REPORT
OF THE
STATE BOARD OF GEOLOGICAL SURVEY
OF MICHIGAN
FOR THE YEAR 1903

BEING THE REPORT OF

ALFRED C. LANE

STATE GEOLOGIST.

BY AUTHORITY

1905.
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FIFTH ANNUAL REPORT
OF THE
STATE GEOLOGIST
ALFRED C. LANE
TO THE
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FOR THE YEAR 1903.

LIMESTONE.

The study of the limestones of the northern part of the Lower Peninsula has been continued by Mr. Grabau, who is preparing a monograph upon them. Over 124 forms of the rich variety of fossils have been figured for reproduction. These studies have great scientific interest, as Michigan lies between and connects the eastern and western, or as Schuchert calls them Cumberland and Dakota Devonian seas.[1] They have also, however, a practical bearing. The limestone itself is of increasing value. It is shipped to Manistique and Gladstone to make acetate of lime; it is largely used in sugar manufacture. It is the raw material now of the Elk Rapids Portland Cement Co. which has recently consolidated with the Bay Shore Lime Co., as well as the Alpena Portland Cement Co. The rock Portland cements, are, I am told by practical engineers, no stronger, but smoother, and able to go farther than the marl cements.

Dr. Grabau writes:—"We still need about as many more illustrations as we have already made, and I trust you can give us an appropriation of $150.00 or $200.00 for this year. I will fully justify the expenditure in the report, when I think that I can easily prove the knowledge of the fossils is absolutely essential for the finding of limestone deposits of economic value and I also think that I can show that by means of fossils we can trace out anticlines in the limestone region, which may lead to the discovery of gas."

The development of the limestone business is illustrated by the Bay Shore Lime Co., recently consolidated with the Elk Rapids Portland Cement Co., concerning which the following facts are given. We have also, through the courtesy of the Elk Rapids Portland Cement Co., copies of analyses of their raw materials, showing their excellent character. The limestone is the Petoskey limestone, and the analyses are essentially similar in character to analyses given in 1901, 1902 reports. The analysis of the coal is given later.

BAY SHORE LIME CO.

"The Bay Shore Lime Co. is a corporation of this state, capitalized for $250,000,—$200,000 common and $50,000 preferred stock. It has been in business for the past 16 years at its present location and has built up a business which for several years past has paid good dividends on the capitalization. Its output of lime for the past ten years has increased from 16,500 to 118,517 barrels per annum, indicating a steady and profitable growth during the panic of 1892 to 1897, when other lime companies did very little. This is accounted for by the high grade of lime made from the rock in their quarries, which seems to be superior in quality and commands a better price than other limes in a great many markets.

[1]Am. Geologist, Sept., 1903, pp. 137 to 156.

"Mr. Sly, the president of the company, makes a sworn statement of their profits for the year 1901, after paying all salaries, repairs, etc., of $28,280.87. With the addition of its present stone-crushing plant, recently built, and two new kilns which are now nearly completed, the earnings of this company will be easily increased to $40,000 per annum, and can be made to exceed that amount by natural growth.

"The property of this company is all located at or near Bay Shore on the Pere Marquette railroad and Little Traverse Bay, seven miles west of Petoskey. They have four (4) large lime-kilns in operation and two building which will make 140 barrels of lime per day each. Their property consists of nearly nine (9) hundred acres of land, more than half of which is underlaid with limestone with a workable depth of from fifteen to sixty (15-60) feet. This is divided into several grades, one for building lime, the others for use in blast furnaces, wood alcohol and beet sugar plants, tanneries, paper mills, for making calcium carbide and Portland cements."

LIMESTONE.

Ig'n loss	49.91
Silica	3.37
Alumina	2.57
Iron oxide	
Lime	51.43
Magnesia	.50
Sulphur anhydride	.60
	100.38

SHALE.

Ig'n loss	17.50
Silica	56.00
Alumina	13.50
Iron oxide	6.50
Lime	2.50
Magnesia	2.00
Sulphur anhydride	.80
	98.80

W. G. BANKS.

"The limestone we use here is located about 21/2 miles south of Petoskey, Mich., on the Pere Marquette R. R.

"The shale is located on Pine lake about 8 miles up from the city of Charlevoix, and comes to us by boat."

The development of the Detroit and Mackinac R. R. from Alpena toward Cheboygan, has opened a number of quarries which are in the same general horizon as Petoskey and Alpena.

Mr. A. N. Clark of the Alma Sugar works has been kind enough to give us results of a number of tests, from which it appears it is possible to get calcium carbonate by the car load with but 2% or 3% of deleterious impurities. He writes, giving analyses below:—

Alma, Mich., Nov. 18, 1903.

We have been using some Onaway limestone here at the factory. Some is good and some is poor. Runs from 90 to 98% $CaCO_3$. Some of it is of a rusty color and contains 6 to 8% sand and iron.

Yours truly,
A. N. CLARK.

PETOSKEY LIMESTONE.

A. N. CLARK, ANALYST.

	March, 1902.	April 28, 1902.[2]	
		Stratum 1.	Stratum 2.
Organic	.62[1]		
Insolubles	.41	1.03	1.21
$Al_2 Fe_2 O_3$	.43- mainly Fe_2	.80	.70
$Ca CO_3$	96.58	83.06	90.62
$Mg CO_3$	2.-	15.11	7.41
$S O_3$	bare trace		
	100.05	99.99	99.94

[1]Hydrocarbon limestone smelling strong of petroleum when struck, has shale like appearance. Fine texture. Small sample sent.
[2]In kegs, two strata.

LIMESTONE NEAR LAKE HURON—NORTH OF ALPENA (NORTHEASTERN MICHIGAN).

	D-1.	E.	A.	D-2.	B.	C.
Insoluble	2.80	1.25	8.60	1.01	1.75	.40
$(O_3 Fe_2 Al_2) O$	.40	.40	1.40			
$Ca CO_3$	96.13	96.47	88.86	94.77	97.70	96.36
$Mg CO_3$	.68	1.60	.38	1.28	.60	3.—
Undetermined and $H_2 O$		.82	.76	2.34		.24
	100.01	100.—	100.—	100.—	100.05	100.—

COMPOSITE SAMPLE OF ALPENA LIMESTONE FROM ALMA SUGAR CO. (AUGUST, 1902.)

Insoluble & $(Fe_2 Al_2)O_3$	1.30	Insoluble and difference	1.—
$Ca CO_3$	97.60[1]	$Ca CO_3$	[1]96.—
$Mg CO_3$	1.09	$Mg CO_3$	3.—
	99.99		100.—

[1]Checked three times volumetrically with permanganate gave 97.06 Ca C O_3 or 97.55. In car No. 146 gave 96.6 Ca CO_3.

SAMPLE OF LIMESTONE FROM ONAWAY.

Organic matter and moisture	1.30
$(Fe_2 Al_2)O_3$	.40
$Ca CO_3$	97.—
$Mg CO_3$	1.70
	100.40

The following analyses also by Mr. H. R, Browne, are of interest, especially the very complete one of the Bellevue quarry in the carboniferous limestone, because this property has recently been purchased by the Burts of Saginaw, for a Portland Cement plant, and it is unusually complete.

BELLEVUE.

Soluble in H Cl:		
$Si O_2$	0.1208	
$Al_2 O_3$	0.1008	
$Fe_2 O_3$	0.2093	
$Fe O$	0.2916=	.4698%
$P_2 O_5$	0.2692	
Mn	0.0449	
Arsenic	trace	
$Ca O$	53.300	
$Mg O$	.483	
$C O_2$	42.15	
$S O_3$	.098	
	97.0676	97.0676
Gangue insoluble in H Cl:		
$Si O_2$ soluble in $Na_2 CO_3$	.354	
Insoluble	1.63	
S as pyrites	.175	
$Al_2 O_3$	.369	
$Ca O$	.021	
Alkalies	.062	
	2.654	2.654
Organic matter	.1334	.1334
		99.8550

Three different beds of the Christiancy quarries in Monroe County show both a high grade and a magnesian limestone.

CHRISTIANCY QUARRIES.

	1	2	3
Insoluble (silica) in H Cl	0.49	0.61	3.31
Iron and alumina oxide	0.13	0.15	0.35
Calcium carbonate	97.59	97.64	77.78
Magnesium carbonate	1.66	1.55	18.48
	99.87	99.85	99.92
Difference (organic, etc.)	.13	.15	.08

Analyses by H. R. Browne.

CORRELATION ACROSS DETROIT RIVER.

INTRODUCTION.

Prof. Sherzer for us, and the Rev. Thomas Nattress of Amherstburg, on the Canadian side, are gathering very interesting information about the limestone along the Detroit river, upon which the various well records which I am able to turn in from my work from time to time, will throw much light.

I quote a letter of much interest from Mr. Nattress. The change of dip noted by Mr. Nattress, may be of importance in collecting oil. The Anderdon quarries near Amherstburg and Sibley quarries near Trenton, both dip southwest and seem to lie on the northeast side of a

synclinal tongue of the Dundee or Corniferous limestone. A fault may bow the southwest side. To the north of them there should accordingly be a subordinate anticlinal or pitching fold, passing through Wyandotte.

St. Andrew's Manse,
Amherstburg, Ontario, Feb., 1903.

Dr. Alfred C. Lane,
State Geologist for Michigan,
Lansing.

Dear Sir:—The accompanying comparative statement of strata in (1) Monroe county, (a) "Monroe," and (b) "Dundee," and (2) Anderdon Tp., Essex county, Ontario, may not be without interest to you. I have a hope it may be of some service in getting at our problem in determining the relationship of said strata. I may say that the elevation of surface of white sand rock, here, is 552.00 above mean tide at New York. Mr. Dixon and I will ascertain the elevations of the successive outcrops of the Anderdon quarries. * * *

I believe I have found the point where the variation of dip begins. All I shall say just now is that I am obliged to admit an error in my former assertion that the sandstone (which is indeed "south of") is "superincumbent upon the Corniferous described in my paper." It is *not superincumbent*. This I now know. When, however, you become acquainted with the locality of the several outcrops, and note the very short distance in which the change of dip takes place, you will not be much surprised at my mistake.

There still remains to be explained the presence of the gray dolomite-superincumbent (in the Anderdon quarry) upon the Dundee (Corniferous) limestone. This gray rock is in no way to be mistaken for Hamilton.

Very truly yours,
THOMAS NATTRESS.

[1]Tests made by Mr. Nattress and myself in 1904, (letter of July 13), prove this *not* to be dolomite, though not so pure calcium carbonate as layers below. I expect to have the matter treated more fully in the Wayne county report.

A COMPARISON OF THE FORMATIONS IN MONROE COUNTY, MICHIGAN, AND ANDERDON TOWNSHIP, ESSEX COUNTY, ONTARIO.

	I. The Monroe beds:[1] (Page)	II. The Dundee: (Page)	III. Anderdon:
Above the Sylvania.	(1) Dip. N. W. to N. (30 or 40 feet per mile.) ... 45 —W. 25° S. ("Water collects at S. W. corner.") ... 79 W. by S. ... 82 —"A fold * * * a high local dip" ... 87	(1) "General dip to the N. W." ... 37 —"Christiancy quarry * * * 24 ft. per mile * * * W. N. W." 37 —"Pulver quarry * * * 119 to the mile" ... 37	(1) Dip. "The approximate dip is ⅓ of an inch to the foot, S. by W."
Below the Sylvania.	—"Stripping increases to S. W." ... 92 —"Rock dips in four directions, from 2° to 5°". 95 —N. 61° W. ... 96		
Above the Sylvania.	2. Color: —"Gray to drab" ... 46 —"Where weathered * * * of almost a chalky whiteness" ... 46 —"A light colored, finely laminated" ... 79 —"A drab and brown dol." ... 80 —"A firm grained drab dol., smooth" ... 81 —"Buffish gray" ... 82 —"Dark when damp, but drying to a light gray" 86 —"Buff" ... 87	2. Color: "Light gray to brown * * * running into blue" ... 39 Cf. Orton, Ohio, "Is light colored, gray, drab and brown." ... 39	2. Color: The only rock that may be described as "drab" here is *not a dolomite*, but the pure limestone, lying between the *gray* rock above and the *brown* dolomite below; unless it be the rock next below the brown.
Below the Sylvania.	—"A light or dark drab dolomite" ... 92 —"A gray or drab dolomite" ... 93 —"A drab dol." * * * "Deep blue" ... 94 —"A gray to creamy white dol." ... 95 —"A light drab dol." ... 95 —"* * * covered with a black carbonaceous deposit" ... 95, 96 —"The rock weathers to a soft mealy substance of a creamy color" ... 97		
	Cf. Above and below Sylvania sandstone. "Bituminous matter is present locally, but does not impregnate the rock as in the case of the Dundee" ... 46 Cf. ... 95, 96	"Most of the beds have a strong oily odor, and semi-fluid bituminous matter frequently collects in the cavities of fossils" ... 39	None of our rock is impregnated with bituminous matter. Semi-fluid bituminous matter does not occur in cavities of fossils. There is a slight odor of oil in brown dol. from bed of river. There are thin layers of black bituminous substance in the same strata, one of them half an inch thick.
Sylvania.	3. Peculiarities: Weathering to a "chalky whiteness" ... 46 —"Thin bedded" ... 47 —"Brecciated beds" ... 47 —"Ripple marks and mud cracks" ... 47 —"Immense concretionary bodies" ... 47	3. Peculiarities: "The upper beds are thin bedded and shattered" ... 39	3. Peculiarities: Some of our chert weathers chalky white,—some of our high grade limestone is thin bedded. Nothing brecciated; unless wavy surface layers of pure limestone. No ripple marks identified; nor mud cracks. No large concretionary bodies. No caverns. No ellipsoidal cavities, except where Favosites hemispherica has decayed away. No stylolites. No concretions observed
Above the Sylvania.	—"In places cavernous" ... 79 —"Ellipsoidal cavities" ... 80 —"Peculiar stylolites" ... 89 —"Ellipsoidal concretions" ... 90 —"Thin wavy carbonaceous films traverse the rocks" ... 94 —"Between the strata are layers of a soft putty-like clay which hardens on exposure". 94	"Seams of clay very frequently separate the layers" ... 39	Similar films observable near the juncture of brown dol. and true limestone (perhaps in both) in Detroit river bed. There is no clay deposit between layers anywhere.
Below the Sylvania.	—"Breccia" ... 95 —"Sink holes * * * with diam. of 6 to 10 ft., * * * produced by solution of the dolomite" ... 114 —"The individual strata have very rough surfaces, covered with black carbonaceous deposit" ... 95, 96 —"Thin bedded fissured dol." ... 96	"A two foot bed of chert at the Sibley quarry" ... 41	—No breccia observed. Sink holes of small size; but in the true limestone (where it is a surface area) and *not in the dolomitic rock*. There are rough surfaces in the true limestone. (Also at certain elevations in the gray rock with black carbonaceous deposit.) —But this is the peculiar formation known as *crystallites*. —There is an apparently thin bed of chert in the brown dolomite (which may be "a fine crystalline massive quartz").
	4. Essential characteristic: The typical dolomite layers show the normal proportions of lime carbonate and magnesian carbonate; from 50 to 55 per cent of the former and 42 to 45 per cent of the latter ingredient ... pp. 46, 82, 83, 86, 87, 92, 95	4. Essential characteristic: —"Essentially a pure limestone" ... 38 —"Carbonate of magnesia * * * may run up to 25 per cent. ... 39 —"A very small amount of iron" ... 39	4. Essential characteristic: —Gray rock $CaCo_3$, $Mg\ CO_3$. 60 983 36 463. —Brown rock 57 28 , 41 15. —Gray rock $Fe_2\ O_3$, $Al_2\ O_3$ = 0.230. —Brown dol. " " = 0.32. Between these is pure limestone.
	5. Crystals: —"Small cavities carry celestite, calcite, and a little native sulphur" ... 80	5. Crystals.	5. Crystals: *In the gray rock*, the characteristic crystal is *dog tooth spar*, small to large in size, and fluor crystals, in cavities: fluorite and *calcite* in light seams. In the brown dol. the characteristic crystals are *Scalenohedra of calcite* (carbonate of lime). Also *Strontianite* and *celestite*. Then there is the stratum of "minute closely cohering grains of quartz," = Sylvania.
	6. Strata: —"Thin bedded" ... 47 —"Strata average eight inches" ... 92 —"Thin bedded fissured dol." ... 96	6. Strata: —"The upper beds are thin bedded and shattered" ... 39 "Deeper layers * * * reaching a thickness of several feet" Cf. Orton, Ohio, "The individual beds may reach a thickness of five feet" 39 —"In the upper division * * * the beds seldom reach one foot in thickness" ... 39	6. Below: Your Dundee limestone corresponds closely with our pure limestone in bedding. —The gray rock beds measure (in descending order) 2,[1] 8, 4, 8 and 10 feet. —The brown dolomite is not thin bedded, though no measurements are to hand.
	7. Fossils: —"A stratum of gasteropod molds and casts". 79 —"Generally quite poor in fossils" ... 222 —"Crinoids, corals and bryozoan remains are found occasionally" * * * "lamellibranchs rarely" ... 222 —Vide ... pp. 223-225 —"Conularia, Tentaculites, Stropheodonta, Orthis * * * Conocardium, Platyceras, and numerous gasteropods, lamellibranchs, trilobites, crinoids, cyathophylloid, and favositoid corals" ... 226	7. Fossils: —See p. 227, Dr. Rominger's list ... 227 —Fenestella, Polypora, Orthoceras, Gomphoceras, Nautilus, etc ... 227	7. Fossils: —See pp. 124, 125 of my paper in 1902 Bureau of Mines Report (Ontario), for fossils in the gray rock. —See pp. 126, 127, b. for fossils of brown dol.

[1]Monroe County Report.

[1]Examination of a fresh break of this ledge after observing the same stratum on Pelee Island indicates thin bedding, not at first evident.

Notes on the Fossils in these Different Beds.

The "stratum of gasteropod moulds and casts" (p. 79) in bed A of the Woolmith quarries, above the Sylvania sandstone, *though differing entirely in color*, would remind one of a stratum of our brown dolomite, exposed in Detroit river bed, as to its gasteropod contents. The "occasionally" (p. 222) and "rarely" with reference to crinoids, bryozoans and lamellibranchs in the Monroe beds, apply here also; but do not apply with reference to our corals, especially in certain strata of the brown dolomite. *Tentaculites*, which you include among the fossils of the Monroe beds, does not occur here at all so far as observed, though it is abundant in the subsequent Hamilton formation, as at Bartlett's Mills and Arkona, Lambton county, Ontario.

Though there is a certain amount of identity between the forms found in the Monroe beds and the strata here, it would not appear to me to be greater than might be looked for from persistence of the fossil forms of one formation in the next later formation.

On the other hand, the Dundee fossils (p. 227) so far as enumerated, correspond very closely with our much longer list from the Anderdon quarries and the Detroit river bed exposures, a list that is made larger still when supplemented, as from "Geology of Canada, 1863," page 378.

But your Dundee is "essentially a pure limestone" (p. 38); whereas our high grade limestone appears to contain very few fossils, save a few cup corals and a few far-spreading Stromatoporoid, the low grade limestone (gray rock) above, and the dolomites below, being the fossil bearing strata.

(Signed) THOMAS NATTEESS.

In the Upper Peninsula, various well records, for which see the paper on Water Supply, have added to our knowledge of the geological column, with its heavy belts of limestone along the Lake Michigan shore. This has been treated in connection with the water supply.

Limestone Mountain, an interesting and isolated group of outcrops of the section up to and including the Niagara,

has recently been made very much more accessible, by the line of the Mineral Range R. R. (D., S. S. & A.), which skirts the foot of it. It is so far from any other limestone, and so near points like Houghton, to which limestone is largely supplied, that I think it worth while to call attention to it. The Survey has done work upon it, which has never been published. This work was done very largely by W. L. Honnold, and a report on the fossils, written by myself over ten years ago, but the railroad and sundry new facts should be incorporated.

It was visited this year by Mr. A. G. Ruthven, who found it quite accessible, bare from recent fires, and with a limestone quarry proposed. Being so far from any other limestone, this might well be profitable, and I trust may be further studied in the near future. But I think it justice to Mr. Honnold that his work be given first, in addition to the fact that it will materially aid the next workers. I myself visited the district in June, 1894, and studied it with L. L. Hubbard and A. E. Seaman, having previously studied the fossils. We also visited other exposures of the limestone in two small hills on Sec. 7, T. 51 N., R. 34 W., which apparently had not been observed by previous geologists. It is not as high. All these hills rise from plains of flat clay apparently not unlike that at Mass City and elsewhere referred to. The plains appear to correspond in level to the towns of Houghton and Hancock, being from 90 to 205 feet above the lake, the level of Upham's Beaver bay beaches. From this general level of about 210 feet, the hills rise often in steep wave cut bluffs, the higher hill on Sec. 7 is about 250 feet above Lake Superior, 852 A. T., the lower limestone thin bedded, the upper with a bird's eye effect, with *Murchisonias*, *Crytodontas*, Rhynchonelloids, bryozoa, and Alveolites.

Limestone Mountain itself is fully 400 feet above Lake Superior, 1,002 A. T., 250 feet above the plains and 150 feet above the highest sandstone outcrop. The lines of wave cutting are at 325 feet, 240 to 270 feet, and at 210 feet I estimate (barometer). In addition to the specimens collected by Honnold and described below, we collected specimens 155067 to 166016, which show Maclurea, Ambonychia, Orthoceras, Murchisonia, Pleurotomaria, etc. 16571 and 16572 represent the Niagara, the remainder being apparently, Trenton. The following is a quotation from letter of W. L. Honnold, dated July 14th, 1894:—

"The principal question to my mind is: Whether the contact exposed is between the limestone, i. e., Calciferous and the L. S. sandstone=Potsdam, or between the Lower Magnesian (=Calciferous) and Madison sandstone. That is whether the Madison sandstone and Mendota limestone exist here. The sandstone I exposed under the limestone compares well with the Madison (better than with the Potsdam) and it may be that if excavations were made further west, the Mendota limestone would be found, and still farther west the Potsdam."

It is clear we have here in a short space, a section from the Niagara limestone down. The Lorraine and Utica shales have not been discovered, however, and the Trenton has not been well differentiated from the Calciferous. It affords most excellent opportunities for careful paleontologic study, which would be of great interest in connecting Minnesota with the east.

In connection with the limestone business, one of the discoveries of most interest to me is that shown by the samples of the Manistique well,[1] of the belts of real limestone, not dolomite, from 80 to 107 feet down, which should be the first rock encountered in a belt passing two or three miles north of town.

So far analyses of Niagara limestone have generally shown dolomite, and the presence of belts of chemically acceptable limestone, would be valuable to the calcium carbide and calcium acetate industries.

[1]See pp. 140 to 141. It may be in this belt that the Osborn caves lie.

CEMENT MATERIAL.

