clear and deposited but little detrital matter. Very possibly there was then a dry climate, for this would not only check erosion on adjacent land but assist in the evaporation necessary to produce those beds of salt and gypsum which mark the Helderberg. There seems to be a certain symmetry of arrangement, with this series of salt and gypsum as a center, *i. e.*, dolomites above and below, next to them limestones, then shales and black shales, which may indicate that salt and gypsum represent the culmination or maximum in some great variation either in climate or in geographical conditions. The evidence points rather to a steady progression in geographic conditions, and this renders the theory of an epoch of dryness at least plausible. The facts to which we have called attention are, of course, practically the same as some from which Newberry derived his conception of cycles of sedimentation.

While the top of the Clinton and Niagara is ill defined, the bottom is well defined. Only at Wyandotte does the drillers' log

*Geol. Ohio, VI. 13-15.

seem to give us alternations between this formation and that below it—the Medina.

(*l*) MEDINA SHALE.

This formation is grouped generally and by paleontologists with the formation immediately above it. In our state both lithologically and in the drillers' records, it is quite as likely to go with those below it. It is really a transition bed. Its red color and ferruginous nature link it with the beds above, its argillaceous character with those below. We know that it occurs farther east, in New York, as a sandstone, and we compare it with the Berea, which in the eastern part of the state is also a sandstone, but further west is represented by a red shale.

In northwestern Ohio, 50 to 100 feet of it are reported, and it continues north unchanged, as a series of red and green shales, as far as Monroe. From Wyandotte we have only the drillers' record, which is not to be safely interpreted.

(*m*) HUDSON RIVER SHALE.

When once we have fairly pierced the shales of the Lower Silurian, the color of the formation changes to the more usual one of green and bluish gray. The shales are more or less dolomitic or calcareous. After descending three or four hundred feet they become darker, and we may consider that they are passing into the next group.

(*n*) UTICA SHALE.

This is brown or black and is not unlike the St. Clair shale. It is thought to be one of the great oil and gas producers of adjacent states; the product collects on the under side (?).

In this state, however, the formation lies excessively deep, and has been reached but once in the Lower Peninsula. Unless the signs of a favorable geological structure should be plain, the large cost of exploring through it to the Trenton beneath would not be worth while. One or two borings sunk in the north part of the state to see how deep it really lies, would, however, be of great scientific interest.

(*o*) TRENTON LIMESTONE.

This formation reached in borings at Monroe and South Bend appears as in Ohio, and is really a dolomite; it is buff, shows

traces of gas, and is charged with brine. It is the great oil-bearing and gas-bearing stratum of Ohio; but even there it does not produce them unless the other conditions are favorable. It is practically unexplored in this state, and there is little encouragement in attempting to pierce to the enormous depth necessary to reach it in the only places where there appears as yet any hope of finding the requisite structure for the collection of gas and oil reservoirs.

ECONOMIC PRODUCTS.

§ 2. Having thus run over the different formations, it seems worth while to make some general remarks about the valuable products thus disclosed. Building stones will not enter into consideration, because they can be worked to advantage only from the surface, and require large samples to determine their qualities.

(*a*) Coal also must lie reasonably near the surface to be available, and indeed in our state it lies only too near. By reference to the map it will be seen that there is a considerable area of Coal Measures in the state, not all of which can, however, be expected to produce coal in paying quantities; much of it is, as yet, entirely unexplored. The seams of coal have never proven much over four feet thick, yet there is enough coal in the state materially to regulate the prices set by outside corporations. It is all soft bituminous, it need not be expected below the first two or three hundred feet of rock, and is apparently more liable to "wants" than to faults. That is to say, if a coal seam fails at one point it is more liable to be found at about the same level on the other side of a channel filled with sandstone, than at some higher or lower level.