The exhaustion of our timber resources is a present fact to this extent, that for many uses it is already too dear. There is, therefore, a great activity in the development of materials to replace it.

The lime and cement business is, therefore, in a flourishing condition, and we have given some notes about the Bay Shore Lime Co., consolidated with the Elk Rapids Portland Cement Co. We have recently published a report, Volume VIII, on the cement business, and so we have only to add occasional notes as they may develop.

The Michigan Alkali Co., having sold their Bellevue quarry, an analysis of which is elsewhere given, have acquired land around Alpena (see 1901 report), containing limestone. It is probable that salt may also be obtained, thus making an ideal place for soda manufacture. (Alpena News, 5/11/03.)

In Branch county[1] it is suggested that the marl of Marble, Middle, Bartholomew, Wing, Long, and Coldwater lakes may soon be utilized for cement manufacture by draining the same. The Quincy plant is now on Middle lake.

Marl beds are reported on Maple river near Brutus;[2] South Monterey near Allegan,[3] and borings have disclosed it at Saugatuck,[4] and Union Pier. It is probable that most of the lakes along the Lake Michigan shore, may have some marl, but it is doubtful if it is of high quality.

It must not be forgotten, however, that almost all of our surface clays are highly calcareous and worthy the name of marls, according to dictionary definition, though not according to cement factory usage. Bog lime is a much better term for what they call marl. In the clay analyses given later, there can generally be allowed about twice as much limestone flour as there is of calcium magnesium oxides. We see accordingly, that there is often about a fourth calcareous matter in such clays. It is not surprising, therefore, that specimens come in for my judgment, taken for marl. So they are, but not in the

Portland cement man's sense. There are marl beds and calcareous clays near Port Huron.

In regard to the question as to the amount of pyrites permissible in a coal to be used in cement manufacture, we have the following:—

Elk Rapids, Mich., December 15, 1903.

Mr. Alfred C. Lane,
State Geologist,
Lansing, Mich.

Dear Sir:—Replying to yours of the 9th inst. I wish to thank you very kindly for Volume No. 8, which you are sending us, and if there is any charge for it please send me bill and we will remit.

We are pleased to give you the information desired in regard to analysis of coal, and the effect of sulphur and pyrites of iron in the same, upon the clinker. We have found in our practice here that on the average not more than 3/10 of 1% of the total sulphur found in the coal is retained by the clinker. This will vary a good deal according to whether the coal is finely or coarsely ground and whether a large or small amount of air is used in burning. By the use of a large amount of air, we found the pyrites of iron in the sulphur was blown out. We have also found that the use of a shale containing quite a high per cent of pyrites of iron in the form of knobs, after it is incorporated in the slurry and ground, causes us no particular trouble as far as the sulphur is concerned. This resulted because of the fact that the oxidizing in the rotary is such that all the sulphur is driven out or oxidized to a condition which is not harmful.

We found no more sulphur in the clinker made from shale than will be given by the materials themselves, burned with the flame containing no sulphur. Of course, this is accomplished by careful burning and careful grinding of the coal.

Trusting this may be satisfactory, we remain,
Yours very truly.
ELK RAPIDS PORTLAND CEMENT CO.,
F. B. Moore, Sec'y.

[1]Detroit News, 8/23/1903.

[2]Petoskey Democrat, 7/4/1903.

[3]Grand Rapids Herald, 6/27/1903.

[4]Holland Sentinel, 5/9/1903.

Coal Analyses.

SHIPMAN CO.'S COAL (PITTSBURGH NO. 8) OHIO.

Volatile combustible	30.375%
Fixed carbon	46.175
Sulphur	5.09
Ash	18.36
	100%

CAMBRIDGE COAL, OHIO.

Volatile combustible	33.00 %
Fixed carbon	58.00
Sulphur	1.61
	92.61 %

W. C. CLARK CO.'S COAL, PITTSBURGH NO. 8, FROM OHIO.

Volatile combustible	36.455%
Fixed carbon	49.385
Sulphur	3.29
Ash	10.42
	100%

SUNDAY CREEK (WEST VA.) COAL.

Volatile combustible	35.19 %
Fixed carbon	49.55
Sulphur	1.30
Ash	13.96
	100%

WOLVERINE COAL, BAY COUNTY.

May 27, 1904.

Analysis of Wolverine No. 2 coal, by Dickman and Mackenzie, for Wickes Bros. Dried at 212 degrees F. Sample from car load lots.

H_2O	6.76
Volatile comb.	42.67
Fixed comb.	42.01
Ash	8.65
	100.10
Sulphur	3.50

B. T. U. 12,295.

This is the Upper Verne, according to Mr. Cooper.

Analysis of a coal from Bay City, Michigan.

Moisture	5.92
Volatile combustible	37.74
Fixed combustible	36.54
Ash	19.80
Sulphur	8.60

E. D. CAMPBELL.

Sept. 14, 1903

This may be the Lower Verne.

BUILDING AND ROAD MATERIALS.

The lumber supply of Michigan is not only approaching exhaustion, it is exhausted so far as the cheaper uses of wood are concerned. Instead of cedar blocks, plank, and corduroy roads, asphalt block, bithulithic or tar macadam, and macadam roads are coming in; instead of cedar fence posts, cement posts, and for building material instead of wood, brick or clay, sand or cement, concrete blocks, and concrete and steel constructions.

The asphalt block is made of Calumet and Hecla or Tamarack stamp sand, i. e., crushed quartz porphyry or

felsite, cemented by asphalt. The following experiment on a limestone, a trap, and a conglomerate sand asphalt block was made, to show the relative durability.[1]

"The blocks were placed side by side near the periphery of a ten-foot marble rubbing bed, running thirty revolutions per minute. Each block was weighted, so that block and weights combined weighed forty-five pounds. They were all kept on the running bed forty-five minutes, sand and water being freely and properly supplied all the time. The limestone block was worn away one inch on its 4x12 inch face, the trap-rock three-eighths inch, and the conglomerate sand-block one-eighth inch. It is proposed to use the conglomerate sand in the factory mentioned above" (Detroit or Toledo).

The sand is shipped from the waste piles at Torch Lake to the factory at Toledo, and while water transportation is cheap it would seem as though a factory of these blocks could be started to good advantage at Lake Linden. This has been suggested.[2] The raw material could be improved by using the felsites of Mt. Houghton or the Bare Hills region[3] without doubt, which would not be decomposed as the wall rock of the copper lodes. But I do not think the advantage would pay for the cost of crushing.

The pavement of asphalt blocks is used in Pontiac and Ann Arbor and is well spoken of. It is also used in Kalamazoo. Occasional complaints are that the rock is crumbly under changes of temperature. Whether this is due to defects in the manufacture of particular lots I cannot say.

[1]Michigan Engineer, 1899, p. 110.

[2]Portage Lake Mining Gazette, October 22, 1903.

[3]See Vol. VI, Part 2, of Report of Geol. Survey of Michigan.

The "bithulithic" pavement[1] is meeting with much favor. It is essentially a macadam with a patent filler and binder of coal tar origin and bituminous nature. A full account will be found in the 1904 report of the Michigan Engineering Society. It has been used in Saginaw, Port Huron, Mt. Clemens, Bay City, Manistee, Kalamazoo and Pontiac. It should not be laid in cold weather. From the point of view of the economic geologist, the essential points are:

(1.) Like all macadams it must be well underdrained. On till or heavy clay a drainage two feet below the surface of road should be provided, and a bed of gravel or cinder, broken brick or other porous material laid.

The foundation proper is of 1 to 3 inches of broken stone, for which the various limestones of the State will do. The trap of the Upper Peninsula is better, and crushed field stone are usually all right. Layers of finer material should be laid on top, to fill the coarser material and a coat of bituminous cement applied. Then the surface coat of from 13/4 inch to 1-10 inch material mixed with cement is applied. Possibly stamp sand of the coarser grades could be used to good advantage here, and any way, a harder and less dusty rock like granite chips, crushed field stone or crushed trap is preferable to limestone for this top coat. A thin layer of stone chips is rolled into the surface, and this might well be waste jasper, crushed stamp sand, granite chips, or similar material, with which the State is well supplied. So far as raw materials are concerned Michigan should have good roads.

Perhaps an ordinary macadam might be converted by repeated sprinkling with crude oil into a somewhat bituminous macadam.[2]

As regards plain macadam and gravel roads I would call attention to the pamphlet "Modern Road Building,"[3] which, though an advertising circular for gratuitous circulation, contains many good hints, no matter what machinery may be used.

Road Materials in the Upper Peninsula.

The Upper Peninsula has a wealth of good road making materials. Around Ishpeming and Negaunee the waste rock of the iron mines, the "jaspilite," a red jaspery chert, is used. The chert makes a hard road and the iron gives it good cementing power. The main drawback is the bright red, paint-like dust, of which it is almost impossible to rid oneself. In damp weather these roads are fine, and a treatment with crude petroleum might be an improvement.

In some places the diorite, which is often the foot of the ore bodies, and makes most of the prominent knobs, is used. This is also a good material and the color is not so objectionable.

Northeast of Teal lake a crusher has been installed, crushing the gannister, or Mesnard quartzite. A road near the cemetery is finished with this. The same rock has been used near Marquette. It is very hard, but not tough, and does not cement so readily as some rock. There are also quantities of very fair gravel.

In the copper country the crushed trap of the copper mines is used and makes an excellent material. In a few places near the Allouez, broken conglomerate, which is practically broken felsite, is used. Both are among the best of materials.

[1]See advertising literature issued by Warren Bros, of Boston and New York.

[2]Year Book, Department of Agriculture, 1902.

[3]Port Huron Engine and Thresher Co., Port Huron, Mich.

Quartzite is on the whole probably the most widespread of materials, but usually does not cement well.

Hard limestone is found at Manistique and numerous other points and has good cementing powers, but for a combination of toughness with cementing powers, it will be hard to find a rock to excel the copper country traps and the iron country "diorites" or amphibolites.

Clays and Shales.

As regards paving brick, I have repeatedly called

attention to the waste of the coal mines as furnishing suitable raw material.[1] The coal measure shales, like those naturally exposed at Flushing, often make good paving brick. The neighborhoods of Grand Ledge and Williamston, and Jackson are also promising. The exposures along the east side of Huron and Sanilac counties and of the Antrim shales in the northern part of the Lower Peninsula, as at Boyne Falls will also be likely to prove satisfactory. The Antrim shales are the same as the New Albany shales of Indiana. In the Upper Peninsula some of the slates near L'Anse would probably be all right, if the cost of grinding were not too much.

In as much as we have recently issued a report on clays we have only a few notes to add.

At Mass City, on Sec. 9, T. 50 N., R. 38 E., close to the little creek that flows through the center of the section and about 800 feet from the C. M. and St. P. R. R. station, is the newly opened brick yard of the M. Van Orden Co. The brick are mainly light red. The bed of clay is some 190 feet deep as shown by borings,—all clay, but only the top 12 feet or so are now used. There are kettles of slightly sandier (6 per cent. sand) clay on top.

Analysis of clay from Mass City, by Elmer E. Ware, gave:—

Ann Arbor, Mich., Oct. 20, 1903.

$Si\ O_2$	52.12
$Al_2\ O_3$	14.95
$Fe_2\ O_3$	4.41
$Ca\ O$	10.21
$Mg\ O$	4.56
SO_3	.20
Loss on ignition	12.32
Difference	1.13
Total	100.00

Mr. Gustave Voelcker, superintendent, has analyzed all the clays around and finds them very low in free silica (quartz flour), the highest being 6 per cent, and less the further down they go, yet he says they are fairly resistent. The finely divided lime which the analyses show, he says, is not deleterious.

[1]See Vol. VIII, Part 1, of Report Geological Survey of Michigan. Also the Gateway, Jan., 1904. There is a brick plant at the Valley Coal Co.'s mine south of West Bay City.

We have also analyses of the same clay made at the College of Mines, Houghton, for the management, given in the following letter:—

Houghton. Mich., Dec. 4, 1903.

Alfred C. Lane,
State Geologist,
Lansing, Michigan.

My Dear Mr. Lane:—In reply to your favor of the 17th of November, in which you send me a copy of assay of our Mass City clay, would say that the same tallies very closely with Dr. Koenig's assay of our bottom clay. I give below copy of his assays of upper and middle and bottom belts. No. 1 being 7 to 8 feet thick; No. 2, 6 to 8 feet thick, and bottom unknown beyond 30 feet.

	1	2	3
Thick, feet	7 to 8	6 to 8	30 & more
	Top	Middle	Bottom
$Si\ O_2$	68.20	53.86	49.00
$Al_2\ O_3$	15.72	17.96	14.56
$Fe_2\ O_3$	4.32	5.72	4.64
CaO	2.00	5.22	10.54
MgO	1.00	2.42	3.98
$Mn_3\ O_4$	trace	trace	trace
$K_2\ O,\ Na_2\ O$	2.72	3.26	4.02
$H_2\ O,\ C\ O_2$	5.83	11.51	13.26
	100.00	100.00	100.00

Our experience shows that the combination of No. 1 and No. 2 makes a very hard brick, of uniform pink color. Very satisfactory in every way.

Respectfully yours,
(Signed) M. VAN OKDEN.

The peculiar thing about this clay as compared with others is that there is more lime and magnesium than carbon dioxide to combine with them, so that they must exist as silicates, and we may associate this with the fact that the clays lie close to the Copper Range, in the rocks of which calcium and magnesium silicates (such as laumonite, epidote, prehnite, chlorite, serpentine, labradorite olivine) are abundant. Many of these silicates are quite fusible, and it is probable that such clays would be quite fusible, especially No. 3, which would be almost a slip clay. Another plant has been talked of at Mass City as there is a large amount of clay there and also one has been proposed at Kenton.

A clay or shale encountered in a well at 40 feet near Daggett proved to be a hard white clay quite free from carbonates and highly resistent.

We have also an analysis of a surface clay from this part of the State, as follows:—

Dec. 8, 1900.

For W. S. Oberdorffer. Menominee Co., by F. S. Kedzie.

	No. 1.	No. 2.
Insol	60.96	61.42
$(Fe\ Al)_2\ O_3$	9.38	3.62
$Ca\ CO_3$	11.81	22.77
Water, organic matter and difference	18.65	12.19
	100.00	

This "clay" is really a rock flour. There is very little alumina or kaolin about it. It must be very finely ground up silica and limestone, and would not, I should imagine, be a bad material to add to sand brick or cement brick.

There is a new brick yard at Munising, the Anna River Brick Yard. But at Munising a calciferous dolomite is also used for buildings.

The following is an analysis of a shale clay of the Michigan series, taken from near Alabaster and Sherman:—

Michigan Agricultural College.
Experiment Station.
Agricultural College, Mich., June 7, 1900.

E. A. McKay,

502 Phoenix Building,
Bay City, Michigan.

Dear Sir.—Herewith please find analysis of clay specimen:—

Silica	58.95%
Aluminum oxide	14.45
Iron oxide	7.60
Calcium oxide (lime)	2.94
Magnesium oxide	.86
Sulphuric anhydride (SO_3)	1.73
Alkalies calculated as potassium oxide (K_2O)	2.54
Water of combination	7.50
Organic matter and loss	3.43
	100.00

It is a good clay. It is entirely free from calcium carbonate and is to be recommended for its content of silica and freedom from grit.

Very respectfully,
(Signed) FRANK S. KEDZIE.

The following is a Maple Rapids drift clay. See record of well in Vol. VIII, Part II, p. 197.

$Si\ O_2$	49.90	51.00
$(Al_2\ Fe_2)\ O_3$	19.85	17.18
$Ca\ CO_3$	18.32	17.31
$Mg\ CO_3$	10.53	9.45
Total	95.60	95.54
Difference, alkalies and water	4.40	4.46
	100.00	100.00

F. S. KEDZIE.

The following is another drift clay from the Saginaw valley:—

Case School of Applied Science,
Chemical Laboratory.
Cleveland, February 5, 1900.

Mr. S. G. Higgins,
Saginaw, Michigan.

Dear Sir.—The sample brought me some time since by Mr. Dow contains :—

Silica ($Si\ O_2$)	41.2%
Alumina ($Al_2\ O_3$)	13.4%
Iron oxide ($Fe\ O_3$)	5.0%
Lime (CaO)	10.4%
Magnesia (MgO)	0.5%
Sulphuric anhydride (SO_3)	0.5%

The material is more clay than marl, and would require the addition of lime or marl in order to make a Portland cement mixture. For this purpose it would be well adapted, as the sulphur and magnesia are low, and it contains little free sand.

Very truly,
A. W. SMITH.

Finally, we have a typical series of surface calcareous clays from near Detroit, good mainly for building brick, which have been analyzed in the laboratory of Prof. E. D. Campbell for Prof. W. H. Sherzer, who is studying them for his Wayne county report, and adds the following notes:—

Jacob Daniels & Bro. East of Pere Marquette and one-quarter mile south of Michigan avenue, Springwells.

No. 1. Middle of upper layer—21/2 feet from surface and 2 feet from top of bed.

No. 2. Second or red layer—21/2 feet from top of bed and 7 feet from surface.

No. 3. Third or blue layer—5 feet from top and 141/2 feet from surface.

George H. Clippert & Bro. East of Pere Marquette and about one-half mile south of Michigan avenue.

No. 4. Upper layer—21/2 feet from the surface or 2 feet from top; 41/2 foot bed.

No. 5. Bed or second layer—2 feet from top of bed or 7 feet from surface.

No. 6. Blue layer—5 feet from top of bed or 14 feet from surface.

L. D. Haggerty & Son. At Pere Marquette, just north of Michigan avenue, Springwells.

No. 7. Upper yellow brown layer—2 feet from surface and 1 foot from top of bed.

No. 8. Red or second layer—2 feet from top of bed or 51/2 feet from surface.

No. 9. Blue layer 5 feet from top or 121/2 feet from surface.

Lonyo Brick Co. About one mile east of Pere Marquette railroad and just north of Michigan avenue.

No. 10. Sample 5 feet from surface.

No. 11. Sample 21/2 feet from surface.

Proctor Bros. One and one-half miles east of the P. M. R. R. and just north of Michigan avenue.

No. 12. 5 feet from surface.

No. 13. 21/2 feet from surface.

M. Downey. Two miles east of P. M. R. R. and just south of Michigan avenue.

No. 14. 5 feet from surface.

No. 15. 21/2 feet from surface.

At Haggerty's, Daniels' and Clipperts' there are three sharply defined beds—the upper yellowish-brown, 2 to 5 feet thick, considerably leached and not very plainly stratified. A second or "red layer"—yellow brown, but rusted and reddened—3 to 4 feet thick and very distinctly stratified.

The third is a blue layer, fine grained and not leached; beautifully stratified. It overlies till and at Clippert's may run to a depth of 40 feet judging from borings. The clay is a lake deposit, back of the Detroit moraine, and the three beds may have been formed in the Maumee, Whittlesey and Warren stages—or the various stages of Lake Warren alone.

Eastward from the railroad the red layer gives out or

passes into a yellow-brown one not to be separated from upper. Deposit of clay thins out towards Detroit and disappears on moraine. Main body to the east lies to the south of Michigan avenue.

WAYNE COUNTY CLAY ANALYSES.

BY ELMER E. WARE. UNDER THE DIRECTION OF PROF. E. D. CAMPBELL.

	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.
Silica	57.18	57.55	56.16	55.86	57.58	74.77	57.75	55.53
Alumina	16.04	13.42	10.95	15.24	13.63	8.32	14.75	10.89
Ferric oxide	5.36	3.92	3.32	4.50	3.62	3.02	3.70	4.30
Calcium oxide	6.46	7.40	10.24	7.10	6.94	3.04	5.92	9.23
Magnesium oxide	4.60	5.96	4.86	5.05	4.68	2.52	4.68	5.38
Loss on ignition	10.07	11.43	13.95	12.33	11.18	5.07	9.90	12.51
Sulphuric anhydride	.01	.04	.04	.06	.05	.05	.06	.80
Sodium oxide	.....	.....	.....	.....	.....	1.85	.....	.....
Potassium oxide	.....	.....	.....	.....	.....	1.54	.....	.....
Difference	+.38	−.32	+.48	−.04	+1.72	−.18	+3.24	+1.38
Totals	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

December 31, 1903.

	No. 1.	No. 10.	No. 11.	No. 12.	No. 13.	No. 14.	No. 15.
Silica	71.32	66.19	67.06	65.75	58.42	69.50	59.46
Alumina	12.73	12.78	16.78	15.04	13.44	14.84	14.88
Ferric oxide	4.88	5.18	4.30	5.26	4.70	4.92	4.40
Calcium oxide	1.70	3.37	1.70	3.10	5.86	1.92	5.18
Magnesium oxide	2.19	3.58	2.30	3.05	4.46	2.09	5.01
Sulphuric anhydride	.13	.06	.06	.06	.01	.16	.11
Loss on ignition*	4.67	7.42	4.98	6.85	10.08	4.42	9.38
Potassium oxide	.....	.....	.87	.74	.....	.....	.....
Sodium oxide	.....	.....	2.60	2.45	.....	.....	.....
Difference	2.38	1.42	−.74	−2.30	3.00	2.15	1.58
Totals	100.00	.....	.....	103.40	.....	100.00	100.00

* Includes combined and hydroscopic water, organic matter, carbon dioxide, alkaline chlorides, etc.

ELMER E. WARE.

These analyses show beautifully the leaching out of the calcium oxide and sulphur.

CEMENT CONCRETE. CEMENT BRICK.

Another industry which has rapidly developed in this State is the Portland cement industry. As we have just issued a report on this subject[1] we need only add a few notes of current interest referring also to the heading limestone.

A sample of marl has been sent by James Searing of Lyons, from the Maple river bottom to Prof. Kedzie, which runs 96 per cent. Ca CO_3.[2]

The Lakeland deposits described by us, under the head Standard Portland Cement Co., are now being developed by the National Portland Cement Co. The average depth is said to be 18 feet, and there is a good deal of peat associated.[3]

On the other hand, the Standard Portland Cement Co. is said to be testing beds near Edgewater, 12 miles north of Frankfort. The contract is said to be for $350,000, by the Robert F. Wentz Engineering Co. The plant, like the Newaygo plant, expects to use water power which the Platte will furnish.[4]

[1]Volume VIII, part 3.

[2]Michigan Investor, 12/16/1903. See also our report, Vol. VIII, part 3, p. 311.

[3]Detroit News, 2/11/1903.

[4]They have since turned to a limestone proposition near Charlevoix.

Mr. Wentz writes:—

Toronto, Ont., Feb. 29, 1904.

Mr. Alfred C. Lane,
State Geologist,
Lansing, Michigan.

Dear Sir.—I received a copy of the State reports, etc., at Detroit, and in reply beg to thank your prompt attention to this matter. I have practically read over the entire matter on my way home, and in my spare moments at the hotel. I am pleased to say that your investigation has been very thorough and the report, especially on marl, in which I am particularly interested, is very complete, containing a large amount of very interesting and important information. I shall be pleased to send yon reports and results of analysis of Michigan raw material which I have made in the past several years. This I will do as soon as I possibly can.

I have recently made very valuable improvements in the manufacture of Portland cement from marl on the wet process, almost reducing the cost of burning to that of rock or dry process. The cost of burning however, is governed by the purity of the marl to a great extent. Marl containing a considerable proportion of organic matter is much more expensive to burn,[1] requiring a much larger amount of fuel as you will know, but with a pure marl, free from organic matter, I am able to produce with my process, from 180 to 225 barrels per kiln with a fuel consumption of about 125 pounds per barrel.

Yours very truly,
(Signed) ROBT. F. WENTZ ENGINEERING CO.,
Robt. F. Wentz, President.

A number of plants referred to in Volume VIII as in erection are, like the Fenton plant of the Egyptian Portland Cement Co., now in operation. In addition we have the El Cajon Portland Cement Company (with 425 acres near Alpena), the Onaway Cement Co. (which may also be a limestone proposition), the Aetna Portland Cement Co., near Fenton, the Logan Portland Cement Co. (the same areas as the Twentieth Century-Portland Cement Co., referred to in Volume VIII), and the Palatine Portland Cement Co. (to operate on the marl beds of Genesee, Livingston, and Shiawassee counties), are among the newer propositions.

Not only is the Portland cement business growing in a substantial fashion, but industries dependent upon it, such as the making of concrete block, cement brick, and hitching and fence posts.[2]

One of the earliest places to use cement brick is Durand, where there is a church built of them. Other places are:—

The Utica Cement Brick and Block Co. (plant using gravel of Geo. B. Davis pit) ; Jas. Pryor & Son, Houghton (plant to use the stamp sandwaste from copper mining,

the old Franklin mine); F. P. Bradley, Hudson, Midi.; Ypsilanti Cement Block Co. (using Jollifer gravel pit near Plymouth, Wayne Co., i. e., an old lake gravel); Mason Tile and Cement Co., of Detroit (make cement brick and have tried some for paving), Dowagiac.

The Portland cement is always the more expensive material and should be used in quantities sufficient to fill the voids. Now even grained material has more voids, even though individual grains are very small, than gravel or sand of uneven grain, where the small grains can pack in between the large ones. Therefore in concrete it is necessary to mix gravel with sand enough to fill the voids, and then finally cement enough to fill the finer remaining voids. The theoretical maximum porosity is .4764 of the whole volume empty or about half and half. In an even grained sand, minimum porosity is 26 per cent, of the whole volume. An average clean beach sand will run about 40 per cent, voids, so that a cubic foot, which if it were solid quartz, would weigh about 2650 ounces (1000 ounces of water to the cubic foot), will weigh but 1590 ounces, or 100 pounds. The average specific gravity of Michigan sands and gravels according to my test is not far from 2.65. Thus if we take the number of ounces of water a cubic foot of a given sample of sand or gravel will absorb, and divide by 1000 we shall get the proportion of the volume which is pore space. Or, if we take the weight of a cubic foot in pounds and multiply by 0.6, or, more exactly, find the weight in ounces and divide by ten times the specific weight (say 2.65) we shall get the per cent, which is not pore space.

[1]These are commonly bluer or clay colored rather than white. L.

[2]Lansing Cement Post Co., American Cement Post Co., of Marshall. Hillsdale Fence Post Co., Geo F. Demorest, Lapeer, and Pulfrey & Pond, St. Johns, hollow cement blocks.

The per cent, of cement by volume required, therefore, will vary with the porosity of the sand. Two or three parts of sand to one part of cement is about all that it is wise to add. Any further dilution of the cement should be by coarser material. A common proportion may be 1 cubic yard broken stone or gravel, with one-half volume voids, requiring one-half yard of sand, which will have one-third its bulk voids, requiring so much or one-sixth cubic yard of cement, i. e., the proportion of gravel, sand or cement for one cubic yard of concrete will be 1 cubic yard gravel, one-half cubic yard sand, one-sixth cubic yard cement, and about the same proportions (a little less cement) by weight.

I do not think that pure sands will be so economical of cement as less assorted sands, beach and river sands and shingle, and as I have said, the kame and overwash gravels and eskers of the glacial epoch.

I understand that beside at Durand, concrete block plants are planned near Rochester, St. Charles, Lansing, Ypsilanti, etc.

The economic geologist is more especially concerned with the other raw material, the sand or the gravel. This should of course, be convenient to transportation and free from clay, mud or slimy material. But that does not mean that it must be very even gravel. Quite the contrary. "The best sand is that of very uneven sizes and sharp." The more uneven the sizes the smaller are the voids and the heavier the sand.

But here in Michigan the glacial gravels are often unassorted, so that little or no sand needs to be added[1] and in any case of material for any extensive proposition, one should have the amount of pore space tested.

[1]See article by Geo. S. Pierson, Michigan Engineer, 1904.

SAND BRICK.

Another important industry in development is that of making sand brick. Among the most important papers are those of S. V. Peppel, formerly of the Ohio Geological Survey, now of "Rock Products," Louisville, Ky. I am also indebted to Prof. O. P. Hood for suggestions, and to Mr. W. O. Kutsche.

A sand brick is a mass of sand or fine gravel (under 1-20 inch) cemented by a net work of silicates of lime with or without magnesia or other earths made by steaming under pressure, a mixture of sand or gravel with slacked lime.

The sand, as for concrete, should be of varying size, which may be provided by crushing some of it. "If we had a sand with a good assortment of sizes from coarse to fine, we ought to have sand finer than 150 mesh equal in amount to the weight of lime to be added." Clay is deleterious, but, if not over 10 per cent., may be counteracted largely by using more lime. It adds ease of working and the sand should not be quicksand, but mold well. To the sand 5 per cent, to 10 per cent, of slacked lime are added. A molding pressure of best about 15,000 pounds per square inch is used, and they are then exposed to steam at a pressure of 120 to 150 pounds, and temperature of 180° C. to 185° C., for say 8 to 10 hours. Mr. Peppel found that freezing actually improved the brick materially.

The absorption is said to be 8 to 10 per cent, of the weight of the dry brick. One Michigan specimen which I tested ran as high as 12 per cent. The crushing strength is better than that of the best sandstone if properly made, but a heavy pressure of 200 to 250 tons per brick is important to get the best results, and a uniform pressure is not always attained.

In regard to merits of different systems of manufacture, that is a matter for the mechanical engineer, and we would refer to the gentlemen whom I have mentioned above. Great advantages of all methods are, however, rapidity of production and economy of fuel.

Among the sand lime brick plants in operation or construction in the State are as follows:—

The Holland Brick Co., working under the patents of H. E. Brown of Coldwater, and making dolomitic sandstone brick, W. O. Kutsche, superintendent. They are working

on sand at their plant corner of Fairbank avenue and Eleventh street, at Holland. The Jackson Pressed Brick Co. and the Battle Creek Dolomitic Brick Co., are also to use this process. This means that they use a slacked lime made of magnesian limestone. Most of the Monroe county lime (except the Christiancy quarries) is of this character. The quarries in the Niagara limestone along the west shore of Lake Michigan, as the Manistique, are pretty sure to be dolomitic lime. The Petoskey, Alpena, Bay Port, Sibley and Bellevue limestone is ordinarily not a dolomite, though layers may be found at Petoskey and Alpena which would yield it. There would be an advantage in combining this process with the making of cement, in that the dolomite lime is just the kind which is not wanted for cement. There is probably no especial advantages in quality in using magnesian lime. Peppel thinks the contrary.

The American Sandstone Brick Machinery Company has a plant at the south end of West Saginaw, near the glass works, well spoken of by Peppel, using a sand connected with the old Lake Algonquin beach line. The sand lies in a ridge running north of N. W. and cut by the M. C. R. R. It is at least 10 to 15 feet deep, with no apparent stratification. It is probably a wind or dune deposit between the Tittabawassee river inlet and the great lake of the time, on a projecting spit, and rain percolation since has destroyed what little stratification there was. It is *not* a quicksand, but molds well and has a little organic matter. This and a Muskegon plant are on the system of F. Komnick of Germany. Another plant is talked of for West Bay City. Peppel gives a description of the process.

Finally, we have the plants using Huennekes system. The parent company of the State is the Michigan Sand-Lime Brick Co., of Saginaw. They have a plant in operation using Saginaw river sand at the north end of the city near Saginaw, and as they have the rights for Michigan, are interested in plants in the copper country, Middleville, Detroit, and the Sault.

"C. W. Boyle and Geo. O. Cole, of 76th North Market street, Grand Rapids, Michigan, are taking preparatory steps for the organizing of a brick manufacturing plant. Mr. Boyle is the inventor of a new machine for manufacturing sand or chemical brick, on which he obtained a patent from the government, July 31, 1903. The new brick after leaving the machine is so soft that it cannot be handled, but after being subjected to a chemical treatment become harder and more durable, it is claimed, than any variety of brick now used for building purposes, and the brick can be manufactured and put on the market in 48 hours. One residence in this city has been built of this brick, which has proved satisfactory."

Mr. Peppel[1] remarks: "If the last five systems described, were all to work under parallel conditions, I do not believe that the cost of production would vary more than 35 cents per thousand." * * * "The cost of production in this country, independent of depreciation and interest on investment varies from $2.40 to $4.00 per thousand. The selling price ranges in different localities from $8.00 to $15.00 per thousand." * * * "I see no reason why plants should not be made independent of all the above mentioned patents or systems." * * * "There is no patent process of hardening with steam under pressure, since Dr. Michaelis of Germany allowed his patent to expire some years ago." * * * "We are not advocating sand lime brick for pavers." * * * "Those locations should be first selected where sand is abundant and fuel inexpensive.

The last remark seems to indicate Lake Superior as an appropriate region, and it is to be noted that freezing and thawing seems to strengthen them. But in general, Michigan is well supplied with sand, and while we have coal and peat, fuel is not and never will be as cheap as farther south, for there is more demand and less supply.

[1]S. V. Peppel, Louisville, Ky. Further contributions to the manufacture of artificial sandstone and sand brick, p. 43.

TRANSMISSION OF HEAT INTO THE EARTH.

In several lines of investigation the question of conductivity or diffusivity of substances has come up as an important geological factor. Peat moss is a good non-conductor, and this lends it part of its practical value in growing nursery stock. Moreover it cannot be without influence upon peat bog vegetation that in the very heat of summer their roots are immersed in cold water while their leaves are exposed to the fierce heat of the summer sun. Again the heat diffusivity of the soil seems to indicate its porosity.[1]

From the temperatures of flowing wells we can draw some conclusions as to the depth from which their water is drawn, and in the same way we can infer from the temperature of springs the depth of their source. Mr. Frank Leverett has made practical use of this in studying the Ann Arbor water supply.

Finally in studying the temperatures at great depths and the rate of increase in mines we need to know the surface temperature from which the increase of temperature in going down begins, and in all these cases we find involved the fact that the temperature of the ground varies, being perceptibly affected for two or three feet by the daily range of temperature and for about twenty times greater range of depth, by the change from summer to winter. I found a large series of observations on soil temperatures by Prof. E. C. Kedzie which had never been completed, and I spent quite a while in finding a method of treating the subject which should be sufficiently accurate for the geological purpose and for the observations and yet not too technical.

We may treat the variation of temperature for a day and its spread down into the earth very nearly as though it were the only variation and suppose each day the top of the mercury of the thermometer rose and fell as a ship would rise and fall while a wave passed under it. If that

is so and the period of variation is a day, the average of two observations half a day apart will give the average mean temperature of the day. If we subtract this mean temperature from observations of the temperature one-quarter of a day apart then the square root of the sum of the squares of the difference of two successive observations six hours apart will be the greatest difference for the day. We find this difference decreasing as we place our thermometer deeper in the earth, and the less the diffusivity of the soil for heat and the greater its porosity the less will the daily or annual differences of temperature be at a given depth. Moreover the quotient of the differences is proportional to the exact time when this greatest difference from the mean occurs, and again we find this time is greater the deeper in the earth the thermometer is and the less the diffusivity of the ground.

[1]See pages 24 to 25 of this report.

The mathematical treatment below gives us the exact method of computation.

We may pick out from it certain facts of general interest. The range of surface soil temperature is greater than that of the air temperature. In a soil like that at Grayling or Lansing with the usual summer amount of moisture, etc., it takes about a day for the heat to penetrate two feet and the range at that depth is only about 5% of that at the surface. The annual variation would penetrate in a year about $\sqrt{365}=19$ times as deep or say 38 feet, and at 19 feet it would be coldest in summer. The range of variation of temperature at 38 feet would again be only about 5% of the range from the mean daily temperature the last of July to that the last of January. These figures vary of course according to the diffusivity.

Mathematical Treatment.

The variations of temperature at the surface of the soil may be taken as the result of a combination of a number of different variations of temperatures. These latter will differ in amplitude, that is to say, in range of temperature due to them. They will also differ in period, that is, the time which elapses between the occurrence of the greatest divergence, and the recurrence of the same, that is, between successive maxima. Two of the most prominent periods are the day and the year. They will also differ in the date at which the first maximum takes place, after any date that we take from which to begin to reckon our time, say midnight of January 1. It may be shown by Fourier's theorem that no matter how complicated the variation of temperature, it may be considered as the sum of a series of such harmonic variations,[1] each being expressed mathematically as—

$$(1)\ T = c \cos\left(2\pi\frac{t}{p} - l\right)$$

In this expression—

T is the divergence of temperature from the average, eliminating this particular variation, at a time t.

c is the amplitude, that is, the maximum divergence from the average.

p is the period for the particular term, the length of time between maxima.

π is 3.1416, but in estimating angles 2 π = 360°, so that $2\pi\frac{t}{p}$ is an angle which is to four right angles as the time t for which T is sought is to the time between maxima.

l is the value $2\pi\frac{t}{p}$ assumes at the time of the first maximum, and the time of it after the date of the beginning is l. $\frac{p}{2\pi}$

[1]Byerly, Fourier's Series, Chapter II.

Now, at a depth, which we will call x, the temperature, so far as it is due to the surface temperature, may be represented as the sum of a set of vibrations having the same periods, but the maxima will be less and later.[1] Each will be expressed mathematically as—

$$(2)\ T_x = c\, e^{-R} \cos\left(2\pi\frac{t}{p} - l - R\right)$$

In this expression—

T_x is the temperature of a point at the depth x at the time t as before.

c, π, p, t and l have the same meanings and values as in expression (1).

e is the exponential base 2.71828.

R depends on the retardation of the maxima which depends on the depth, the period, and the capacity of the ground to diffuse heat. This latter we will call K.

K is by Byerly called a^2 and by Kelvin $\frac{k}{c}$. It is proportional to the rate of change of temperature with the time at a given depth. It is also inversely proportional to the acceleration of the change of temperature for different depths at the same time; i. e., $D_t u = KD_x^2 u$. K is usually assumed to be invariable, though this is not strictly true, and in such case if the temperature was proportional to the depth, it could not change with the time.

It may be shown that—

$$(3)\ R = x\sqrt{\frac{D_x^2 u}{D_t u}}\,\frac{\pi}{p} = x\sqrt{\frac{\pi}{Kp}}$$

As to the units, x and $\sqrt{dx^2}$ are referred to the same unit, also dt and p, du and d^2u, and consequently a change in units does not affect R, nor does a change in temperature unit from degrees Fahrenheit to degrees Centigrade affect K. K is the conductivity and c the thermal capacity per unit volume, which is for water, 1; for most rock, about .5; and for air, .000307.

Obviously the diffusivity, or spread of heat, when the strata have to be heated up as the heat wave spreads, will be relatively less than when the conductivity or flow has become steady, if the body absorbs a good deal of heat in being heated up. One must be careful not to confuse the conductivity and the diffusivity, as is often done; and in part I myself, in my Annual for 1901, page

247, have mixed some conductivity and diffusivity data, as writers are sometimes obscure. The conductivity may be defined, for instance, as the number of calories, or heat units, which an indefinite slab, without varying the temperature, will transmit per square centimeter through a slab a centimeter thick, the difference of temperature of the two sides being 1°, while the diffusivity is the conductivity divided by the thermal capacity per unit volume. This is the specific heat per unit weight multiplied by the specific gravity. The former is calculable from the chemical composition, and is for most rock-forming minerals not far from .20. For water, it is 1.00. The specific gravity for rock-forming minerals is usually between 2.5 and 3.5, consequently the specific heat capacity per unit volume of the strata, except for porosity, is near .5 to .6. If the pores are filled with air, the heat capacity per unit volume is diminished; if filled with water, it is increased and the diffusivity diminished relative to the conductivity. Unless convection currents of water come in, therefore, a wet soil will propagate temperature changes less than a dry one. It may propagate heat from below more rapidly, but heat from above less rapidly.

[1]See Byerly's Fourier's Series, Art. 69, much simplified here.

To get the greatest values of the temperature T_x we shall have in eq. 2 $\cos\left(2\pi\frac{t}{p}-1-R\right)=1$, the greatest value a cosine can have, and then $1+R=2\pi\frac{t}{p}+2n\pi$, the *first* maximum (when n = o) being at the date $\frac{1p}{2\pi}$ at the surface, and at the date $\frac{(1+R)\,p}{2\pi}$ for the depth x. The difference $\frac{Rp}{2\pi}$ is the time it takes the heat to penetrate the distance x, which is from equation (3) —

$$(4)\quad \frac{x}{2}\sqrt{\frac{p}{K\pi}}=\frac{Rp}{2\pi}$$

Variations of long period move in more slowly than those of short period, but they are appreciable at a greater depth. For when we come to consider the amplitude or range of variation in temperature, it is the original amplitude multiplied by e^{-R}, i. e. $(0.36788)^R$, which is always a fraction decreasing from 1 as R increases from 0, and thus decreases with the depth also, but more slowly the better the diffusivity and the longer the period of variation.

The diffusivity (K) in materials such as those of which the earth's crust is composed, usually varies from .001 to .01,[1] if the unit of time is a second, and of distance a centimeter.

In the progress of fluctuations of temperature from the surface they soon tend to smooth out minor irregularities as they go down, and if not strictly harmonic, become more nearly so. Now for any one particular set of heat waves, say those due to day and night, as they go down—

(1) The times of maxima are retarded by an amount which is to the period (p) of the heat wave (in the instance cited 1 day) as R is to 2π, where—

$$2\pi=\frac{66}{7}\ \text{and}\ R=x\sqrt{\frac{\pi}{Kp}}$$

(2) The amplitude of vibration is to the original amplitude as 1 : e^{-R}; i. e., is $(.36788)^R$ of the original. We can for any one fluctuation take p= 1 if we choose a proper value of K.

[1]Annual Report 1901, page 247. B. O. Peirce. Rocks like traps have a diffusivity of about .006 to .007. That of the Calumet conglomerates is as high as .01, which is taken as a rough average of underground strata by Lord Kelvin.

TABLE OF DIFFUSIVITY.

K for different units of depth (x) and time (p).

	Second.	Hour.	Day.	Week (7 days).	Month (1-12 year).	Year.
Centimeter	1 (a)	3600	86400	610800	262800	31536000
Meter	.000001	.0036	.0864	.6108	.2628	31536
Inch	.154	556	13700	93600	40600	4870000
Foot	.001073	3.87	92.8	684	2830 (b)	33800 (c)

(a) Units of B. O. Peirce, Callendar, and McLeod.

(b) Units of Angstrom.

(c) Units of Kelvin.

Suppose, for instance, we ask to what distance from the surface does the variation amount to one per cent of that at the surface? Then

Amplitude = $c(0.36738)^R$ = .01c

Canceling and taking logarithms.

R (-.4343) = -2 Therefore $R=4.6=x\sqrt{\pi/Kp}$

Suppose the variation is daily, if we let p= 1, and the diffusivity is (.01, in centimeters and seconds i. e.) .928 in foot day units then x is about 2.3 feet. The soil diffusivity will be usually from 2/3 to 1/5 of this, and since the daily variation of the surface soil temperature is not over 30° to 40°, the daily variation is usually less than a degree Fahrenheit, even at less than 2/3 foot below the surface.

It is plain, however, that when we come to consider thawing frozen ground, or vice versa, an enormous amount of heat will be absorbed in thawing the same out. The diffusivity may be easily ten times less. On the other hand, a warm rain may carry the temperature down very rapidly.

For instance, I made the following temperature observations on the peat bog of Mud Lake, Sec. 1, T. 1 S., R. 5 E., in Washtenaw County, July 16, 1903:—

	Fahrenheit.
Temperature of air in shade	86°
Temperature of air in sun, surface of bog	117°
Temperature at ½ inch depth	94°
Temperature at 2 inches	73°
Temperature at 4 inches	63° or 62°
Temperature at 12 inches	57° to 56.4°
Temperature at 18 inches	57°

At other places in that same bog the some day, we found at different times: In sedge marsh at 3 inches depth, 64°; at 4 inches depth, 50 feet within shade of Tamarack belt, 64° F.; in Cassandra belt, 3 inches below water level, 56°, and at 8 inches, 561/2°; 2 feet deep in peat, 56.3°; away out on the floating bog, at 4 inches

depth, 68°; at 18 inches, 66°. Now the maximum temperatures that day for adjacent stations of the weather service were 80° to 82°, and the minimum the previous night were from 46° to 55°.

July (1903)	14	15	16	17	Ave. July	Ave. Aug.
Ann Arbor	72 —52	74—45	79 —51	81—57	88.5—60.2	76 0—56.2
Ypsilanti	71 —50	72—44	76 —55	81—58	80.5—58.2	85.0—54.9
Average	71½—51	73—44½	77½—53	81—57½	81.5—59.2	75 5—55 5
Average for day	61	59½	65	69	70.4	65½

The range of soil temperature for the day could hardly have been over (117-65) 52x2 = 104°. The amplitude at 1 foot and 1.5 foot would then be at a diffusivity K = .928 for units of a foot and day 15.9° F. and 6.35° F. respectively and the maximum or the minimum would be reached 29/100 of a day and 44 /100 of a day later respectively, than on the surface, and a greater range means a greater diffusivity. To get a temperature of almost 10° below the daily mean at a foot, as we have, we should have to assume a lower minimum soil temperature than is probable, aud greater diffusivity than is really likely. Finally, the possibility of the temperatures at a foot and a foot and a half diverging from the daily mean 10° on account of the cold the night before, utterly breaks down, in view of the relative constancy of the temperatures both in depth and at various times of day.

We must then take the other alternative that the temperatures are practically unaffected at a foot's depth by the daily variation, the amplitude of which at that depth is reduced to not over 2°, and then the diffusivity (c.g.s.) will be not over .004 to .005. From considering the temperature at 1 foot as fixed by the annual variation in temperature we find that the greatest summer temperature at a foot depth would be nearly thirty-seven days later than at the surface1. This leads to an extremely low diffusivity, like that of pumice or dry sand, and shows what a good nonconductor peat may be taken to be. The result may, however, be affected by evaporation and consequent depression of , temperature, the peat acting like the wet flannel wrapper of a Hindoo water bottle.