(*b*) Plaster has for a long time been a staple article of production in Michigan. Our records show that there is enough to last for a long time. Between Grand Rapids and Alabaster Point there is a strip of country that can furnish supplies of it for ages. Not only that, but about St. Ignace another set of beds come to the surface that underlie the whole Lower Peninsula, are in many places very thick, and can be worked whenever and wherever the cost of sinking to them is not too great. At great depths wells show the plaster to be in the form of anhydrite. It is not absolutely settled whether this is formed by precipitation under pressure, or by exposure to heat.*

(*c*) The mineral waters and sanatoria of Lower Michigan, while not perhaps world-wide in their reputation, have, some of them, a more than local reputation. Many of these depend not on real springs, but on wells or artesian borings. Quite a number of analyses have been collected by Dr. Albert C. Peale.† We can easily divide them into three groups, with one or two apparent exceptions.

The first group contain free H_2S, are the "sulphur" springs, and draw their water from below the St. Clair black shales, probably in most cases from the upper Helderberg or Dundee, which almost always yields mineralized water very freely. Analyses of such water show, beside the free sulphuretted hydrogen, some salt, the other chlorides and the bromides in very small quantities, and the sulphates predominating over the carbonates. In this group are the Alpena Magnetic, the Ypsilanti, the Mt. Clemens, and the Wyandotte wells, and the sulphur springs in Ash township, in Exeter township, near La Salle, Monroe and Raisinville Monroe county, and in Brownstown township, and at Dearborn, Dundee, and Gibraltar, in Wayne county, and also at St. Clair. These, as we see, all lie on the margin of the basin. The Sand Beach deep well belongs in this group, but is unique in its large yield of KCl and $Mg\,Br_2$.

The second group contain CO_2, if any gas, and little else beside carbonates; they are, in fact, common hard waters. They occur mainly within the coal basin. Such are the springs at Hubbardston, Leslie, Otsego, Owosso, St. Louis, and Bay Port,‡ and Warner's spring at Albion.

Such wells will be classed as carbonated, chalybeate or calcic.

The third group consist of more or less impure brines, containing mainly or largely sulphates or chlorides. This group are largely wells, and lie nearer the center of the basin than the first group.

* See Neues Jahrbuch, für Geologie, 1887, II. p. 292.

† Lists and Analyses of the Mineral Springs of the United States, 1886. Bulletin No. 32 of the U. S. Geol. Survey, pp. 145 to 149.

‡ Analysis by R. C. Kedzie, per imp. gall. = 70,000 grains:

$Ca\,CO_3$	10.36	
$Mg\,CO_3$	1.14	
$Na\,Cl$	.50	
Total Solids	12.00	
H_2O	99.98	per cent.

Their composition varies a good deal, according as chlorides of sodium, potash, magnesium or calcium, or the sulphates of calcium or magnesium predominate. In this group belong the wells at Eaton Rapids, at Fruitport, at Lansing, at Midland, at Spring Lake, and Butterworth's spring at Grand Rapids.

Many of the waters of this last group might be used for the manufacture of salt (although they are rather impure for this purpose), and so they lead naturally to the consideration of the most important geological product of the Lower Peninsula.

(*d*) Some kind of a brine commercially valuable for its salt is found in every porous bed which we strike at a depth great enough to prevent its being leached out by descending currents, notably in the Parma sandstone at the base of the Coal Measures, in the Marshall, in the Richmondville, or Berea, and in the Salina. The quality of the brine is different for the same horizon at different places, yet not entirely without law, as we shall endeavor to show.

In the first place the slow leaching out, due to descending water, will tend to make the rock near the outcrop less salty. This water will not go very far, however, if there is no place for it to go, to produce a circulation. As Michigan is a comparatively undisturbed basin, this action has not gone far, and at low points in the outcrop of the basin salt springs may be found.