Suppose we have observations at intervals of one-fourth of the period of variation in temperature apart, i. e., in the case of the daily variation six hour intervals, we have, calling them

JR (—.4343)=log. 2-/104 or log. 2/24, according to the amplitude of the surface variation taken = —1.716 f or —1.079 -f.

.-.R ^3.96 or 2.48-f .'. if x = 1 and p =1. From eq. (3).

K=^q-- = 0.2, or 0.5 in day foot units = .002 or .0056 c.g.s.

Supposing that the temperature at 1 to 1% foot depth 56.6° is fixed by the annual variation (it is probably 2° or 3° too low on account of previous cold days), which is, or should be, just about a maximum (70°. 6 daily mean) at the surf ace on July 17; reckoning the time from that same date last summer (1 = 0), taking this time p = unity = 1 year (the diffusivity will accordingly be referred to years and feet), we have—

Tx = (56°.6 — 46°.6) = 10° -f = (e = 24° = 70.6 — 46.6)

e~B (cos 2 tt -1 — 1 — R) = 24 cos (2 tt — R) e ~~B= 24 cos R/eB

= log 24 -f log cos R —R (log e = .4343) = —.38. This equation is nearly satisfied if R = (3%) 2?r = ,646 in foot year units. S3B?0- X -M*. = 37 days, which is the difference between the time of greatest heat at the depth of 101% feet at which 56°,6'is taken and at the surface. The maximum mean daily temperature at a foot depth is over a month later than at the surface. And if R= .646 — x */ ^

7T Kp-

,'. K = -=^- = 7.6 in year foot units = .0002 in c. g. s.

t! + M,T2 -f- M,T3 + M,T4 + M, M being the average temperature. t! =G e-R cos (2 tt - —1_R)

T2 =c e^E [cos (2 tt (1 + 1/4 p)_l_R) = sin (2 tt ^ —1—R)]
T3 =c e-B [cos (2 tt (- + 2/4 p)—1—R) - —cos (2- —1—R)]

T4=ce-B [cos (27T (l + 3/4p)—1—R) = sin 2 tt ^ _1_R]

The sum of two observations a half period apart rl\ -f M and T3 + M or T2 + M and T4 + M will give us twice the mean average temperature. Then we can get Tx, T2, etc., readily. Squaring the sums, we get—

T2! + T22 - c2e-*B (cos2 + sin2 = 1) = the square (c e~B)2 of the amplitude at the depth x, from which we can readily find R, if we know c. Or, if we have a series of different observations at different depths, we can eliminate c between them. Also dividing—

T t

—^-= tan (2 tt -—1—R). from which we can also compute R.

J-i P

There are thus two ways of computing the diffusivity of heat. In the former case we estimate from the decrease in amplitude or amount of maximum Variation and that is all we need to know. Bat if we have a series of timed observations, we can also eliminate the diffusivity from the time at which this maximum temperature occurs for various depths.

To illustrate these principles and get some idea of the diffusivity near the surface we inay proceed as follows:

Between 1888 and 1892, measurements of the soil temperatures at different depths were made at Grayling and at Lansing.1

These were read three times a 'day, at 7am, 1 p. m., and 7 p. m.? i. e ; six hour intervals, but not in the winter. Therefore they do not help us as regards the blanketing effect of the snow in winter, and a study of the annual variation must be very imperfect. We can. however, get some comparative results as to daily variation and as to diffusivity, and apply the formula above; and it is well to notice also that the composition and porosity of the Grayling soil has been tested, as well as its diffusivity.2

The addition of morning and evening observations

should give us twice the daily mean, free from the daily variation.

m rn ——————————.

at -MA. m. A -i p. m. fnv, i f r>Also
™——— = m—— = tan 1 + 1\.

-•-IP. M. J-l P.M.

From this we derive 1 + r, which is proportional to the time after 1 p. m. that the daily maximum arrives. Finding this for various depths, and

remembering that R == x ~l -?=• and that we know the depths, and the

i Report State Board of Agriculture, 1888, pages 154-184; 1889, pages 85-101: 1890, pages 143-152; and 1891, pages 92-97.

2Bulletin State Board of Agriculture, Bull. 99, p, 11, also this report above, pp. 15, 16. 26

period (p) is taken as 1, we shall have expressions with only 1 and K, so that if we have these observations for two different depths we can find both 1 and K.

Lansing.

Taking for instance, the observation for September, 1891, at the Agricultural College, we have: —

If there were only daily harmonic variations to account for, the column of means should be identical. The variation in the means is due to sine terms of a period longer or shorter than a day. Throughout we assume that we can isolate pure harmonic vibrations corresponding to the single curve. This is not strictly true, but the farther from the surface the more the curves tend to become such. "With the exception of the 24-inch thermometer, which is distinctly lagging in temperature, owing to the annual variation, the variation is less than -J-0.

We have, accordingly, as variations from the means for the various depths:—

From the two shallowest depths we infer that the hottest part of the day at the surface was almost exactly 1 p. m. and 1 = 0. The diffusivity1 will vary between .003 and .008. Apparently it takes about four hours for the daily heat wave to penetrate half a foot, but nearly twenty-four hours for it to penetrate two feet.

Grayling. Let us now apply this same analysis to July, 1888, at Grayling:—

irThe lower diffusivity may be due to the greater dampness of the lower layers.

The variations in the means shows the importance in influence of periods with others terms than 1 day. In the first three depths the difference is not over -J°. Obtaining T we have :—

We obtain, using the values at three inches and six inches to determine 1, 1 =2 (.79) •— 1.35 = .23, indicating that the warmest part of the day at the surface was nearly an hour after 1 p. m. The values for E will be: .57, 1.12, 1.89, 2.26, and 5.08 respectively; and of E/x =

-\/-tf— -19, .19, .21, .19, and .21 respectively, a fairly uniform rate

averaging .020 in inch-day units, which will lead to a diffusivity of 78.5 in inch-day units, or .006 in c.g.s.

For amplitudes we find, for the y Tx72 + Tlx2 successively, 8.17°, 3.36°, 2.30°, 1.23°, and 0.71° respectively. If we assume the maximum divergence from the average at the surface is 15°, we shall obtain for values of E: .61, 1.33, 1.88, 2.50, and 3.06, and for E/x .20, 0.22, 0.21, and 0.14, which agree quite fairly (except the last, where the amplitude at two feet is so slight as to be greatly affected by the error of observation, and may be affected by the yearly variations.)

Thus we may conclude that the mean diffusivity at the point where the observations were made at Grayling was on that July close to .006, the average surface temperature between 69° and 70°, while the daily range of the soil temperature was 14.6 above and below; i. e., from 56° F. to 84° F.

We have also tried one other month, April, 1889. The results were as follows: The mean range of temperature at three inches was greater than that of the air, so the surface range of soil temperature may have been much greater. The whole variation was not nearly so great as in July. By taking the differences from the mean value of the temperature at any two times six hours apart, and squaring them, we obtain the square of the greatest difference at that depth as before, and accordingly find at 3, 6, 9, 12, and 24 inches respectively, maxima of 8.1, 2.62, 2.03, 1.34, and 1.21 respectively. From these again the diffusivity may be computed. If we assume E = 51 for three inches, we find a maximum at the surface of 13.3 above the mean, the mean daily variation being about 27°, which harmonizes well with atmospheric data, and we find for successive values of the retarding factor, E, values of 1.62, 1.9, 2.3, 2.5, respectively. Then E/x will be .17, .27, .21, .20, .11, respectively, or an average of .18, or for the diffusivity in units per day, .98, or in c.g.s. units, .007. The average diffusivity computed from the retardations of the maximum was .006.

We see, then, that records of the temperature at different depths give us check methods of determining the diffusivity and that only three observations a day, at intervals of six hours, will help us out pretty well. And after we have the diffusivity determined, we can readily figure the amplitude of a heat or cold wave at a given depth, and how long it will take to get down there.

It is scientifically desirable that the observations taken with so much care by Prof. Ii. C. Kedzie be worked up completely to obtain the different diffusivities of the soil. Important light on soil physics would probably be obtained. The direct geological bearing is not great enough to warrant my undertaking the work. The results above give us an idea of the diffusivity.

The above treatment must not be taken as a thorough and accurate treatment. Byerly, above cited, gives the necessary mathematical foundation, and I also have the following papers which work out especial cases in detail.

Louis Saalschutz: Astronomischen Nach rich ten, Altona, 1861, uUeber die Warmeveranderungen in den hoheren Erdschichten unter dem Ein-pltisse des nicht periodischen Temperatur wechsels an der Oberflache."

Angstrom: Nova' Acta regiae Societatis Upsaliensis, pp. 147-224, series III, Vol. I, 1855—"Temperature de la terre.55 The same pp. 50-72, Vol. HI, 1861, U0onductibilite des corps."

JB. 0. Pierce: Proceedings of the American Academy of Sciences, August, 1898, October, 1899, June, 1900, May, 1903, a series of papers.

Gallendar and McLeod: Transactions of the Eoyal Academy of Canada, 1895-1896, a series of papers on soil temperature observations.

GEAIN OF EOCK.

In connection with the Isle Eoyale report1 already referred to I developed a theory that the coarseness of grain in igneous rocks was not only somewhat dependent on the rapidity of cooling, but sometimes depended on it in so definite a way as,to be capable of mathematical expression. I found that if a mineral was formed in a time Tl — T2 during a drop in temperature U1 —U2, then the area of a cross section of an average grain was proportional to the time and inversely proportional

T1 _ To to the drop, or dependent on ^f——fp

LJ -^ —— U 2

ffig. 1. This shows the cooling of an igneous sheet, the margins of which are kept at a constant temperature, taken as 0° and represented by the bottom line of the diagram. The temperatures are represented by ordinates, and three different scales of temperature are given, corresponding to different values of the initial temperature. The main scale at the left is the same as used in the Isle Royale report. To the right is the scale if, as is assumed by Queneau, uq =.8862, and also if the initial temperature of the igneous sheet (that is, its excess of temperature over the surrounding rock) is taken at 1. The abscissas to the right represent the lapse of time, the main scale at the bottom being proportional to dec. log. q and I, and the scales above being proportional to m0 and q, which are defined in the text. Curves for twelve points from the center to the margin are drawn in full lines, and in dotted lines two curves still closer to the margin, one twenty-fourth and one forty-eighth of the distance to the center respectively. Also for curves 12, 4, and 2 we indicate by dashes the points where the curves of the approximate solutions which we have used in practice leave the curve which we have taken them to represent, to show how small the error is which we make in using them.

i Vol. VI, Part I. This subject has been worked on independently by Tammann and Doelter. I have not se'en all the original papers, only the summaries given in Neues Jahrbuch, 1903, 1, and Central Blatt, 1903, p. 608. The poiver of crystallization is defined as the number of crystal granules forming in a unit volume in a unit of time. The velocity of crystallization is the linear velocity of gro.wth in millimeters per minute. It seems to depend upon the number of degrees below the temperature of saturation, respectively fusion, at which the crystallization takes place and apparently attains a maximum some 15° below and more, according to Doelter's ideas, 20° to 25° below the fusion point for augite and plagioclase, nearer the temperature of solidification than of fusion.

Pressure does not make much difference except as it may retain H^O, etc., but the crystallization is very sensitive to addition even of chemically neutral substances.

Glass formation may be due either to slow velocity of crystallization or weak power of crystallization.

During the first few degrees below saturation temperature, microlites and elongate forms tend to occur, later come the more equal sized grains. In augite the length of the grains formed in 100 minutes is not ten times that formed in ten minutes, but Doelter's cylinder, which cooled in 100 minutes, had a slow cooling margin and a more rapidly cooling center, a case we shall refer to later.

fig. 2. Illustrating cooling", as in Fig. 1, where there is a narrow effective contact zone, one-twelfth the width of the dike. The dotted line shows the rise and fall of temperature in the middle of the contact zone. There is also shown by dashes the point where curve 2 of Fig. 1 diverges from the curve of marginal temperature.

fig. 3. This figure is based on Fig 1, and is for similar conditions. The full lines show tangents to the curve of grain of an injected igneous sheet (supposing the same to be proportional to the square root of the slowness of cooling) as derived from the approximate equations referred to in the text. The position of the point relative to the margin is represented by horizontal coordinates, the average linear dimensions of grain corresponding by vertical coordinates, while the decimals attached to each curve show the ratio corresponding to it of the consolidation-to the initial temperature. The lines in dashes are the actual curves sketched in, where they diverge markedly from the tangents.

fig. 4. Illustrating the variation of grain from margin, (to the left) to center (to the right) in flows, intrusive dikes, or sills which have a narrow contact zone, by the tangents to the curve of grain. The decimal figures adjacent to the curve indicate the ratio of the temperature of consolidation to that of initial injection or effusion, the temperature of the country rock being taken at 0°.

fig. 5. Similar to Fig. 4, but illustrating the variation in grain in case the contact zone is broad. It stands in the same relation to Fig. 3 that Fig. 4 does to Fig. 2.

Many of the remarks and the theoretical results given below will be only slightly modified in case the above formula is not strictly true if only it be granted that the grain is some continuous expansible function of the slowness of cooling increasing with the same and zero when the latter is zero. In the Isle Eoyale report I worked out the theory of grain especially on the supposition that the top and bottom of the sheet were kept at a constant temperature, by water or air currents or otherwise, and found that this supposition illustrated by Fig. 1 fitted the facts fairly well for the augite of the Keweenawan traps and is an important help in studying the sections. Certain principles there enumerated it may be well to repeat here. It will be more convenient, however, to compare the grains by their linear dimensions than by the areas of their cross sections, and, if we call the average linear dimension1 the grain, then:

(1). The grain will vary as the square root of the slowness of cooling.

i Determined by taking the largest grain in a number of different areas, usually five.

(2). Points at the same distance from a surface of fixed temperature will, if other conditions are similar and the grain was formed before the center cooled appreciably, have the same grain regardless of the size of the sheet. This was found experimentally to be true in the Keweenawan flows.

(3). The grain in such a case would be proportional to the distance from the bottom or top of the flow. This was found to be nearly true for the augite of a common type of flow mainly composed of labora-dorite and augite, and probably nearly a eutectic mixture, of which the Greenstone is a type.

This is illustrated in a plate of drill cores prepared for my next annual report while this is passing through the press.

This ratio of the increase of grain of the augitfe to the distance from the margin was found to be .0002, two millimeters for ten meters or about one inch for 400 feet. More accurate theory, as will be shown in this paper, indicates a more rapid increase close to the margin of the flow so that the first millimeter is attained within ten feet.

To illustrate the method of computation we will take the observations as given on page 245 of >the Isle Eoyale report on thin sections 15252 to 15258 and reduce the distance to millimeters, allowing for fractions not given there. There is, however, an uncertainty of probably one-half of a foot (152 millimeters) in most of the distances. We obtain the table below:

In this table the observations in thin-section 15258 are uncertain, for it is decomposed, and those on 15252 and 15253 are not very satisfactory, for the grain is so coarse that it would require a number of sec-

tions to give us a fair idea. It is obvious, however, that from 15257 clear in to the center, represented by 15252. the gradient is fairly steady and somewhere about .0002, which is what we found for the group on page 129 of the Isle Royale report (.06/304).

Taking the gradient from 15257 to the center, we find it to be (9-1.25)/(36,500—296) or .000213. Assuming this gradient from the margin, we find the column headed 4iAx" and the difference between these and observed values will give us the average value of B. These differences are given in the column headed "B". Thus we can, as we shall later see, nnd the contact zone y', which equals B/A, or 2,400 millimeters.1

But we did not find this to be true for all flows, for there was another law in evidence:

(4). Other things being equal the greater the abundance of its constituent molecules, the coarser the grain.

practical applications.

Some practical applications of the above theories may be suggested.

1. A thick sheet of trap very fine grained as to ground mass is pretty sure to be a felsite or "ashbed diabase'5 = (porphyritic mela-phyre or andose) type, more alkaline than the normal ophites.

2. From the coarseness of the lustre-mottling of even a small exposure of ophite a considerable bed may be inferred. For instance mottles an inch across would mean a bed some 800 feet thick. This may help to fill gaps in cross sections, and save trenching or exploring for amyg-daloids uselessly near.

3. The direction in which the mottles or grain gets finer is probably (faults, etc., excepted) the direction of the nearest amygdaloid. Dr. Hubbard has used this successfully in cross cutting from shafts, and other exploratory work which he directed.

4. As Dr. Hubbard has suggested, if a flow appears by a chemical or petrographic analysis to be a normal ophite, but when cut by a drill hole or otherwise the grain does not increase at the normal rate of 400 feet per inch diameter of grain but at some other rate it might be possible to infer the dip.2 But on account of the difficulty of determining the average rate of increase of grain accurately, and the liability of the drill hole to veer somewhat, and a possibility that an immediately succeeding flow may have modified the rate of increase this method can only be used with extreme caution, as a suggestion of probable dip. I have, however, used it.

5. In sinking or drifting sudden variations in grain may serve to call attention to faults and slips, and a normal diminution in grain forewarn of an amygdaloid or conglomerate.

In surface flows and for minerals formed immediately after the intru-

11 believe this is really too high, and that part of the coarseness of grain at the margin, which makes B and hence y so large, is formed in flowing. I suspect y' should be about two-thirds of the value used.

2 The new rate would be (400 -*- cos dip) feet per mile, in a vertical shaft or drill hole,

27

sion of a dike, before the temperature of the wall, which may be considered to start in at a temperature half way between that of the country rock and the intruded lava, has perceptibly varied, the facts agree nearly enough with the assumption of a constant marginal temperature, but in general we really ought to allow for a greater or less width of contact zone. In my Isle Royale report I showed how the contact zone could be allowed for, and yet I assumed that for the Keweenawan traps and corresponding intrusive diabases, the contact zone could be counted as insignificant. In this so far as the intrusives are concerned I was mistaken, and I also misled somewhat Mr. Queneau.1

He guided by Woodward, nevertheless, furnished a rapid method of computing the early and marginal temperatures, with the help of which I have been able to put the theory of intrusive sheets with a contact zone into much more calculable shape The labor of getting numerical results, and the apparent agreement of numerical results obtained in the Isle Eoyale report with the possibilities of the case, had previously led me to be too easily satisfied.

The following paper is strictly technical and puts the matter in more satisfactory shape.

general formulas for rock grain.

We may briefly summarize the results of the mathematical investigations as follows:

marginal temperature fixed.

In an injected sheet of uniform temperature and diffusivity whose walls are kept at a fixed temperature the temperature may be expressed in two ways, the former most applicable at the early stages of cooling, the latter in the latter stages of cooling.

Curves showing the manner of cooling, at first fast at the margin and! slow at the center, then later slow at the margin and faster at the-center are given in Fig. 1.

(1) 7I~ = -tm —— (Irn0-f-m —— I m0—m) + (-^ 2m0+m —— -^ 2m<5—m) " " " U0

7T 11 Q9 Q25

(2) — — = q sin tt x/c + -f- sin 3 tt x/c + -~- sin 5 v x/c - - -

4 uq o o

where:

u is the temperature after a certain time (t);

u0 is the initial temperature;

t is the time from the beginning of cooling;

x is the distance from the margin;

c is the thickness of the flow;

a2 is the diffusivity, K it was called in the article on soil temperatures.

1 See "size of grain of igneous rocks in relation to the distance from the cooling wall," by Augustin L. Queneau, School of Mines Quarterly, XXIII, 181-195. January, 1902. Contributions from the Geological Department of Columbia University; Amer. Jour. Science. November, 1902, Volume XIV,, page 393.

m = x/2a^/1_

m0 = c/2a^/ t = c m/x

nat log q = —7r2a2c~2t = (7r/2m0)2

Pm = —_ / — m2dm

'^ J o

ir =22/7 =3.1416

Formula (1) is the Wood ward-Queneau formula and converges most rapidly at early times and near the margin when m0 is greatest.

This is apparent from the table below p. 222, in which Pm varies but little from 1 as soon as m is much over 2.

Formula (2) I used in the Isle Koyale report1 and converges much more rapidly for large values of t the time or q. "When formula (1) ceases to give a result approximate to the third decimal place, a couple of terms of formula (2) will usually give it. The linear grain if we call (Ti-Tg) dt and (TJj-Ua) du will be expressed by the formula (where k depends on the power of crystallization of the mineral under the given conditions and will be assumed independent of the temperature and time, except as provided):

<*> «-lVi

For ordinary igneous magmas where probably according to Doelter da is often not over 40° and u0 and u are to be reckoned in hundreds of degrees dt and du may be treated by the infinitesimal calculus or that of finite differences.

In any table of the values of u in the terms of t, such as are given in Volume VI and here, we should find the ratio dt: du as the quotient of the corresponding consecutive differences of argument and functions respectively, for the same value of x2.

But a glance at equation (2) shows, what is not so clear in (1), that it is only the ratios u/u0 ,x/c and a/c which are involved in determining t, moreover our tables are not constructed directly with t as an argument, though u/u0 is the function. It will therefore be convenient to express

(3) otherwise and introduce instead of t m0= 2~T7f== of* / ^ r we have then:

(4)g= * .° /^j^t-

V ; & Vu.0 a A/ 2m03 \ldu7^ Now in studying the variation of grain from center to margin in any

ck

one sheet —-^=-- may be supposed not to vary. I have denoted it by K.

_____ •£

The expression V-du/u0 if u/u0 and - be given may be found from the tables

c

on pages 221 and 222 by subtracting successive values of u/u0 and

so may be the expression / ~c mo or an average value of the same

% 2mj* which is the same for any column of the table I.

iSee Byerly, Fourier's series, Article 60, ex. 1.

21. e. we deal with the partial derivative of t relative to u, x being supposed constant.

We may write :

(5) - JES= /V-^.aVCM x /I^K *Af _ ;a\/2mo3 y ^a uq.c;--aio = - v.__=_M==Vdt

so we have g = KM0 /Vdu/5^~

It is also at times worth while to replace dt by

d(m = ^= -^L-\ \ 2aVt 2a/<yt /

dt (a partial derivative,—x constant)^ - li^ anc{__ a \/ 2m3

m°-k^£^-x.^^^

P FsroTh2m'i0V-.>,a"'1 "^ '?>," al>'le"s "« »•>>» ">„> 3.5 «A =

sust.va r^rf "S^t^ii^i;

proportional to it and m = ^74 u/u0 = * i = .8863 u/vIf therefore we assume ' U°

(8) h=A/^mT^/u^_3

•4. -ii i p * —du/u0: m 3

it will be for a considerable range of temperature close to .8863, for a

still wider range be ^ , and for all early times be practically independent of t so that it will be convenient to introduce it in (7) and find

(9) s=Iv'c- viTO?

(10) g = C x where C =——JL=

and C in early times i. e. for the grain clSfto "the° margin is a func tion of u/u0 and of K/c, i e., k, a, and u0, not involving^ nor x

As soon as the cooling has proceeded so far that there is a belt of uniform grain at the center (the cooling is expressed by the first term of Eq. 2) the gram at the center E may be written 1

(11) g=E=K/n,u7u7

rninS^r I6 the™te1of increase of g™n at the margin determined by observation and also the grain at the center. Then we may determine when at the rate of increase at the margin continued the gram would be of a coarseness equal to that at the center.2 We may call this (x) the width of the belt of increasing grain. It is:

(12\ x' _E_h V'~2 u ,i , _____(} ^-Q--^-^ = -4u/uo

*£rom (3) by differentiation of the first term of (2) " " "_____

-Point of intersection of the tangents to the curve of grain at center and at margin.

marginal temperature not fixed.

When we come to consider the case that the sheet is supposed to have a heated contact zone, we find it again important to consider the conditions close to the margin and those at the center, for in each case we find relatively simple expressions for the grain, though the intermediate grain does not depend on them so simply.

First, we can see that a formula which we found in the Isle Eoyale report will enable us readily to construct the curves of decreasing temperature, which are shown in figures 2 and 3, in the former when the contact zone supposed heated is narrow and in the latter when it is as wide as the distance to the center of the dike.

This formula is as follows:—If v represents the temperature at a time t of a point at a distance of z from the center of a sheet the thickness of which is 2w with a contact zone of breadth y on either side, so that the whole zone affected or c is equal to 2w+2y. then—

(13) v = i (uw+z + uw_z)

where uw+z is the temperature which would exist at the same time t after the beginning of cooling and conditions otherwise the same (except that its margins are kept at a constant temperature) in a sheet whose thickness was equal to c at a distance of w+z from the margin and uw_z is the temperature at a point at a distance of (w-z) from the margin in the same sheet. - Or if (w-z) becomes negative— that is, the point lies in the contact zone—we must assume

(14) uw_z = —uz_w (in the contact) 'Now if we let x' be the distance of the point in the sheet with a con-

'c

tact zone from the margin of the sheet—that is x' =^- — z — w

(15) v = -J- (ux,+2y + ux,)

So if we take y to be -^ of c, then for various values of x' from 0 to 11 the center we shall have as corresponding values of v respectively one-half the values of curve 2 of 1, values half way between curves 1 'and 3, 2 and 4, 4 and 6, 5 and 7, 6 and 8, 7 and 9, 8 and 10, and at the center the values of curve 11 for the same time. These curves are drawn in Fig. 2 which illustrates, the cooling, therefore, in case the contact zone affected is only narrow.1

Similarly if y be 6, the margin will have half the values of curve 12 Fig. 3 and the center will have the values of curve 6 for the same times. Thus we can obtain the curves of these figures either graphically (very rapidly) or by taking means of appropriate rows of the table of solutions of the case where the margin is kept at a fixed temperature, a table which is given in the Isle Eoyale report for an initial temperature of .7854, and here for the initial temperature of 1. (Table I.)

Thus expressing the grain of the sheet with a contact zone y on each side as a certain function g () of x', of u the temperature of crystallization of u0 temperature of injection, of y the width of the contact zone

One might ask, why should narrow and broad contact zones be assumed? The answer wquld bef to allow for the varying diffusivity of the country rock and its capacity to absorb heat by the convection or evaporation of water, or by chemical reactions.

and of k, to include all other factors, such as diffusivity, crystallization power, etc., we have:

at the center. Here.

(16) v = uw whence we have.

(17) Center grain

g (k, x = c/2, v, u0, y, c) = g (k, x = w, uw, u0, y = o, c.) The expression for the grain at the center will be then,

k _ ____

(18) g (k, x = c/2 or x' = w, u, uc), y, c) = -7= /v/dt /V -du/u0

Vuo T;r a /^/w v a\ .-_____

= K <r/(c'^'cRdV/U"

In this expression and in the table we must confine ourselves to the row for which most nearly x — w/c, and find the point for which most nearly u/u0 has the value v/u0, and then interpolate to find _. / f — ? —•>-). Or if the cooling has gone on so far that there is a belt of constant grain at the middle (ra0 > 2.5 practically) by Eq. 11.

c ^ 1

(19) g (k, x = 2°r x/= w> u> uo, J, c) = ^r^^-E

at the margin.

(Consolidation temperature nearer that of country rock.} Here.

(20) v= yz u2y whence we find that the grain at margin if u < u0/2 is,

r=- A/du

since A/av =^=-' V2

(21) g (k, x - y or x; - 0, v, u0, y, c) - v;2 g' (k, x - 2y, u, u0, J = <>5 c)>

or in general,

g (k, x' = o, u, u0, y, c) = y'2 -7= y'5F/V^r/iF0

(22) =KV5/(^^|)/Vd57Sr,

or if u/u0 is so low that this value falls in the second period, i. e., m0< 2.5. (23) g (k, x' = o, u, u0, y. c) = K V2/^V157i^=K/VV"v7u^i Comparing equations (22) and (23) with (18) and (19) we infer that if the temperature of consolidation is low enough the grain may be the same from center to margain. Otherwise it will be coarser at the margin if u < u0/2.

(Consolidation temperature nearer that of injection.) In as much as v = 1 /2 u2y at the margin, so long as u2y has not droppe4 from u05 v will be equal to u0/2. During this time the cooling will be as though the temperature at the margin were fixed at 0. It

will be the same as that of a sheet of constant marginal temperature (which is taken as 0) of which the initial temperature will be u0/2

and u will be v——. In as much as we have expressed the grain in terms of the ratio u/ u0 we can now write

(24) g (k, x = x' + y, v, u0, y, c) = g (k, x', v— J, |°, 0, 2w),

where 2w=c—2y and going back to equations 3 to 10 we find from (4) and (5)

(25^ * k /V-fL 2v_l M 1

•() 8== /ht/^w-uo I***)/ TTT^^

A'T~ _ A'-^-1)

(26) ,JL. X/ /__iL___^CV

c -k'A/»(^->y

xr 2 v x

Where h' stands in the same relation to — • —— — 1 as h to —

2w u0 c

and — , i. e., h7 is for points close to the margin crystallized in early

uo

x; times independent of -—, and this will be true for the linear rate of in-

2w crease of grain (tangent to the curve of grain) at the margin, and while

2 v 2 vit depends on — — 1 it will vary only between .7 and 9. if — —1 is

less than .966, i. e., — is < .984:. That is unless the crystallization is

^o

practically coincident with the consolidation hr is roughly constant.

J-d-4, /^-iV

(27) h' = X ^V7t / do__ I,/2v v I x I

H^-1) V 2^F / _____

=H-^-£-0:-!K£-^) v'(^

\~fiv ~^ = ^(M0)\^-V,

d?^-I II°

in which t is a function of — and ——1 and (— yrdt ^ = Mr

2w u0 \2w /

x' 2v

must be taken from the table L using — for the distance, — — 1 for

0 2w u0

the temperature.

intermediate zone.

We observe in figure 2 that the curve of cooling of the extreme margin thus indicated soon becomes coincident with a curve of cooling of the sheet of reference Fig. 1 with width c and fixed marginal temperature of 0. If that is so,

(28) v = iu2y = uy,

when 2y represents|the distance of the curve of cooling of the sheet of reference with which it becomes coincident. If the cooling has gone so

far that it can be represented by the first term of •— — = q sin * -, we can see that (24) can be true and that

/^nx tt v Iq . *• 2y . tt Y

(29) — — = -^- sin ——- = q sin ——

v J 4 u0 2 c ^ c

gives us a simple equation to solve to findy% which can always be found.

(30) ?LIL = sin"1 i sin tt *I

J c c

'But we also see that if y is so small, that is, the contact zone so small, that sin 2?ry/y/c is proportional to 2?r y /c then yf will be the same proportional to y, and more generally, if it is so small that sin n tt y / c is proportional to n tt y /q to the number of terms of (2) covered by n will y; be proportional to y and eq (28) be true. Not only that, but inequation (1) if v/u0 =P , and P « , is nearly proportional

«/_ _«y_

2av't 2 a ^/ty; vto —^—- which it is if — < .33, then to the same extent will:

2 a yt «o

(31) ^- = i^ = i (constant X)-^=

uo u0 2 a V t

v; = (constant x) ——-=__

y2a Vt and v = uy,

Thdt is to say if the contact zone y is small enough so that 2v = u2y becomes .33 before the center has cooled perceptibly,1 or the marginal temperature becomes say 1 / 6 of die initial, the cooling at that margin will be the same as at a corresponding point of the sheet of reference whose walls are kept cold. At the same time the cooling at the " center is the same as that of another sheet in the reference sheet, at a

c distance — — y from the wall. The cooling on two planes, center

and margin being the same as on two planes of the reference sheet, the cooling between must be the same, except that due allowance must be

1 And table I shows that 2y must be about ^ —, for then when the temperature at the center is still .9626, the temperature for x = -~ is .3048.

made for the different distance apart of the two sets of planes. The distance of corresponding planes being thus proportional we obtain a formula:

(32) g (k, x, u, u0, y, c,)=g (k,^^-' x'+y', u, u0, 0,)

if 2 sin y ?r c = sin 2 y ?r c nearly.

At the center formula (32) reduces to formula (18) and writing (32) (29) = g = Ax' + B and comparing it with (3), (7) and (9) we find

(33) ^_go-2y-2y' i__'

c c-2y 'hv/2(u/u0)8

(34) B = K •- . _*

c h7 v^(u/iio)3"

The equation (29) is the equation of another tangent to the curve ordinarily or a line parallel to one. It will only appear in the case of small contact zones at the point of minimum curvature. It may be distinguished from the other tangent to the curve of grain by the fact that it does not give a 0 grain at the margin. "We notice, too, that

(35) * = y' - °-2y_ = / _^L_ = y7 J?L_

^ J A J 'c-2y-2y7 J *2w-2y7 J ' w-y'

This is always positive unless y + y; > 1/2, i. e., unless the contact zone is greater than the width of the dike > c/4 on each side, and is for small contact zones practically proportional to the contact zone.

If a series of observations of grain give a value of B negative or very small it is pretty likely that they refer to the equation y = C; x7 and that the value of B is due to the errors of observation.

From the formulas above given not only can the grain be roughly constructed from the data K, u, u0? y and c, but more important still, conversely if from observation we can construct the curve of grain for a given mineral with such accuracy that we can locate the tangents in question we can then draw inferences regarding the size

of the dike, and the heat at injection.

From the curves of grain we may infer the order of crystallization of the different minerals.

A glance at a few typical curves of grain will show us what inferences may be drawn without any special calculation. Fig. 4 shows a number of curves of grain of different values of u/u0 and a small contact zone. Fig. 5 gives curves of grain when the contact zone is large. As the contact zone becomes smaller and smaller the curves approach those appropriate to the case when the contact belt is kept at a constant temperature.

We may make the following comments:

(1) The shape of the curves depends wholly on the ratio of the initial temperature to that of the crystallization of the mineral whose grain we are studying.

(2) Unless these temperatures are very close together, however, the grain at the center does not vary with their ratio, but is proportional to 28

(kc/aVuo), being greater the greater the size of the sheet and the less the diffusivity and temperature of consolidation.

The last condition may be put more suggestively by saying that the grain at the center is greater the nearer the temperature of the country rock is to the temperature of consolidation.

(3) The grain at the margin should be 0 if the initial temperature is more than twice the temperature of consolidation.

(4) The grain will be greater at the margin than at the center if the initial temperature is more than twice the temperature of consolidation, but if it is much more the grain will be practically even throughout, as with some aplites (curve .40 of Fig. 5).

(5) If there is a broad contact zone and the initial temperature is not far below twice the temperature of consolidation, there will be a belt of coarsest grain not at, but parallel to the margin, (curve .52 of Fig. 4).

(6) When the contact zone is quite small and the initial temperature below the twice the temperature of consolidation the increase of grain will at first be linear and very rapid, then the linear and less rapid. This leads to the following practically somewhat puzzling uncertainty.

Suppose we have found by observation a nearly linear increase of grain. We can then locate a tangent to the curve of grain, which will be either that of formula (9) or that of formula (11). But which? Theoretically we can tell by this sign that the equation of (26) should lead to a value of the grain at the margin of zero, while the equation (29) should not lead to a value of 0 at the margin, but one of B, proportional to the effective contact zone y'.

Practically, unavoidable errors, of observation will be shown by a divergence of the equation from giving a zero value of the grain at the margin, even if it is really referrible to the equation (26) g = C'x'. But if the values of B come out negative, indicating a negative contact zone, they are likely to be due to error, and once more as C' is independent of the width of the dike or of the contact zone it is more likely to be fairly uniform for the same type of rock.

(36). Thus from (19) to (26) we find: -^-=— V (2¥;~~1)B

U C 7T I ——————————————

I v/u0

As long as u/u0 is low enough, i. e., < .80 eq (36) expresses the relation of E / C' 7c. We can construct a curve or compute a table to express E / C;c in the terms of v/ u0 (Fig. 6) and from such a curve and the observation of the grain at the middle, the rate of increase of grain at the margin and the probable breadth of the zone affected c == 2vv + 2y we can at once infer the ratio of the crystallization temperature to the initial temperature. In this expression the actual width of the dike or the ratio of contact zone to dike does not appear. This is because by the time the temperature has dropped to .80 uo the contact zone and dike are cooling together as one mass.

fig. 6. Showing E/C'c or tbe ratio of the grain at the center to that which would be reached if the rate of increase at the margin C' kept up for a distance c, equivalent to the whole zone affected.

But if the crystallization is earlier and we have to use eq. (18) instead of eq. (19) it will not be so. The actual grain

tt*

will diverge from that of E and ^ from that given by (36). But

as the crystallization temperature approaches u / u0 as we have seen the increase of grain becomes more and more linear and E approaches

® w. — ~. An ordinary range of contact zone mav perhaps be fromC'c c joy = o to y = w, and for that range of contact zone, the point which

j^- approaches will range from .5 to .25. The accompanying figure 6

\j C

gives „:?__ for various values of u/u0 and also the ratio of E/C'c as

derived assuming three values of y, to wit: y = o, y = —, and y == w and computing as follows: Going back to (18) we have for the center g ^K ^f(^ ^^) V =dv~7T0 - KM0 / ^=577^. We will

assume y = 0 then - = 1 /2 and we must use the row 12' (- = — \J c /
\c 24 /

of table I. Taking this row we notice that — dropped from

u0 .8742 to .7597 when M0 has the average value of .1234. Accordingly

jL_ *1234 „ E

r= /jrns = -868-=K

The average value of the temperature we will take for this Interval tobe (i?742 + 7597) = ^16^ Then/^X A will be .6338. Now for the2 Vu0 /

temperature at the margin table II holds, and we find P"1^— -lY=m'

^no '

x;

= -—r=- to be .630. Taking the nearest differences we find that for an 2<& V t

increase in m' from .63 to .64 or dm' =.0100 there is a change

in Pin' or (2— -l) of .0076 so that going back to (27) and (26)

^ u0 / _____

eg ^ c(y__ = ,~~ !_. _. /"ToToiT" (.630)^

Kx7 ~~ ~K~ "" 2 V.01)76 \ 2(7^338)3 (.6338;^

- _J_

= ."M5~ Thus the ratio of grain at center E/K to c C' /K is

.^7-= .368/—|- - .1651cC' / .445

Similarly we may go on to compute the values for the drop of temperature given by values of the temperature in the same row and adjacent columns of table I. Each row will correspond to a different value of the contact zone. C; c/ K may be also found and the quotient, E/ C'c Some of their values are shown in Table III below and the curves showing the dependence of E / C'c upon v/u0 are shown in figure 6for different contact zones.

In a very rough way the value of the actual grain relative to C' c is proportional to the amount by which the temperature of crystallization is nearer the initial temperature than the country rock temperature. In fact If the contact zones have the width of the dike the actual grain E Is to the grain which there would be if the marginal Increase continued to the center (i. e., —t-\ very roughly as the amount by which

the consolidation temperature is nearer to the initial temperature and exceeds the consolidation marginal median temperature, is to the median

temperature.

i Ttiese calculations are made with a slide rule and are not very accurate.

Whenever u/u0 = Pm h is independent of x and we have the following table:

approximate formula.

Now, if we suppose that we can make certain simplifications, which can often be done, we can obtain approximate formulae which are very easy to handle. We will assume that y is equal to y' and that the

fraction —^—^-^ = 1. This we may do when the contact zone is

c-2y J

relatively small. We will also introduce h; as before and call v/u0 =f*. Also we will call the expression (k c/a vruj K and we have the following formulae :

(40). Cf = K/_chx(2v/u0— 1>3 = K/ch/(2/2 — 1)* from (26 and 27) As K/c = k a vruo, C' is independent of the size of the dike or the contact zone.

(41) A - K/ch(v/u0)* /g = K'/chfVg", from (33).

(42) B = KyYch(v/u0)i /2~ = KyYchf3/2 , from (34).

(43) E = k/tt fwu0 = K/irf from (19).

From (41) and (42) we can determine y7, the effective contact zone, which is B/A.

(44) y' = ^-.

If y is less than 1/12 of c, we may be sure that so far as the contact zone is concerned our approximate solutions are pretty close. From (41) and (43) we can find c in the terms of A, E and K—that is, we can sometimes by observation of the grain determine the thickness of the . dike when it was not previously known. Moreover, we can find f in the terms of A, E and c, and if f2 does not come too near to unity we may feel that our approximate formulas and results from them are not likely to be far out. We can also find K in the terms of A, E and c, or if we have also Eq. (40) we can either check on our observations or get along without c or some other factor. From formulas (40) and (41) we can find f in the terms of C' and A, although the equation is a cubic. It is quite rapidly solved by approximation. We can then find K/c.

Then let a certain observed rate of increase of grain, represented by the slope of a certain straight line tangent to the curve of grain be s. We may not know whether it represents C or A as we have said. We shall have either

(45) f2 = u/u0 == E/.45 hsc — from equations (43) and (41) letting s — A; or from equations (43) and (40) letting s = c

(46) 2/2 = 1 + (E/.45 h'sc)* (2/2)*. This equation is, however, already solved approximately in figure 6. Thus it will be comparatively easy to obtain the alternative values of v/u0 on the two hypotheses. Since 2v/u0 is always between 1 and 2 and the cube root varies but slowrly, it will be easy to insert an approximate value in (46) and obtain nearer approximations. Moreover having found v/u0 we can go on to find K.

(47) K = *rE/= trE IJL = Cch'(2v/u0 — 1)* = Ach(v/u0)i f2. It remains to be seen if K which depends on the diffusivity, the size,

the initial temperature, and a constant which represents

the facility of crystallization of a particular mineral in a particular magma, will prove constant for one and the same flow as it is assumed to be for the sections from a given point.

An interesting question is where the various tangents meet—that is, wrhere will the zone of marginal grain become equal to that of the center. If we refer to the equations of the three tangents we have the following formulae:

(48) x'^E/C^ch'^l2 — 1)1 / tt/,

where x;13 is the abcissa of the meeting point of the two tangents; x;13 / c must be less than .282 according to this formula which is the same as that represented by the full line of the figures showing the ratio E / Cxc. Similarly

(49) x'23=(E—B)/A=.45 hcf2—y%

where (x^—Jr)fv is less than..4; and finally lines g; and g/;, formulse (40), (41), and (42) will meet at a point given by

(50) x^ = B/(0'-A)=y/^(l-^)~f-l.

From formulse (48) and (49) we shall not be able to find the width of the contact zone, but we may often be able to if we know over what range some of these formulse are closely applicable. If, for instance, formula (40) holds at least to a value x', it may be shown that

(51) 2y is not less than x'/P-' [(u/u0)—1 or 2w] Also in equation (50), if we know exactly x;12

~«(62) y = '((^?^-lK = (l.4toooJL,-l)*'B

p C must always be greater than A and between C; and A there is

the relation

(W\ °' /h ^2"(2-l / 52)t ^ / 0-2y \ (53) — = {— ———————————) ^_____j

up the values of f2 — u/u0 of about .80 =-7- is nearly 1 but as u/u0 gets above .90 it rapidly diminishes but does not fall below —r=. Thus for small contact zones

™ t-i£t<-»h

a n .c i c—2y 2w w i /

Again as c — 2y = 2wwe find ———!~^ = -——^-7 =——=!/

5 J c—2y—2y' 2w—2y' w—y /

(iLZl)so thatifr^w^ °°

\ w / J A

A = 0

application of theory of g-kain to the light house point dike.

We will now proceed to apply this theory numerically to a typical intrusive—the quartz diabase dike of Light House Point, Marquette, 29

probably genetically belonging to the Keweenawan flows; but we wish to make two preliminary comments.

First: It is likely that the margin of the dike will be somewhat cooled during the act of intrusion before the molten magma has ceased to flow, and in so far as it has done that and crystals have been formed floating during motion, we cannot expect our formulae to apply. The irregularities will be greater in the earlier formed crystals.

In the second place microscopic examination shows that olivine is more conspicuous near the margin and intergrowths of quartz- and orthoclase near the center. This suggests a chemical change and the analyses of this dike given in connection with the theory of copper deposition show that it really occurs. Apparently the olivine crystallized first and a less magnesian magma was crowded to the center. The variation of grain due to these factors remains to be seen. Initial irregularities of temperature rapidly smooth out in cooling.

augite.

We will begin with the mineral which appears to be the latest formed' of the unquestionably primary minerals, the augite. Some observations are found on pages 243 to 245 of Volume VI, Part 1, but I did not consider whether the marginal zone of increase there discussed was limited by x13 or x23, a serious omission. The average observations on a set of sections more recently taken, on Michigan Street, Marquette, July 17, 1902, are (accuracy of measurements not over 10 per cent):

*Augite tends to gather into chondri.

The specimens at 8,230 is from the center of the dike, so that 2w is-16,460 millimeters. The specimen at 1,622 millimeters was taken at what seemed to be the end of the zone of increasing grain, and it is obvious that if the rate of increase which holds from the margin up to 761 millimeters continued the grain of the augite would there be .9 millimeters, or nearly the same as at the center, so that the field estimate was not very far out of the way.

A second set of specimens were collected by Mr. F. E. "Wright at another point not far off, where the dike is about 55.9 feet or 17,040 millimeters wide, and the contact with the Mona schist is 20 paces east

of the fence at the foot of Circle street, Marquette. "We had one section which was made 5 centimeters long, to cover the 50 millimeters next to the contact. This shows that even at the margin the increase of grain is not so much greater as it would have to be if the slope we called C were A.

The result of observations on the augite at different distances are given below. It must be remembered that when the grain is very fine it is difficult to get an accurate idea of it. The average grain for the three center slides agrees well with what we found before. E is 1.07. Up to 670 millimeters the rate of increase C is .00046, which is quite as near to that previously found as we could

expect, but the grain of augite at 1,890 millimeters, is certainly much finer, and that at 4,155 mm, perhaps somewhat coarser than we might normally expect. I have made repeated sets of observations on the former section, and can only account for the fineness as due to some initial irregularity of temperature or composition.

i Figures obtained upon revision, the second set of five sections, not quite so carefully measured. As there is none of the country rock visible in section 1, a few millimeters should perhaps be added' to the distances. A further discussion of this dike will be left till later.