Another cause for the different composition of brines may be found in the following considerations. A column of sea water will not have the same amount of salts in it at all parts. This is true of the sea itself. There will be a tendency for the salts to be more concentrated in the lower part. Not only that, but the percentages of the various salts will not be in the same ratio, the heavier salt having a tendency to gather at the bottom, although the actual amount present has a modifying influence. Now, it seems probable that the same action will go on slowly in a porous bed of brine-bearing sandstone, so that we shall get the stronger and more impure brines from the deeper parts of the basin. If we look at the records of White Rock, of the upper horizon at Sand Beach, and of Port Austin, as given by Garrigues*, we shall see a steady increase in the ratio of $Mg\,Cl_2$ to $Na\,Cl$, with the depth of the Richmondville. So, too, East Tawas and Oscoda, the lower horizon of Sand Beach, and the St. Clair wells, show

* Geol. Survey of Mich. III, 183, 184.

the same thing. If this is true, the brines richest in bromides would be found near the center of the basin. Another thing that may affect the brines is the original composition of the sea. It is easy to perceive, for example, that inasmuch as gypsum is first precipitated, a sea which has long been depositing gypsum beds, but never got so far concentrated as to throw down its salt, will have less $CaSO_4$ than usual. The beds in which the gypsum was deposited will have an excess, and those above will have a deficiency, of $CaSO_4$.

Around Bay City the brines from the Marshall formation show less gypsum than those above, from the gypsiferous Subcarboniferous, as Garrigues long ago remarked. Undoubtedly, however, the best brines come from beds of rock salt. Such rock salt brines are furnished by the deep wells of the St. Clair district, of Alpena, Manistee,* Ludington, and the northwest coast. In pumping all such brines, care should be taken either not to bore down into the bed of gypsum, that always lies underneath, or to stop off the gypsum, as well as to stop off any impure brines that come from higher levels. Salt beds will probably be found by any borings north of a line from Wyandotte to Muskegon.

(*e*) As we have already noticed, the brines of our wells and mineral springs contain a good deal beside pure sodic chloride, and the mother liquor left after the precipitation of the salt might find a variety of uses, if it were economical to separate the different salts. The only product which it has been found worth while to save hitherto is the bromine. As this sells for 25 cents to 35 cents a pound, it has considerable value. Bromine and bromides are heavy, and accordingly we expect to find them in the center of the basin most richly. We are not surprised then to find that Midland is the chief seat of the industry. Two new wells have just been put down solely for the bromine. Bromine has also been manufactured in East Tawas. The bromine at Midland is derived from the Marshall group, which, as we have already noted, is rich in $MgCl_2$, with which the $MgBr_2$ would be naturally associated. I append an extract with an analysis from the Tenth

[*The following is an analysis of the Canfield and Wheeler brine, by Albert H. Prescott, showing that it is an excellent brine for salt making; Sp. Gr. at 60° F., 1.20054]:

H_2O	73.80
$CaSO_4$	0.4395
$(Ca, Mg)Cl_2$	0.3449
Total solids, rest mainly NaCl	26.20
	100.00

Census Report*. As regards the East Tawas works, we have no details. The other waste chlorides have uses as disinfectants, as bases for chemical and pharmaceutical industries, as fertilizers and in the various uses mentioned by Garrigues.† I have already suggested the possibility of finding deposits of these more soluble sea salts.

(*f*) Oil has been much sought for, but as yet with no great success. The difficulty lies rather in the structure, than in the nature, of the rocks. To be sure the Trenton, the great oil- and gas-bearing horizon of Ohio, lies buried so deeply under most of Michigan that it is hardly at all explored, only a well or two in the extreme south of the state having reached it. Yet the horizon of the Dundee or Upper Helderberg is more accessible and has been reached all over the state. Now this is the oil-rock of the (Petrolea) Canada oilfield, and almost invariably we encounter traces of gas and oil in it in this state. So, too, in Pennsylvania the Subcarboniferous has several oil sands, and in this state traces of oil and sand are met with in corresponding levels. The real difficulty seems to be that oil and gas will gradually work their way out to the outcrop and escape, and not collect in any quantity, unless there are little folds or at least terraces in the porous strata, in the top of which they may collect. These do not need to be very prominent, as is shown by the way the gas occurs in Ohio.

Now, the general structure of the Lower Peninsula being that of a basin, we can expect oil or gas only where there is some minor undulation, enough to overcome the general dip. Are there any such? I cannot say positively, but from the best evidence before

*Vol. II, p. 22. Rowland on the manufacture of chemical products and salt. Samples taken in 1880, from Midland, Michigan, and analyzed by Mr. Ayers, at the university of Michigan, resulted as follows (specific gravity, 1.2557):

	No. 1 Per cent.	No. 2. Per cent.
Sodium chloride	5.5754	6.0801
Calcium chloride	14.3574	14.5859
Magnesium chloride	3.9263	3.4019
Magnesium bromide	4.8356	4 8356
Calcium sulphate	0 0160	0.0160
Water	63.3941	63 3941
Total	92 1048	92 3136

At Pomeroy, Ohio, about one ounce of bromine is obtained from a gallon of bittern, or one pound for every two barrels of salt made. The salt brines of the United State are richer in bromine than those of any other part of the known world, and now furnish large quantities for exportation. Home competition has lowered the price until the profits of the business have been reduced to a very small margin. Since the census year the manufacture of bromine has been started at Midland, Michigan, with considerable success.

† Geol. Survey of Mich., III, 216.

me, not having been on the ground, there appear to be minor flexures running south from Point Aux Barques and about Tawas City, and also in the center of the basin. To reach the latter would require the deepest wells, and on the whole the anticlinal indicated just west of Clifford appears to me to be the most favorable position for experiment. It is known that the gypsum and salt deposits are very irregular and it is not impossible that underlying them in the northern part of the state may be pockets of gas or oil. In any event, in view of the fact that heavy brines are so frequently to be encountered, it is necessary that they should be cased out or they will drown out lower seams of lighter material.

(*g*) Almost the same remarks that apply to oil apply to gas, except that it is worth noting how often gas collects in pockets under the drift along the outcrop of the Black shale.

Such wells, not wasted, may last for quite a while and pay for the labor of piping them. They will of course furnish only a house or two with light.

I wish to emphasize the fact that with regard to gas and oil wells, the occurrence of any particular bed is of less importance than the structure of the beds. There are many horizons in the paleozoic rocks of this and of adjacent states and of Ontario that yield traces of oil and gas, and the horizon that in one region is very productive is in another barren, as is also noted by Brumell.*

§ 3. The State Geological Survey is anxious to secure samples of all well-borings, and for this purpose will furnish the necessary material in the shape of bottles, boxes, corks, printed blanks, etc., for the preservation of such samples and their records, and in return for samples sent to it will furnish a report on their character. In order to help improve the records of the drillers and to enable the latter to keep themselves posted, we append a few hints on the determination of samples from deep borings, hoping, however, that this will not lead drillers to neglect correspondence with us.

(*a*) The tests suggested are the simplest possible and require the use of material obtainable anywhere, namely:

A candle or lamp;

Some strips of glass about an inch wide and three or four

*Bull. G. S. A. 1893, IV, 234, et passim.

inches long, such as are used by doctors to lay objects under the microscope; or watch-glasses will do;

Acid: Citric acid, the crystals of which may be carried around dry and a small quantity dissolved when needed, will be very convenient; dilute muriatic acid, or strong vinegar will do;

A pocket lens.

(*b*) The more important substances to be recognized are:

Silica, SiO_2, in the form of quartz-sand or of chert. Chert is a translucent, sometimes impure mixture of chalcedony or opal, and of quartz, of organic or of chemical origin. A rock composed mainly of quartz-sand is called sandstone or freestone. If a rock contains merely a little sand it is called arenaceous. A rock containing chert is called cherty or corniferous.*

Carbonates, of lime, magnesia, or iron (Ca, Mg, Fe), CO_3. Rocks composed of these are called, in general, limestones. If they contain merely a small amount of carbonates they are said to be calcareous or calciferous.* If the limestone contains magnesia it is said to be magnesian, or dolomitic, and when it consits of about half carbonate of magnesia (21.7% MgO) it is called dolomite. A certain amount of iron carbonate often occurs mixed with the other carbonates and is not mentioned, but it also occurs in bands or rounded masses of kidney iron ore in many shale formations.