A third set was taken. Dr. F. E. Wright wrote Dec. 2, 1903: " Have just sent ten samples of the Light House Point diabase dike to Voigt and Hochgesang. The numbers of the specimens are 1, 10, 40, 96, 137, 170, 280, 404, 516, 670 and 740. The numbers express the distance in cm. of the specimens from the contact of the dike with the Mona schist. The specimens were taken from the same old place just east of the fence, leading off north from Arch street. You know the thickness of the dike from last year's measurements, I believe. Width — 55.9 feet—17,040 mm. Not corrected for dip which is from 5°—10° to N. (measured on jointing pillars. Strike to N 75° W. The walls of the diabase are approximately parallel to the planes of schistosity of Mona schist. Dip of latter 75°—80° N.)"

One object of taking the third set was to see how far accordant re-ults would be obtained ; also the first sets did not suffice to determine A.

The results of measurements were:

1 This was misnumbered in section; I was enabled to detect the mistake by the grain. Average gradient margin to 2,800 mm. = .000246.

The thickness of the dike is about the same in all three cases, as also the coarseness of the augite at the middle. It appears to change slowly if at all over quite a broad belt. It agrees very well with the central augite grain in Yolume YI, part I, p. 244, and plate XY. We have in this later case, for a distance to the center of the dike about (23 feet) 7,000mm. to (25 feet) 7,600 mm. dimensions of 1.0, 1, 0,1.3, or in average 1.1 mm. Dr. Wright's specimens for one set give us 1.13 mm. and for the other set 1.07. My specimen at 80,230 mm. gives us 1.13 mm. It is plain therefore that E can hardly differ 10% from 1.10 mm.

In the Isle Eoyale report we had only one observation on a section close to the margin at a known distance from it> p. 244. That would give us .1 (mm.) -*- 76.3 (3 inches = .0013).

The more recent sets both show an irregularity of increase of grain from the margin to the next adjacent section. Then the increase of grain is nearly uniform or shows no systematic tendency to vary from a uniform rate up to 761 mm. in one case, 670 mm, in the other, and 400 mm. in the third set. Though there is considerable variation in the various slides the average rate of increase or slope of the tangent is nearly the same in both. In the one it is

.410 — .018 - .392 >AAA_ . ,. ,,

• -W=r-5er=rm= '°00553 m the other>

•SIQ-.QI^^^ .00046, in the third

670— 10 = 660 '

.243- .01-.238

400— 10 - 390

These observations agree within 10% of their average and, considering that the sections are taken at different points where the dike had different thicknesses and probably not exactly the same initial temperature and pressure, as well perhaps as we could expect, and this constancy in the rate of increase rather points to its being C' instead of A. We will, however, work out both suppositions to show the method and how we may distinguish whether it is 0' or A.

If the slope .0005 ± is C' :

Then we may find E /C'c = 1.13/ (.0005 ±) (17,040 +) = .132-.

Accordingly by Fig. 65 following the curve of E/C'c for y = o, (because unless we do this we ought to take c > 17,040 which would make E/C'c proportionately less since c — 17,040 + 2y), v/ u0 == .77-.

Or we may assume (—) =1.2 for a first approximation and solve

^ ^O / fi |

in the equation (46).

To get some idea of y we note that apparently the grain is as coarse at 4,000 mm. as at the center but not as coarse at 2,800 mm.

Therefore by equation (49) x'23 > 2?800 = A5 h ° P ~~y "

Orx'ffl = (.293-) c-y'

Also 17,040 = c-2y.

Assuming y = y' as a first approximation : 2(4,000-a part of 15200) = (.586-) c-2y;, whence subtracting and eliminating c 0.414 c= 9,040 + part of 1,200 c = 21,800 + part of 2,900

, 21,800 +part of 2,900 -17,040 _ oon , , , _, . .A

and v = ——————————5-^————————— = 2,380 + part of I?4oO

" Z

y /c = c/8 very nearly. And if we substitute the value of c in the expression E /C'c it is about 1.04 or v / u0= about .73.

But there is another way of getting the contact zone. In the third set of observations between 960 mm. and 2,800 mm. the rate of increase is fairly linear as a

diagram shows and corresponds to the line Ax' + B. .690-.368 __ 322 = 0001/-7 ^ 1

~~ 2,800 - 960" ~ 1,840 ~" ' """5,650*

Also B will have a value between .048 and .150 more likely the

larger. Thus B/ A - y' p^j^^r = 850 ; whence y' - 900.

These two values do not agree very closely but they do agree in indicating so small a contact zone that we are justified in assuming y = y'.

Again we have remarked that the change from the slope C' to that of A, comes somewhere about 760 mm., between that and 400 mm. Then

from equation (50) we have y / ^r-r(1-^2) ~^ ^ ^ = .77 = —-•

Hence y = 1.46 (400 to 760).

This value of the contact zone is in harmony with that already found. Hence we are safe in assuming that the contact zone of appreciably affected rock of the Light House Point quartz diabase is not far from a

meter at the point in question. We then should use a value of c of 17,040 + 2(1,000) say 19,000 mm.

E/ .45 hAc = 1.13/(.45)(.86) (.000177) (19,000).

= ,87 or v/u0= .70. E / Cxc = 1.13 / (.0005) (19,000).

— 1.20 or v f u0= 75-. Or as an average v / u0 = .72.

Greater refinement might be gained by manipulating the data, but would hardly correspond to a real increase in accuracy.

Drawing all the observations of grain to scale in one diagram we seem to find :

For C' .00072 and less especially for set 1. For A .00022 and more for set 1. For B .150 and for

B / A = y1 = y nearly 660 (mm.) and almost precisely the same for set 1.

Thus set c = 2w + 2y = 17,040 + 1,320 = 18,360. E = 1.14 and possibly less for set (1), i. e., 1.03. From E/0'o=(1.14)/ (.00072-) (18,360) = .87 we have by the diagram Fig. 6, v / u0 = .80.

Fromeq. (45) E/.45 h A c = v, u0^(1.14) / (.45) (.86) (00022) (1,836) we have v/u0= 74.

We will therefore assume these values as the most likely: v/ u0 = •^2, 7= 71= 660, but we know that the ratio v / u0 may be ± .02 out. According to this supposition, then, the augite. latest formed of the minerals crystallized from the magma, had hardly formed at all when the magma came to rest,—not over a very few mm. from the contact. It was formed at an average temperature about three times as near the initial temperature of the magma as that of the country rock. So that if the temperature of the country rock was about 40°' C. and that of the formation of the augite 1,0900"C. the initial temperature of the magma would be 1,440°. Moreover there would be a contact zone appreciably warmed on each side of about a meter.

This is undoubtedly the correct supposition. For if we assume that this slope of .0005 to 7, instead of representing 0', represents A, multiplying it by (x'), the distance of the various sections from the margin, and subtracting it from the grain we ought to get B, and the B/A would bv Ecl- (44) give us (y) the contact zone. But as a matter of fact if we take the^slope from 50 mm. to 761 mm. or 60 mm. to 670 mm. we get as in the last column on p. 226, negative values of B, and hence impossible values of the contact zone, except in one case. And even if we suppose we assume the slope taken for A to be very slightly in error, though we can find slopes within 10% which will not give us negative values%f B, they will still be very small and the contact zone accordingly also exceedingly small. Practically we shall have to suppose that owing to the wetness and convection of the country rock or some other cause°the country rock was kept at a nearly constant temperature. This is the

erroneous supposition I made in the Isle Royale report. But in that case v/u0 would be by Eq. (45)

y_ " = __E__ ^ _____1.13_____

u0 .45 hAc (.45) (.88) (.0005) (17,040-f)

= .300

I got a similar value in the Isle Royale report, simply by observing the curve. If the country rock temperature was 30° C. and the augite formation temperature was 1,090° the initial temperature would have to be 3,350° C. We should have to assume a very much hotter magma initially and get at the same time practically no contact zone, a much less likely state of affairs. Not only this but the rate of increase .0005 should continue practically up to1 1,622 mm and beyond, which it evidently does not. So we have here a direct argument that the marginal rate of increase of grain can not be A. We have therefore the cumulative effect of, an improbably large error in determining the rate of increase, and an improbably high temperature, especially as coupled with an improbably insignificant contact zone against assuming that the rate of increase .0005 represents the slope A rather than C'.

Moreover if it is C' other minerals formed before and at a higher temperature would be much more liable to be formed in the earlier stages of cooling, or even before flowage ceased than in the latter case. We shall proceed then to discuss the observations on them, taking them in the inverse order of solidification, and shall find that they show distinct indications of having been formed in an earlier and very early stage of the cooling.

magnetite.

The magnetite is in part at least formed after this labradorite, laths of which penetrate it2 in the sections taken in 1,890, 4,115, and 7,600 mm. Furthermore there is almost no sign of a porphyritic texture with flow crystals which the feldspar has. It, however, distinctly

and sharply precedes the augite formation. The rate of increase close to the margin is certainly between .0008 and .0003, and apparently very close to .00036. At the center, however, comparing the observations in the Isle Koyale report and our sections it seems as if values differed greatly. For one thing we can not distinguish aggregates and it also seems as if there may have been some absorption.

The intermediate observations vary quite largely as to the intermediate grain, but it is notable that they point to a y=y' of from 600 to 1,500 mm. Thus it will be safe to assume the same width of contact zone and c as for the augite. The value of A lies between .000117 and .00017.

xlf x'=1622, m=— m0 = .095m0, and 24— has a value between 2 and 3 of table I and if u/u0=.315 it is

c c

easy to see from that table that the value of g will be close to .80 and of m0 close to 3.S4. That implies that u/u0 is nearly equal to Pm, i. e., by table II, that is, near .29 which implies that m0=3.05 but for any such value of m and m0 h is practically invariable. x'=.88 and g' = Ax' = .8, or in other words the linear increase of the grain should continue up to 1,622 and beyond.

2In working up the grain observations I forgot this fact, which I had noted not only in these slides but also in the Isle Royale report p 246, and started in on the hypothesis that it was older than the feldspar. The curves of grain quickly apprized me of my error.

From E/C/c=.78+/(.000365+) (18360) we obtain

E^C'c= 1*16 a greater value than for augite, i. e.; v/u0=.75.

From the equation (45)—

v/u0=E/.45 h; Ac-.78+7.383 (.000117 to .00017) 18,360 we see that to have a value of v/u0 as low as augite, if E=.78+ A must be .00022+, so that vy u0 Is pretty surely greater than for augite. If v / u0=.75 A=.0002.

The indications are therefore that the magnetite is formed at a temperature v=.765 u0 or greater. Taking E larger will increase v/ u0 rapidly. It seems quite possible that the contact zone and grain may vary at different parts.

Very possibly the more or less ready absorption or diffusion of the gases of the magma into the country rock and consequent oxidation was a determining factor. It seems to me likely that with the loss of temperature and mineralizers and the crystallization of labradorite, when the time came that the olivine already formed was corroded (as microscopic examination shows it was) absorbing silica and turning into the augite molecule, there was a release of some of the Fe-O- which, absorbing a little O from the H-0-, allowed that to become H-O-H or water and became itself magnetite Fe3 O4. This is a good illustration of the fact that v and u0 of our expression do not stand for heat merely but for that and any other conditions of crystallization that follow similar laws of diffusion.

Observations on set (3) in mm.

grain of labkadoeite in lighthouse point quaktz diabase.

The feldspar at the extreme margin is more slender and trichitic than when it is coarser and that complicates the measurement of the grain. Near the margin these feldspars show flow arrangement and lines of coarser and finer. At 50 mm. there is a distinctly porphyritic texture and even at 175 mm. and 450 mm. and 616 there is a quasi-porphyritic 30

texture there being a good deal of range in the size of the feldspars, many large but some quite small. Farther in the porphyritic appearance disappears. This plainly indicates that at the time of cessation of motion the temperature had dropped so much for a belt at least 7 and 16 inches wide from the margin that feldspar formation had begun. This being a broader belt than for the augite a temperature and time of formation of feldspar in advance of the augite is indicated, and we shall expect to find more evidence of initial irregularities of temperature in the feldspar grain. This we do as appears from the observations. It is more difficult to measure the grain of the feldspar owing to its pronounced tabular shape, and the fact that at the margin the latter seem to arrange themselves parallel to the walls. This may be due merely to the flow and pressiire but I strongly suspect that it is a thermal phenomenon.

The method of determining the grain, which is fairly successful for the augite and magnetite fails entirely for the feldspar for it is entirely impossible to exclude the rhyocrystals (or crystals formed while the magma) was still in motion from those formed after it came to rest. Moreover their presence as crystallization centers (German ulmpfen", buds or grafts) would tend to produce a finer grain, by interference. At a general look it seems quite plain that the feldspar is coarser at 7,400 mm. than at 6,700 mm., but I have been able to devise no system of measurements to put this into clear mathematical and tangible shape. As a matter of fact, the feldspar began forming among the very earliest constituents, even before the magnetite and olivine. But there are indications that it continued growing while the augite was forming, even though as far as the M (010) face is concerned it is idiomorphic against it. Where the feldspar is imbedded in a patch of augite composed of one or more individuals it is often noticeable that the feldspar laths near the center of the patch are smaller than those in the margin or grouped by the|iiselves outside.

In fact not only did the feldspar continue to grow during the formation of the augite but, changing in composition and inter-grown with quartz, it fills the last interstices. In this case, however, it is apparently orthoclase, and there appears to be a rather sharp line between that and the previous soda lime feldspar.

It is thus indicated that the conditions of formation of the

feldspar are very largely chemical.

A few of the porphyritic laths of feldspar are as long at the . margin as at the center but the average length is certainly much greater, and they are also broader in proportion. Near the margin the rate of increase Cf for the smaller crystals, not formed while in motion is not less than .00075 in any case.

Then O'c will be say 20,000 mm. x .00075=15 mm. E is for these surely not greater than 1.65 x .34=. 56 mm. for some of the porphyritic

feldspar formed in motion might be mixed (or ———— ^l—) from

third set of observations). This would give for E / C'c a value of .038, so low as to point to consolidation immediately at the temperature of the margin, which is not in harmony with what we have said.1

LABRADORITE.—FIRST SET.

3Observations of Ohm sections, Jan. 13. '^Observations of Wright sections, Oct 31. Observations of Wright sections, Oct. Observations of Ohm's sections, Dec. 24.

The lower two sets are rough incomplete observations.

The magma appears to have secreted first a little magnesia silicate (olivine). Then as the temperature dropped there seems to have been no tendency to separate any lime salt etc., until it could crystallize out say the Labradorite Ab2 An3" = 2 (Na2 O A12 O3 6 SiO2)+3 (2 CaO, 2 A12O3 4 SiO2) which has the ratio Na2O : SiO2 : : 1 :12. Beginning with this the amount of soda gradually increased as the variation in extinction shows. The augite may have begun to crystallize when the ratio of Ab: An in the Labradorite was Ab2: Anj for that has the same ratio of bases to SiO2 as augite. Thenceforward the augite and the labradorite may have grown pari passu as a eutectic mixture as above noted, until the lime was practically exhausted. Previously, however, a certain amount of iron (which may at high temperatures have been ferrous iron Fe-O™ having perhaps taken O from H-O) crystallized as magnetite.

After the crystallization of the augite and labradorite the remainder was probably capable of undergoing a considerable drop without crystallizing, being probably a hydrous solution of silica, potash and alumina, calcium and other chlorides.

1 While this is in press, I have seen Day's paper on the fusibility of the feldspars. The higher temperature of formations which he finds for the feldspars and their tendency to undercooling fit in very well and explain much that had puzzled me.

The olivine which very early crystallized out, yet only in very small porphyritic crystals at the margin, did therefore not begin to crystallize much if any before the dike came into position. This inference agrees with the facts: first that the grain varies from center to margin : second that the marginal crystals are not corroded while the central are: third with the fact that Barus found the temperature of thorough liquidity or fluidity of a very similar diabase to be 1,360°; and fourth with the fact that the curve of grain of the augite indicates that the initial temperature of the magma was some 1,400° or a little above that of fusion of olivine as we have already mentioned. Observations on the grain of olivine indicate, therefore, much less.

grain of mt. bohemia gabbro-aplites.

It will be remembered I stated that Mr. F. E. Wright, the Assistant State Geologist, is studying the Mt. Bohemia gabbro. Its composition is much like that of the Duluth gabbro described by Winchell and U. S. Grant as will be seen by comparison of analyses. In it there occur seams or aplite veins and it itself sends out aplitic seams of the red rock into the contact zone of altered ophites. These rocks are mentioned in Volume VI, part 2, pp. 72-73, and the presence of these red stringers from the gabbro in the contact zones confirms the conclusions I drew there as to the intrusive character of the gabbro. They are formed only a few feet from the gabbro in the contact zone, and correspond to the red rock described by U. S. Grant and Bayley, and by Irving.

They are only a few mm. thick but they are uniform in grain from side to side and while fine grained as will appear by no means aphanitic. The fact that they are crystalline though so small and that the grain is uniform indicates (comparing curve 40 of Fig. 5) that the country rock was hot at the time of their injection. Of course the country rock may have been heating first and cooling later as the result of the injection of the gabbro as a whole. But the average effect on the grain is as though the temperature of consolidation was considerably nearer that of the country rock than the initial temperature of the magma, and that we see agrees nicely with the field conditions. The grain is then wholly

kc

determined by the formula forE=—^and u represents the difference

J Tra^ii L

between the country rock and the consolidation temperature. As c is small u must also be relatively small that E may have much value. E, the grain should also depend on c, which we may assume to be proportional to the breadth of the little dike. As we see from the table of the sections below, which gives the average length of the rectangles of orthoclase and the breadth of the dike, such is the case.

We see that the grain does appear to vary quite directly with the size of these feeders. The observations on the grain check with the field observations and distribution and close welded contacts in proclaiming these either contemporaneous with or closely subsequent to the main intrusion.

THE THEORY OF COPPER DEPOSITION.

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During the past few years there has been a lively interest in the theory of the origin of ore deposits, and recently two works have been published by the Institute of Mining Engineers and by the Engineering and Mining Journal, which give a very good account of the present state of the controversy, and references enough to start one pretty well over the whole field of the latter.1 In these discussions our deposits of iron ore and copper of Lake Superior have been frequently used as illustrations of the various theories by those who take part in the discussion. In view of these facts, it seems proper to give a review of what is known concerning the copper of Lake Superior and of the theories regarding the same with reference to recent developments. There is also a practical interest involved in the discussion. As we shall shortly see, all the best authorities at present agree that the copper has been deposited by water, but there is some difference of opinion as to whether the water current is a descending one and the copper was deposited and a circulation produced by gravity, or ascending, and the circulation due to one or more principal causes, which we may call, as a common name, volcanic, meaning thereby, that they are connected with the interior heat of the earth. Now, it is a common notion among the practical Cornish miners of the copper country, although I do not remember to have seen the statement in print, that the copper is liable to occur under high ground.

To understand what is meant by the expression "high ground," we must remember that at the present day the bulk of the copper is deposited in bedded lodes. It would be perhaps more correct to say that it comes from lodes whose strike is the same as that of the beds of the Keweenaw formation. It is commonly accumulated in the originally more porous parts of these beds. Sometimes these porous parts are sandstones and conglomerates, but more often they are the porous upper parts of lava flows. It is, I believe, true that in many cases there are faults parallel to the bedding planes, or so nearly so that the difference has not been detected, which have had an important influence on the production of copper. In some cases we know there are such faults, which generally have a somewhat steeper dip than that of dips generally.1

Nevertheless, in a practical way, the most characteristic feature of these lodes is the porous beds. Any one of these porous beds may contain copper, and there are few of them, which are decomposed, that do not show some trace of copper. But the parts which are relatively rich, rich enough to be the sole object of interest to the miner, are rare, and the meaning of the idea that copper occurs along high ground is, as I understand it, that in following the outcrop of such lode, chutes of copper are liable to occur where the outcrop of the lode is extra high. Now, there is some ground for this idea. If we take the Baltic lode, just developed, we find that in the Baltic, Trimountain and Champion mines, this is rich, while just northeast, on section 16,2 the Atlantic mine has done a good > deal of exploring without being able to find the lode because the lode when encountered was not rich. Eising once more on the high land, we find the Isle Eoyale mine close to the deep trough of Portage Lake, where, on the other side, is the Quincy mine, on high land again. The Sheldon and Columbia and Hancock mines, more down in the Portage Lake valley, do not appear to have been so successful. Going-farther north, we find the Calumet & Hecla, Tamarack, Kearsarge and Wolverine mines, not very far from the Allouez gap on the southwestern side; on the northeastern side is the Mohawk mine. Nearer the gap is the Ahmeek property, which is just being opened up and whose true value has not been determined. If the "high ground" notion has any substantial basis, its prospects would not be so good as those of the Mohawk and Wolverine mines/ although it lies on the same lode and between them. The Phoenix mine and the Cliff lie on higher land, not far from the gap of Eagle river, and turning to the other end of the range we find the Minnesota and the National on one side and the Victoria on the other of the gap made by the Ontonagon river, while the Mass and Adventure lie on the high land between the Flint and the Fire Steel rivers.

Now, this grouping of mines in accordance with this notion that the copper occurs on the high ground may be due to the fact that the porous beds are usually covered by drift, and therefore, not exposed, and not easily exploited or developed, except on high ground. It might also be suggested that the alterations which produce the copper has cemented these beds more firmly and had thus given a greater resistance to erosion, either by ice or water. The copper itself, however, even in the richest mines, is only a small fraction of the rock, and is easily decomposed chemically, and so are some of the associated minerals, and, although at times, copper bearing amygdaloids, as the igneous porous beds are called, are more or less saturated with silica and epidote, I do not think those minerals are so characteristic of the copper-bearing lodes as to lead to a

'Genesis of ore deposits. Reprinted papers from Volumes XXIII, XXIV, XXX and XXXI of the Transactions of the American Institute of Mining Engineers. Published by the Institute at the office of the Secretary, New York, 1902.

Ore Deposits, a discussion republished from the Engineering and Mining Journal, New York, 1903.

See also Geological Survey of Michigan, Vol. I, Part II, p. 43. Vol. VI, Part I, p. 216.

Yet more recent: Trans. Am. Inst. Min. Eng., October, 1902. Igneous Rocks and Circulating Waters as Factors in Ore Deposition, by J. F. Kemp; Ore Deposits near Igneous Contacts, by W. H, Weed, and discussion of same. Annual Report of the State Geologist (of New Jersey), 1902. Copper Deposhs of New Jersey, by William Harvey Weed. The Chemistry of Ore Deposition, by Walter P. Jenney.

iThe top of the Calumet and Hecla is markedly slickensided. See also Volume VI, Part II, Dp. 86-94; the

slide fault in the Central mine appears to be nearly parallel to the Kearsarge conglomerate. The accumulation of (topper was in the vein above this slide, and on reaching the conglomerate they worked on top of it finding good copper ground.

The annual report of the Phoenix mine for 1901 shows in the section by Dunbar D. Scott, the steeper fault slide in that mine, in the St. Glair vein. The old Minnesota, now Michigan mine, had its largest deposit of copper where a steeper fissure intersected a lode. See report Commissioner of Mineral Statistics for 1880, p. 76. Copper Handbook, 1902, p. 195.

See also Van Hise, Iron Ore Deposits of the Lake Superior Region, pp. 344-348, for account of the same system on the Gogebic Range.

2Volf VI, Part II.

sper contra the good rock obtained at the Ahmeek, and as Agent Denton informs me in the south end of the Winona under the swamp, is against this idea.

relatively greater elevation of such parts of the lode. However, there is room here for inquiry.

I leave to the last another possible explanation which has a more direct connection with the theory of the deposition of the copper. If the copper is deposited by descending waters, as Pumpelly, who has done by far the most work upon the subject, suggested,1 and the motion of these descending waters is determined by gravity, descending along the lodes at one branch of the inverted siphon and rising either in the same lode at a lower point of its outcrop, or in some cross fissure, which might very well be the cause of the gap in the range, then we can readily see that the greatest activity of circulation and the greatest deposition of the copper consequently, should be beneath salient points of the outcrop of the lode. Take for instance, the Calumet & Hecla. That deposit outcrops 600 or TOO feet above Lake Superior, and the chute of the richer streaks in the deposit is northward, and we may imagine the waters working down in that direction to reappear over in the Allouez gap or up some fissure which may possibly have determined the gap. We see, therefore, that the question as to whether the copper was deposited by waters circulating in one fashion or another has a practical interest in guiding the search for the richest parts of the lode. Van Hise has suggested not only this, but that the richer parts of the lode—called chutes—will be found beneath upward bends if the waters of deposition are ascending, beneath downward bends if the waters of deposition are descending. If he is right, which I doubt, in saying that the copuer of the Michigan lodes are deposited by ascending waters, the southern end of the Ahmeek and the northern part of the Kearsarge properties is more likely to be extra productive according to Hubbard's map of the Allouez gap area (Volume VI., Part II., Plate VII.), but if the waters are descending, the same area is more likely to be lean.

In the first place, we may premise that it is a settled question that the copper was deposited by water. All kinds of authority agree in this, although at one time a few geologists thought of its being inserted in a molten state. But native copper and native silver occur together, as they could not if they were melted. They would at once be alloyed. Jewelry is often made of sections of nuggets of copper and silver, popularly known as half breeds, where the sharp and irregular line between the copper and silver is beautifully displayed. We also find copper grown upon minerals, like analcite and prehnite, which one can fuse in a candle flame. It is not very rare to find a sharp crystal of dog-tooth spar entirely plated over with copper, and then the growth taken up again.2 Pumpelly has given in Volume I. of our reports, a most thorough discussion of the way in which the copper occurs.

It is worth noting that most of the Michigan geologists from Donglass Houghton down, have recognized that the copper was intimately associated with the traps in its origin, and that Dr. Wadsworth agrees with Foster and Whitney, Mueller and Pumpelly, in attributing the deposition of the copper to descending waters.

In the "Notes on the Geology of the Iron and Copper Districts of Lake Superior," which he issued in 1880,3 he says:—

iVol. I of these reports, Part II, p. 40.

2See Volume I, Part II, Chapter 3; also Volume VI, Part II, pp. 163 to 165 of our reports. ^Bulletin of the Museum of Comparative Zoology, Vol. VII, No. 1, pp. 86 to 130. See especially the resum6 on p. 109. 31

"Whatever may be our view respecting the sources of the copper, it is-evident that it was deposited by aqueous agencies, and that the general course of the solution was downward." p. 110, and again on page 123, he-refers to the decomposition brought about by the medium of the "percolating waters, whose course seems, in many cases at least to have been downwards." On page 126 he writes, "The copper has been found throughout the district underlying heavy beds of trap or a series of smaller ones; in fact, in the parts visited by us, experience has shown that copper in abundance was only found where trap in large amounts overlaid the vein or bed" [this would not apply to the Nonesuch]. "The copper was found filling, at the Calumet and Hecla mine, the joints of the overlying trap,, and extending as a continuous sheet through fissures at right angles to one another. At Copper Falls spikes of copper extend downward out of the overhanging trap into the ashbed. These are generally large at the upper and pointed at the lower end. Like them are the secondary depositions of calcite, in this trap, in long spike-like forms, that here and elsewhere have been taken for fossils. These features prove that the copper comes from fossils above downward,1 and that it was deposited after the jointing of the trap."

A very interesting specimen, owned by Dr. Hubbard, shows a crystal of quartz which has been corroded and mainly replaced by native copper. Moreover, in the

deeper part of the Quincy mines, Dr. Koenig has found a water which is now depositing copper and contains 9 grams to the metric ton of the same, and Mr. Geo. L. Heath, chemist of the Calumet and Hecla has also found copper in their mine water (p. 166).

I have shown in my United States Geological Survey water supply paper No. 31, on the different waters of Lower Michigan, that while each porous bed varies in the character of water from point to point, yet there is little intercommunication between them and it is difficult to see how there could be much, except upward along fissures or drill holes. Beds of clay or shale are known to be so impervious to water and to oil, they may be taken to be, even in a geological sense, impervious layers, permanently guiding and separating the different flows of water. The same statement applies to clayey belts of decomposed rock, paint rock and fluccan, as Van Hise himself has pointed out in ably discussing chutes and formation of the Galena lead deposits. Thus, it must be remembered, that Van Hise's figures of underground flow apply only to a homogeneous medium. His figure 5, for instance, might represent the flow of water in one single porous bed, say of conglomerate, sandstone, or amygdaloid, but not the formation at random. It is by no means practically true, therefore, that the zone of fracture "will be searched to its base by moving waters," unless beside being not only potentially but really fractured, so as to make it practically pervious as a whole, it is also covered by a surface topography so rough as to stimulate circulation. These two conditions will be best fulfilled in those mountainous districts, which, as Van Hise remarks, are most liable to contain ore deposits, page 416.

Now, the difficulty in supposing that the copper deposits are due to such a general circulation of water taken in at the surface, as Van Hise imagines, is very great. The following is a sample of water from the

iSmyth. and Van Hise are the only prominent geologists who look for the origin of the copper outside the formation. The association of copper with traps in New Jersey and elsewhere points to a genetic connection.

Arcadian shaft, a relatively shallow shaft, analyzed by Dr. Koenig, August 23, 1898 :

Elsewhere in this report a number of similar analyses are given. The specific gravity is practically 1.000.

On the other hand a deep mine water coming in at the 46th level of the Quincy, was analyzed by Dr. Koenig, with the following result:

Now these two analyses are typical.

Analyses at Freda and in the Hecla mine, given above, indicate a similar deep water. It will require considerable head to counterbalance such a difference of gravity.

The deep waters are strong solutions of earthy chlorides. A water with nearly 1 per cent, of bromine oozes in the 45th level of the Tamarack. The shallow waters are high in alkalies, and so low in chlorine that the alkalies have to be combined with other acids. It is no wonder that, as Pumpelly remarks, alkaline zeolites occur in the upper levels. One might explain the loss of carbonates if the upper water was descending by a precipitation of the same, such as we know has taken place, but I do not see that we can so explain the presence and absence of chlorine. That must, it seems to me, have been an original constituent of the deeper rock moisture, either from the sea in which the rocks were laid down, or of the igneous magma. Prof. Moore in his presidential address before the Liverpool Geological Society (1903, p. 269) has shown that at the top of a 96 foot thick intrusive sheet there is a 10 to 15 foot belt, corresponding to the amygda-loids of the Keweenawan series, which contains a little over 4 per cent, carbonic oxide and 2.6 per cent, water which are, as he believes, probably primary, although now combined as ferro-dolomite.

Moreover, around volcanic centers the escape of vapors containing chlorine and carbonic oxide and the formation of crusts of iron chlorides are co null on.

Now, if they escape they must be present in proportion to their vapor pressure in the lava and can hardly wholly escape, but must be present more ^r less, in the rock moisture of the acid interstices which I have so fully described for the intrusive rocks. But even in an effusive as the rock above figured, we see that between the crystal of augite and that of feldspar, each having its own shape, is an angular space which must have been a pore originally, filled probably with gas. In a thoroughly crystallized trap, doloritic melaphyre or diabase, like that of Lighthouse

ANALYSES OF STONE FROM LIGHTHOUSE POINT, Under direction of E. D. Campbell, by E. E. Ware, June 30, 1903.

(a) Checked later in another sample.

(b) Determined on new sample, first method incorrect.

Point, whose analysis and porosity we give, the porosity is not over 1 per cent. But in the case of an amygdaloid the original amount of vesicular space may have been very considerable, and this space must have been filled either with the original gases or possibly in the case of submarine flows with sea water more or less contaminated with such

gases. Such an origin would readily account for the saline character of the waters, and it is worth noting that such saline waters attack copper, as is shown by the fixtures around the salt baths of Lower Michigan.

Pumpelly furthermore concludes that the water which deposited the copper was descending. One of the arguments which he used is that the alkaline silicates abound in the upper levels and are (page 40) rare in depth; "in other words, they are abundant in that zone of the veins which lies between walls of those portions of the beds of the melaphyre in which we should look for the most advanced stages of alteration in the components of melaphyre, supposing such alteration to be due to the action . of descending solution." By

alkaline silicates he means analcite, apophyl-lite, orthoclase (and datolite of the same age). Copper occurs of similar

Fig. 7. Illustrates original cavities, in a rock of the copper bearing series such as may have been originally filled with chlorine gases, as at a, wedged in between feldspar laths and an octagonal augite grain.

age in some of these deposits. In studying the alteration of the lava flows which form so large a proportion of the Keweenawan series, I find that the olivine is first to alter, then the augite, and lastly the feldspar.

There are other arguments, like those mentioned by Wadsworth, which may be used to support this theory with regard to the origin of copper. I wish also to add a few new considerations. As has been said, down to say 500 or 600 feet, the water of the mines is quite fresh. In the deeper mines, while there is very little water, it is an extremely strong solution of chlorides. The line between the two classes of water is reported to be very sharp, and there is a chance for a very interesting investigation right here. It would seem quite difficult to suppose a circulation of this heavy water up into a light fresh water, especially under high ground, and to imagine that there could be a sharp line between

them. One would expect to find brackish waters clear to the surface, and

that even if the heavy waters rising were diluted by affluents, they would retain the same general character, whereas the surface waters and the deep waters are chemically entirely different. If there was a tendency for the waters to descend, however, the rocks might naturally draw in fresh water of entirely different character from the outcrop.

Van Hise might, however, suggest that the present distribution of waters is a recent phenomenon, the present circulation being Indeed downward, but much later than the origin of the copper.

We may also suggest another factor which might stimulate the circulation of water. We have mentioned the fact that there has been faulting. Now, if by faulting, the upper light sodium silicate water is brought on one side of the fault plane, and the heavier earthy chloride water on the other, there would surely be circulation, and precipitation, too, unless the fault plane were coated with a very perfect impervious sheet of clay flucan.

Suppose, for illustration's sake, a sliding of the upper beds down, such as that suggested by Hubbard at the Central mine,1 relatively light, and superficial waters wrould be brought above the deep waters and the heavy earthy chloride waters would tend to work up through the fault plane, depositing as they went. If, on the other hand, the fault was a reversed fault, the reverse phenomenon would take place,

Another most weighty argument is the occurrence of copper native in the iron ores near Crystal Falls.2 One can hardly imagine this other than produced by descending waters, since the iron ore is universally allowed to have been formed by descending waters. Moreover, it occurs in the upper parts of iron ore bodies and Is not known to have any connection with lower deposits. It may easily be conceived to have been da-rived from an over-lying extension of the Keweenawan, now eroded away.

Pumpelly supposed that the copper may have been originally deposited with the strata, as sulphurets under submarine conditions. He was slightly inclined to call the old lavas altered (metamorphic) sediments.

Irving apparently agreed with Pumpelly3 and Wadsworth, speaking of

the copper having been arrested in its descent. More recent writers on

ore deposits, however, differ from the Michigan Geological Survey and

seem inclined to refer the origin of the copper deposits to the upward

, rising waters. For Instance, Posepny writes as follows4:—

"Some of the attempted explanations assume, in my opinion correctly, as the cause of the first ore depositions, the action of hot springs—in which connection it is only to be emphasized that these thermal effects occurred long after the intrusion of the eruptive fiowrs between the sedimentary strata, so the ores were brought, not by or in the eruptives themselves, but by the later springs, from great depths and perhaps from considerable distances. This explanation, applicable to all deposits, suits also the exceptional case cited by E. D. Irving, namely, the Nonesuch copper bed in the sandstone of Porcupine mountain, far from an eruptive outflow." Posepny seems to have been influenced in the first place by a strong prepossession as to the role of ascending solutions, and in the

i Vol. VI, Part II, p. 91.

2Prof. A. E. Seaman writes that he has native copper in iron ores from the Cliff mine at Iron Mountain, also with ferruginous chert from the tenth level of the Great Western mine, Crystal Falls, also from the Montana mine, Tower, Minn., where it occurs in the iron ore.

^Copper-bearing Rocks, pp. 426, 427.

^Page 145.

second place by the occurrence of the ore as a mineral or rarely sulfide and not as carbonate. The connection of the copper with the Keweenawan trap formation Is much too close to be ignored, and, in fact, widely in the wrorld native copper and traps (hessoses) are associated, as recently described by Weed in New Jersey. The Nonesuch bed is dark and very largely made up of basic trap fragments.

Prof. Van Hise, in his very Interesting article on "Some Principles Controlling the Deposition of Ores/' uses our

metallic copper deposits as a conspicuous illustration of ore deposits where the concentration by ascending waters has been sufficient without secondary concentration by descending waters, writing as follows:—

"In some cases the deposits thus produced are sufficiently rich, so that they are of economic importance. In these cases, which undoubtedly exist, but which perhaps are less numerous than one might at first think, a concentration of ascending waters has been sufficient."

"A conspicuous illustration of ore deposits of this class which may be mentioned are the metallic copper deposits of the Lake Superior region. The copper was in all probability reduced and precipitated directly as metallic copper from upward moving cupriferous solutions. The reducing agents were the ferrous compounds in the solid form, in part as magnetite and as solutions derived from the Iron bearing silicates. When the copper was precipitated, the iron was changed into the ferric condition. It is well known that metallic copper once formed is but slowly affected by the oxidizing action. Oxidation has, in fact, occurred in the Lake Superior region, but from the facts now .to be observed, not to an important extent. An oxidized belt may have formed In pre-glacial times, but if so, it was swept away by glacial erosion, and sufficient time has not yet elapsed to form another. The ore deposits now worked have apparently remained practically unchanged since the time of their concentration. In this fact we have the explanation of the great richness of these deposits to extraordinary depths1."

Prof. H. L. Smyth, of Harvard, had also adopted the same belief and I have already discussed it In Vol. VI. of our reports. Prof. Sniyth believes that the various flows were surface weathered and the earlier non-alkaline minerals produced thereby. The later alkaline minerals he believes to have been associated with the northerly and northwesterly tilting, and the formation and the filling of the fissures and the impregnation and partial replacement of amygdaloids and conglomerates with copper, the copper not being derived from overlying sandstones nor from traps; but probably by ascending solutions from deep-seated sources.

Eeturning once more to Prof. Van Hise's paper, we find that however his theories may apply to the other deposits, they apply very largely to copper-bearing rocks. His first premise is that the greater number of ore deposits are the result of work of underground water. His second is that the material of ore deposits is derived from rocks within the zone of fracture. This would seem to be true, and there are many reasons for believing that the copper is derived from the associated igneous racks. His third premise Is that by far the major part of the depositing' water is meteoric. By this he means that it is derived from the air, rain water which has worked down into the ground. In view of the composition of the water at considerable depths above given on the Keweenawan Eange,

il>oq. cit., p. 353. See also pp. 414, 429.

It seems probable that this is not true, but that the largest part of the water may either have been buried originally with the sediments (he tells me he would class this as meteoric), or occluded in the original magina,, as he suggests. It is a subject for further investigation, just how much of these three classes of water we have involved.

His fourth premise is that the flowage of the underground water is caused chiefly by gravitative stress. If this is true, I believe it may be, then it follows, as Van Hise himself has remarked (p. 417), that if the copper is most concentrated along the higher parts of the outcrop it must be formed by descending waters; moreover, as he also calls attention (p. 412) in case of the minor flexures and pitching folds in the bed, if the waters are descending the richest parts should be in the troughs of these folds, or possibly on lines leading from an anticline down to the trough of the folds. Referring once more to Plate 10, of Vol. VI., Part II, it will be seen that in such a case the copper of the Baltic and Trimountain may be expected to chute to the north when followed down. So should the mines around Calumet, while the Quincy mine should chute southwestward. The Winona mine also seems to chute southward under the swamp. And yet, as the flowage of water is under gravitative stress, it must be remembered that it will take a considerable difference in head for a fresh water to move or balance water with a specific gravity of (1.1898) a fifth more. We have already referred to the possible effect of faulting in promoting circulation. Moreover, the Keweenawan series consists mainly of a great series of lava flows, many of them over 100 feet thick. (See as an illustration of this, the section of Tamarack shaft No. 5, and correlated beds next following.) They are not likely to have lost heat for a long time after their effusion, in fact very likely not before their burial under succeeding flows,1 so that for thousands of years the remnant heat of the effusions and the heat of the later intrusions may have aided the circulation, and particularly the solvent action of the water, as Van Hise (pp. 300, 346^ 774), but more particularly J. F. Kernp and others have insisted. And yet the accumulation of copper in the Nonesuch belt of sandy shales, made up of lava sand, would indicate that it is the chemical character of the lavas rather than their heat which is most of importance. The source of the copper, Pumpelly considers to be sulphides originally deposited and leached out and reduced by the ferrous iron. This may be so, and

Hn the succession of flows noted in the Isle Royale drill cores of Vol. VI and the Tamarack shaft, arid other sections studied if there had been a long interval between flows and they had been exposed to air, the amygdaloids would have decayed to red clays and iron ores, and if they had been long enough under water there would have been more or less deposition. As is obvious from the Tamarack section, there is but very little deposition, and while there may have been some contemporary decomposition, of the amygdaloids—in

fact probably has been, and it may have helped in the copper concentration, yet in very many cases, it is clear that it did not progress far before the next flow came. In fact in some cases an effect on the marginal grain of the underlying flow is indicated. Now, just for illustration's sake, if (p. 245 of the Isle Royale report, FouquS and Levy's observations) an ophite cooling in about six days has augite grains 0.03 square millimeters in area, then one which has them about 50 square mm. in area, like the Greenstone 120 feet from the wall, would take about (6 x 50 -*- .03) 10,000 days before it had actually consolidated, that is, it would be between twenty and thirty years before the center of a sheet 240 feet thick had fully consolidated, and it would still be red hot. But the increase of the grain of the augite clean to the center shows that it must have been during a very early stage of cooling, and a glance at figures 1 and 2 on pages 205 and 206, shows that after more than ten times that lapse of time, say 200 to 300 years, the temperature at the center would still retain something like an eighth of its original excess of temperature over the country rock. The temperature toward the margin decreases of course, and the total amount of calories yet left in the flow will be readily found by integrating equation (11) or (12) of the Isle Royale report. Of course these figures make no pretense to accuracy. We have no right to apply Fouqu6 and Levy's observtions on the grain of a rock of one composition offhand to another. Yet the order of figures is likely to be the same, and it is plain that if the Tamarack cross section has some fifty flows, and this section only represents a third or less of the whole pile of flows thus rapidly piled on each other there may have been temperatures near boiling tens of thousands of years after the formation of the pile, during all of which time thezeolites we now see may have been farming. Obviously, too, there will be a large amount of energy to promote aqueous circulation.

yet it is strange that we see so little of sulphides in the original rock or of sulphates in the secondary minerals. I have seen some fine selenite from the National mine, but in general sulphates are rare. The arsenides and sulphides that do occur are very peculiar, occurring mainly in the veins, and perhaps rather more frequently, as at Mount Bohemia, associated with the acid rocks. There are signs that at least at times they are secondary after the native copper. It has occurred to me that possibly a ferrous or ferric chloride containing a trace of copper was an early volcanic emanation. It is, however, also true that olivine, which is one of the earliest minerals to develop, contains ferrous silicate with which is likely to be associated a trace of copper and nickel. Furthermore, under the microscope the olivine, an early formed mineral, appears to gather at the sides of this dike and the top of the flow. Analyses (Vol. VI. and here) seem to indicate the same thing in the variation of the magnesia and iron.

Thus the copper may have been concentrated, first, with the olivine in amygdaloid tops or residual chlorides; secondly, by leaching out of the olivine, which decomposed either by atmospheric action and meteoric waters, or immediately after the outflow of the lava in presence of the waters (mineralized and perhaps hot), buried with this formation; thirdly, by reactions due to the circulation downward of this water set up by the uplifting of the edge of the great Lake Superior synclinal and attendant faulting. It must also be remembered that according to the earlier geologists there has been enormous erosion, which, according to L. L. Hubbard's theory (VI., p. 94), may be in part replaced by a sliding of the upper beds on the lower for miles. In either case there may have been a considerable migration downward, in the porous belts of the formation, of the material of the strata and the original water thereof.

There is yet much to be learned, but three things appear to me to be extremely probable: the copper was associated with the original lava flows; that originally deposited water or gas has been an important factor, possibly merely in bringing the copper into solution, and that the water circulation which finally precipitated the copper was downward.

It is chemically reasonable and accords with the analyses from the Quincy, Calumet, and Tamarack1 mines to suppose that the copper is in solution in the strong solutions of earthy chlorides.

That it should be precipitated by solutions of alkaline carbonates is quite natural, and entirely in accord with its occurrence in association with calcite, and also in accord with the fact that silica has evidently been dissolved by the same waters. Electrochemical action undoubtedly attended the deposition of the copper. Whether it would commonly be called the caus% or more ordinary chemical reactions such as those indicated were the cause, remains to be seen. Faulting might cause alkaline carbonate solutions to be brought against earthy chloride solutions.

It is apparent, however, that we need still to test the rival theories. We need to trace some one horizon, some one conglomerate or flow continuously through and survey it carefully and accurately to determine the minor flexures. Dr. L. L. Hubbard has done this in part, but the work is not complete.

iPages 143 to 166, 243. 32

THE TAMARACK MINE CROSS-SECTION

AND THE

KEWEENAWAN LODES.