Clay, a chemical and extremely fine mechanical mixture of silica with alumina and water, is the main material of shales. When there is only a small amount of clay in rocks, they are said to be argillaceous.

Coal, in Michigan always more or less bituminous, is mainly carbon. As the per cent of impurity, or ash, increases it is called coaly or carbonaceous, then bituminous and lastly black shale.

Salt, Na Cl, either massive as rock salt, or as brine; has with it,

Gypsum, hydrous sulphate of lime ($Ca\,S\,O_4.\,2$ aq.), or—

Anhydrite, anhydrous sulphate of lime ($Ca\,S\,O_4$), *i. e.*, "plaster." These are not commonly distinguished from each other, and beds containing them are known as gypseous or gypsiferous.

Limonite, or yellow ochre, the hydrous oxide of iron ($2\,Fe_2\,O_3$. 3 aq.);

Hematite, the red oxide of iron ($Fe_2\,O_3$). When rocks contain a good deal of these they are said to be ferruginous.

*The words corniferous and calciferous are, however, usually restricted to particular formations.

Other substances, such as brassy specks of pyrite, shiny scales of mica, etc., do not occur in sufficient abundance to be of importance in naming the samples.

(*c*) TO RECOGNIZE THESE SUBSTANCES IN DRILL BORINGS.

Carbonates—Place a little of the meal from the boring (not more than the end of a toothpick will carry) on the end of one of the glass slips or on a watch-glass, and add a drop of acid. If limestone is present, the acid will fizz and effervesce promptly and freely; but if there is dolomite or siderite, it will not effervesce freely until heated gently. Do not heat too much, or you may mistake boiling for this effervescence, which is due to the giving off of gas (CO_2). This begins at a lower temperature, and continues much longer after the heat is withdrawn. Add acid until no further effervescence is produced and then dry or evaporate gently. The presence of gypsum may usually be detected by the early appearance, near the margin of the drop, long before the drop is dry, of tufts of needle-like crystals. The pocket lens may be needed to see them. When the drop is completely dry there will be a white coating left, from the amount of which the proportion of soluble matter may be estimated. If there is much iron in the rock it will turn yellow, and then red, as the heat is continued. If the rock was originally yellow or red the iron may have been in the form of limonite; otherwise it was probably a carbonate. A residue that cannot be dissolved, if harsh and gritty, harder than a knife, so that if rubbed between two pieces of glass it leaves fine scratches on them, contains either quartz or chert. Under the lens the quartz can commonly be seen to have the form of translucent rounded colorless grains. The chert is generally opaque, white and angular.

Clay is not gritty; it is cloudy, white or gray, soft and opaque, softer even than gypsum, and settles slowly in water.

Bituminous and *coaly shales* smoke and give off an aromatic odor when strongly heated.

Gypsum and *anhydrite*, being only slightly soluble, remain largely undissolved. To distinguish them apart we must have recourse to the microscope or to chemical tests for water. If the meal furnished by the drill is reasonably coarse we can, by the aid of the lens, distinguish the micaceous cleavage of gypsum and anhydrite. They are, however, brittle and not flexible like mica. Anhydrite, unlike gypsum, cannot be scratched by the thumb nail.

The *soluble salts* may be recognized by their taste to one who is familiar with them, *e. g.*, salt, saline; epsom ($Mg\ S\ O_4 .\ 7$ aq.) and other magnesian salts, bitter; glauber salt ($Na\ S\ O_4 .\ 10$ aq.), cool.