THE KE WEEN A WAN ABOVE THE CALUMET AND HECLA CONGLOMERATE,

ESPECIALLY BASED ON THE RECORDS OF THE CAPTAINS OF THE TAMARACK

MINE SHAFTS AND SAMPLES AND RECORDS PRESERVED BY THE ENGINEERS,

R. M. EDWARDS AND W. E. PARNALL, JR.

. It will be noticed that I have made some changes in the belts, from those given in previous publications and

reports, in some cases throwing together several belts, only one being the true amygdaloid, the others either zones or alterations or slips. As to the practical importance of this, it may be noted that a thick flow is liable to be more persistent and farther traceable than a thin, and that its grain, lustre mottling, etc., is liable to be coarser at the center, and so it is important to recognize these big belts. The lustre mottling is due to the augite crystalline patches. In the normal ophite they are 1 mm. across within ten feet of the bottom of the flow, and then increase toward the center a millimeter for every 15 feet or so. Moreover the belts of faulting and alteration are probably of importance in the stratigraphy of the range and the concentration of copper.

The samples preserved by the mining captains are generally taken from the top of each belt as they observed them, and therefore do not show the true coarseness of the intermediate belt of trap. One object of presenting this section at this time is to show the, importance of the grain, and how different mining men may differ in interpretation of records, which are not fundamentally so very different, and how easy it is to confuse the typical amygdaloid with porphyritic inelaphyre or trap, and altered mela-phyre or sand amygdaloid. If specimens were taken of the coarsest mottling in every belt of trap it would be possible to detect faults, and to know more certainly the size of the flows, than when samples of the trap belts are taken close underneath the amygdaloid, as is usually the case, if kept at all.

The examination of the specimens has often been only with the eye or hand lens, but quite a number of sections have been made. Relative to the systematic classification, I would refer to the Isle Royale report, in which the same series of rocks are treated. Referring to the more recent works of Cross, Iddings, Pirrson, and Washington, it is apparent that the series of Keweenawan flows are mainly dosalic, yet nearly salfemic, and perfelic? that in sub rang they are presodic, but in rang, they may run in the same flow from alkalicalcic at top to docalcic at bottom, e. g., from andose to hessose; generally they are hessose, but practically on the line between hessose and auvergnose. The same variation is noted in comparing different flows and is constantly associated with differences of texture so that I have called the former porphyritic inelaphyre or porphyrite (compare augite andesite, andose and camptonose) and the latter ophite mela-phyre or ophite, compare tholeyite and hessose and auvergnose.

Pumpelly's terrns^ ashbed diabase and lustre mottled melaphyre are nearly equivalent.

One term I use that they do not, that needs explanation. A glomero-

porphyrite is a rock in which the crystallization at the time the feldspar phenocrysts were formed, went so far that these latter are more or less aggregated and bunched together. It is mainly found in the alkalicalcic

flows, I think.

Tamarack shaft No. 5, went through 41 feet of peat and 5 feet of gravelly hardpan (till), before striking bed rock, began Aug. 7, 1895,— Jan, 1, 1896, 140 feet.

On the lower side of the shaft they average 11 feet lower than the figures given. See note book 99, p. *SS, Portage Lake Mining Gazette, March 24, 1901, also Lake Superior Mining Institute, Vol. VII, p. 50.

1. Amygdaloid (T5bl, on N. W. side) ; amygdaloidal trap (T5b2) ; and amygdaloid (T5b3, 20 to 27) at center of shaft. Total thickness, 8+6+13* =27+ (21.2)-1

Compare belt 22 at the Copper Falls drift, and the Isle Eoyale drill

hole IX, 482-493.

2. Conglomerate (T5b4, 27 to 57 at center, 46 at eastern end). Thickness, 30; total 45.3 feet (23.8).

I/K. XL 493-499 and belt 23 at the Copper Falls adit.

3. Amygdaloid (T5b5, 46-139, on the upper, 68-161 on the lower side) and trap (T5b6, 139-185).

Thickness, 139 (110) feet; total (155.2) feet

Light colored zeolitic amygdaloid, and a dark chloritic porphyrite sp«

17674-5.

4. Conglomerate (T5b7, 185 to 195 feet). Thickness 10 (7.9) feet; total (163.1) feet

Mainly feldspathic pebbles, but some basic. Bieder says it is a scori-aceous conglomerate of the ashbed type, and may include the amygdaloid top to- the sheet below, which is of the feldspathic "ashbed diabase" type that has a rough, broken "aa" surface, which is characteristic of the "ash-beds." Sp. 17656. Probably Marvine's conglomerate No. 35 of his Eagle Eiver section, Nos. 25 and 26 of the Copper Falls adit, and the Island mine conglomerate. I. E. X. 170-193.

5. Trap (T5bS, 195 to 340 feet).

Thickness, 145 (115) feet

Fine grained porphyrite of the Tobin porphyrite type, feldspar abundant, though the porphyritic texture is not conspicuous. "Ashbed diabase." Sp. 17657.

Compare on Isle Eoyale, X. 193-306=113 (110) feet thick, and of the same petrographic character.

U. M. the augite is in idiomorphic granules. The feldspar extinctions indicate Abx An±.

The olivine has been largely changed to iron oxide.

^Distances actually measured, usually vertical, are given without parentheses, actual thickness and distances reduced to distance perpendicular to the beds by multiplying by cos 37%° = .795 are given in parentheses as in Vol. VI. Reference as to a given belt in different shafts are indicated by b. Thus T obi means belt No. 1 in the mining section of Tamarack No. 5. TJlb 20 means the twentieth belt recorded in No. 1 shaft of the

Tamarack Junior Mine, now an Osceola property.

6. Amygdaloid (T5b9? 340-395) and trap (ToblO, 395-627),

Thickness, 55 (43)+232 (183.1) —(227).

Total (505) feet.

Porphyritic melaphyre verging toward ophite. This probably includes more than one sheet of porphyrite, but it may be one thick flow which is at the bottom more augitie,—a feldspathic ophite. Sp, 17658, 17659, from T5b9 and Sp, 17660 (ophite), 17661, 17662 from T5blO. This is equivalent to T4bl, T4b2, 347 and T3bl to T3b3, 122. Sp. 16401 (ophitic).

Compare also I. E. X., 335-415 analyzed and studied for grain variation. The magma of this flow seems to have been of such a character thai a more and less augitic portion readily separated.

U. M. 17658, shows iddingsite very abundant, the amygdules are of chlorite and calcite.

U. M. 16402, shows labradorite in large patches of augite; olivine just altered and with a strong pleochroism between yellow and green, remark-ably abundant and embedded in augite.

7. Amygdaloid (TSbll, 627-667).

Thickness, 40 (31.7).

Total (537) feet.

Sp. 17663 to 17667. These specimens show signs of fault slips, claso-litic seams of sediment, crushed amygdaloid, etc.

These indicate that there has been much motion in this belt which may be thus in part cut out. It might even represent the fragments of several flows. It is beter shown in T3 and T4,—T33 122-178, Sp. 16403, 16404 and T4, 347-409, 44.5 to 49.3 feet. It is' probable, therefore, that 16 feet or more are here cut out by a fault.

U. M. 16403, is an ophitic melaphyre, but with amygdules, and much smaller feldspar than 16402.

8. Conglomerate (T5bl2, 667-692).

Thickness 25 (19.8).

Total (557) feet.

Sp. 17668 to 17670. This is equivalent to T3b4, 178-181, and T4b5? 409-413, 16504. Possibly the slide above here has in T3 and T4 cut out of the conglomerate and amygdaloid below instead of the overlying trap.

This is the "Hancock West" conglomerate, Marvines No. 17, the Ash-bed slide, I. B. X., 413 to 426, No. 44 of the Eagle River section. This horizon is characterized by a large bed above, in which, near the bottom, the augitic magma has so accumulated as to give some lustre mottling and make it an ophite (See Vol. VI., part 1, p. 64.), while beneath is a hard feldspathic sheet with a clean conchoidal fracture.

9. Trap (T5bl3, 692-711).

Thickness—19 (15).

Total (572) feet.

Amygdaloid not noted in T3 or T4 in which beds 13 and 14 may have been wanting, or planed off by slide ?

Compact porphyritie melaphyre with small green feldspar phenocrysts.

Equivalent to T4b6, 413 to 476, Sp. 16405, and T3b5, 191 to 243, with a -thickness of 63 (50) or 52 (41) feet.

10. Amygdaloid (T5bl4, 711 to 734), Sp. 17672, and trap, T5bl5, 734 to 784. Sp/17673, 17674.

Thickness, 73 (57).

A porphyritic melaphyre of the type I have called Tobin porphyrite. The amygdaloid has some fine red sediment mixed in, and is of the ash-bed type, and in it there was some water encountered. The trap is a tough grey trap, not as dark as the more augitic varieties, which made sinking very slow. The drill cores in this type on Isle Roy ale were long. This should be good road metal.

U. M. 17673, augite granules idiomorphic, olivine scanty, feldspar symmetrical extinctions often 4°.

11. Amygdaloid (T5bl6, 784 to 808), and trap (T5bl7, 808 to 920), Sp. 17675.

Thickness, 136 (108) feet

Total, 737 feet.

Another Tobin po: phyrite, with an amygdaloid like the flow above and a similar hard, fine-grained porphyritic trap which made slow sinking, and bears the strongest resemblance to the beds at bottom of drill hole IX and the top of VIII, on Isle Eoyale.

12. Amygdaloid (T5bl8, 920-927), Sp. 17676, and trap, (T5bl9, 927 to 1041), Sp. 17677, 17678.

Thickness, 121 (96) feet

Total, 833 feet.

Porphyrite.

Amygdaloid like the ones above, somewhat more laumonitic in To, and a thin green porcelain like decomposition seam was noticed in the trap (datolite?).

The trap is a coarse, feldspathic glomeroporphyrite, the feldspar phenocrysts being gathered together in bunches that show that the crystallization had advanced pretty well before the last motion.

This is the lowest of this series of feldspathic melaphyres, its base being 276 feet below the Hancock West conglomerate.

In T4 we find that T4b9, 627 to 642, Sp. 16409, A. B., is classed as a thick belt of amygdaloid, 93 feet thick, and next underneath comes a well marked dark lustre mottled ophite, with olivine, Sp. 16410, and the bottom of this belt is given as 262 feet below the Hancock West

conglomerate.

It is pretty clear that the bunches of feldspar phenocrysts have caused this whole flow to be classed as amygdaloid in T4 and T3.

T3bS, 389-499, Sp. 16474, also corresponds in part, but more or less of the bottom of T3b8 and T4b9 may be the amygdaloid of the underlying flow.

U. M. 16409A, is a much decomposed glomeroporphyrite, while B shows low angled feldspar, scanty idiomorphic augite, conspicuous olivine. 16410 shows scanty augite, abundant altered olivine, labradorite Ab0 An3, but with zonar varying extinction.

[13. '14. 15. 16.

Amygdaloid (T5b20, 1041 to 1194 feet), Sp. 17679, 17680, 17681 (122) feet, is undoubtedly a composite belt really containing one or more flows, as the records of the shafts T3 and T4 show. Together with the trap? T5b21, 1194-1212 (14)—which is a dark, typical ophite, and another

composite belt, T5b22, 1212-1368, Sp. 17683 to 17684, (124) total, (260) feet, which is described as "amygdaloid with bunches of trap in it, and has at the bottom blue clayey flucan," we have the imperfectly described and separated representatives of at least four distinct beds of ophite, recognized in T4 and T3, probably decomposed in T5.]

13. Trap T3b9, 499-539, with possibly part of T3b8), 40 (32), and T4blO, 742-770 (with possibly a part of T4b9) Sp. 16410, 28 (22).

This is a fresh black ophite, with two feet of hard, fine-grained, typical olivinitic trap at the base, above T4bll.

14. Amygdaloid (T3blO, 539-610, and T3bll, 610-651), (89) and T4bll? 770-823, and T4bl2, 823-865, Sp. 16411 A-C, (76).

U. M. 16411B, augite mainly gone, quartz, secondary, olivine pseudo-morphs conspicuous.

16411C, ophitic melaphyre, but the augite is scanty, the olivine conspicuous, the feldspar in two generations, one old, corroded, the other an andesite.

15. Amygdaloid (T3bl2, 651-772, and T3bl3, 772-792), (112), and T4bl3, 865-963, and T4bl4, 693-988, Sp. 16413-4 (98).

A well marked ophite, somewhat disturbed, slickensided and altered.

U. M. the feldspar is labradorite, Ab2 An3.

16. Amygdaloid (T3bl4, 792-881), (71) and T4bl5, 988-1086, Sp. 16415 A-B (78).

One or more small flows, disturbed and charged with laumonite. U. M. the feldspar is labradorite, Ab2 Ana.

17. Conglomerate (T5b23, 1368 to 1391).

Thickness, 23 (17).

Total, (1110) feet.

This conglomerate was sandy on top, 17685, and then conglomerate 17686. It is the Pewabic West, Marvine's conglomerate No. 16, T3bl5, 881-916, T4bl6, 1086-1110, Sp. 16416 B-C.

It has the same sandy streak on top also in T4, Sp. 16416.

It is 'generally red and has some felsitic pebbles, but others more basic, and an abundant calcareous cement.

T5 is 282 feet deeper than T4 and 487 feet deeper than T3.

U. M. fragments are (1) porphyry with micropegmatite ground mass; (2) epidote; (3) albite; (4) spherulitic porphyry (mierofelsite), calcitic cement.

18. Amygdaloid (T3b24, 1391-1408), and trap, (T5b25, 1408-1425).

Thickness, 34 (27).

Total, (1137) feet.

T3bl6, 916-926, and part of T3bl7, 926-984, Sp. 16477,16478 (53).

T4bl7, 1110-1122, T4bl8, 1122-1150, Sp. 16417, 16418 (32).

With agates and delessitic amygdules, a fine-grained labradorite porphyrite.

U. M. 16417 shows chloritic amygdules, a marginal form of melaphyre, no olivine.

16418, shows idiomorphic augite prisms. 33

19. Amygdaloid (T5b26, 1425-1435) and trap, T5b27, 1435-1452. Thickness, 27 (21.5). Total, (1159) feet. No samples seen.

20. Amygdaloid (T5b28, 1452-1462), and trap, (T5b29, 1462-1834), Sp. 16483%, 16485, 16486.

Thickness, 382 (304).

Total, (1463) feet.

"Mixed bed of amygdaloid and trap," a big flow of melaphyre por-phyrite, often very feldspathic and glomeroporphyritic, which I think is the one just above the Pewabic and Quiney lode. In T5 it showed some sheet copper on the seams.

The middle specimen is very coarse and feldspathic. There may be more than one flow but the records as kept by the various mining captains do not sharply distinguish the feldspathic and amygdaloidal belts.

T3bl8, 984-1014, Sp. 16479, and

T3bl9, 1014-1204, Sp. 16480, correspond to this flow and probably also

T3b20, 1224-1267, Sp. 16481, which is only a belt with bunches of feldspar, not amygdaloid.

T3b21, 1267-1315, Sp. 16482, will then also be

included.

Salt water was struck in this belt in No. 3, and there may be a slip here.

T3b22, 1315-1342, is probably a belt like T3b20, so that T3b23, 1342-1372, will be the last trap belt of this flow, which makes the thickness as in T5 and T4.

Thickness, 388 (307) feet.

Compare specimens 16483, 16485, 16486.

In the same way in No. 4, we have

T4bl9, 1150-1194. Amygdaloid, reddish, with laumonite, Sp. 16420,—a considerable part of this belt probably belongs in the flow above.

T4b20, 1194-1200. Trap, Sp. 16421.

U. M. glomeroporphyritic, with Ab5 An3.

T4b21, 1200-1347, apparently a coarse, very feldspathic center of the same belt. The feldspar is often reddish, and big green flecks may be pseudomorphs of olivine.

Probably we should include—

T4b22, 1347-1543 (or 1453). Recorded as amygdaloid, but from the samples, Sp. 16422, much the same as the previous belt, with few amyg-dules and much red feldspar, U. M. a glomeroporphyrite, with iron oxide growth forms.

Then also we must include

T4b23, 1543-1567, a trap, dark chloritic, greenish but feldspathic, like some belts south of Lake Richey on Isle Koyale. U. M. Sp. 16423, is a glomeroporphyrite.

T4b24, 1567-1582, while classed as "amygdaloid" is really a porphyrite with large feldspar phenocrysts, Sp. 16424. Augite is scanty.

T4b25, 1582-1595, classed as a "trap," is really a porphyrite with feldspar phenocrysts up to 1 cm. long. Sp. 16425, slightly ophitic with an andesite feldspar.

Through all these belts no genuine amygdaloid or flow margin can be recognized in the samples saved.

Total, 445 (less 44—far part of the belt T4bl9, improperlv included (353—35) feet.

The difference in the earlier reports of the mining captains on amygdaloid flows in shafts so near together, shows that they are probably not genuine amygdaloids, but perhaps more altered, more porphyritic or more feldspathic streaks in the one great flow.

21. Amygdaloid (T5b30, 1834-1857), Sp. 16487.

Trap, T5b31, 1857-1916, Sp. 16488.

"Amygdaloid," T5b32, 1916-1924, Sp. 16489.

Trap, T5b33, 1924-2011, Sp. 16490A and 16490.

Total, 183 (140).....(1603) feet.

Pewabic and Quincy lode?

The amygdaloid at the top is well marked, the bubble cavities being filled with chlorite and calcite, Sp. 16487, and epidote and other crystals, 16426, so that the correlation of T5, 1834=T3, 1372=T4, 1595 is a reliable one within the limits of the amygdaloid belt. The trap becomes pretty close grained with light green feldspar, and green jaspery or datolite seams. T. 5b32 is very feldspathic and decomposed, with reddish feldspar, yellow-green epidote and some dark green chlorite spots. It is one of Pumpelly's pseudamygdaloids, not a real amygdaloid. Sp. 16490, T5b33 is a regular glomeroporphyrite with occasional large feldspar phenocrysts.

T5 reached 2015 feet Jan. 1, 1898. • This corresponds to

Amygdaloid, T3b24, 1372-1435 feet. Sp. 16487.Trap, T3b25, 1435-1583

211 (168)

Evidently in this shaft the decomposed belt, T5b32=T4b28, was not present, or was not counted as amygdaloid.

It may or may not be one, though Sp. 16427 suggests to me that it is the ophite base of a feldspathic melaphyre. And this also corresponds to

Amygdaloid. T4b26, 1595-1611. Sp. 16426 (U. M. much altered,

yellow epidote).Trap T4b27, 1611-1652. Sp. 16427 (U. M. much altered,

andesitic). Amygdaloid, T4b28, 1652-1730. Sp. 16428 (U. M. much altered,

marginal),

though classed as an amygdaloid, appears to be largely a badly decomposed belt with vein matter, and a little copper and clasolitic sediment. T4b29, 1730-1806. Sp. 16429.

Total, 211 (168)

T4b27 is a feldspathic ophite like T4b23, and some of the Phelps Island rock of Isle Eoyale and T4b29, is more coarse with a marked diabasic texture, much plagioclase, and occasional large feldspar phenocrysts, a porphyritic melaphyre.

T4b28 may include an amygdaloid which has acted as a line of weakness and been faulted out or overlooked in T3.

The decomposed and copper-bearing belt, T4b28, 1652-1730, covers the corresponding horizon of T5b32, 1916-1924.

U. M. Sp. 16429? is a doleritic ophite, with low angled feldspars, and chlorite interstices, the chlorite occurring as a rind; zeolite also occurs.

22. Amygdaloid, T5b34, 2011-2037. Sp. 16490i/2.Trap T5b35, 2037-2130

119 (95)..... .Total (1698)

The Sp. 16490%, is not typical and rather coarse grained, so that if the correlations suggested are right, this might be considered part of the belt below. The specimen of trap has an interesting red aplitic seam of oligoclase, like those often connected with gabbros. It is still feldspathic. This may correspond to T3b26, 1583-1613, Amygdaloid, T3b27, 1613-1635, Trap, T3b28, 1635-1676, "Amygdaloid," appears to be really a streak of

crushed matter along a fault. T3b29, 1676-1705 122 (97) and

T4b30, 1806-1891, Amygdaloid, Sp. 16430 (U. M. is a rather feldspathic

ophite). T4b31, 1891-1927, Trap, Sp. 16431, like Sp. 16423, feldspathic.

121 (96)

Sp. 16430, called amygdaloid, proves to be a "pseudamygdaloid," was a much decomposed specimen and very likely may represent parts of T3b26, 27 and 28, especially if the difference in depth (about 222 feet) of corresponding levels of T3 and T4 does not vary much.

Compare TJ2, 417.25—440.75, a belt which carried some copper, with T3b28.

23. Amygdaloid, T5b36, 2130-2169.

24. and trap T5b37, 2169-2278.

Total thickness, 148 (118).....(1738)

The top is a well marked amygdaloid with thomsonite, and apparently from Sp. 16432, there was a belt of amygdaloid overlooked in the trap. It still belongs in the porphyrite melaphyre type, Pumpelly's ordinary diabase.

This corresponds probably to

T3b30, 1705-1728, "Amygdaloid."

T3b31, 1728-1740, trap.

T3b32, 1740-1785, "Amygdaloid," probably in part at least.

T3b33, 1785-1820.

Thickness 115 (92).

Also

T4b32, 1927-1947, Amygdaloid, Sp. 16432. U. M. a genuine amygdaloid with fine-grained quartz, epidote amygdules, and two well marked generations of andesite.

T4b33, 1947-1967, trap, Sp. 16433.

Sp. 16433 is reddish brown with small lath-shaped feldspar phenoerysts. U. M. It belongs to the Minong type, has andesitic feldspar, and idio-

rnorphic granules and sharp prisms of augite, and some olivine. Sp. 16434, also apparently represents the very bottom of the bed. Sp. 16435

is much like 16433. Unless there is some mistake, there are two flows here.

T4b34, 1967-2003, amygdaloid, Sp. 16434, U. M. glomeroporphyritic.

T4b35, 2003-2033, trap, Sp. 16435, U. M. texture intersertal, scanty

granular augite, with olivine pseudomorphs. 107 (85) The specimens are still feldspathic and belong to the porphyrite type.

25. T5b38, 2278-2292, amygdaloid. T5b39, 2292-2327, trap. Thickness, 49 (38). Total, (1777). This corresponds to T3b34, 1820-1863. T3b35, 1863-1878.

58 (46)

T4b36, 2033.6-2048.3, Sp. 16436, amygdaloid with calcite filling, U. M. calcite and zeolites, trichitic feldspar, scanty augite. T4b37, 2048.3-2117.6, Sp. 16437, trap.

84.0 (67)

Sp. 16437 is medium fine-grained and not markedly porphyritic. U. M. it is glomeroporphyritic, with andesite, scanty augite, olivine pseudomorphs, calcite and zeolites.

26. T5b40, 2327-2349, amygdaloid. T5b41, 2349-2374, trap.

47 (37).....Total, (1814)

Whether T5b42 is a real amygdaloid, overlooked in the other shafts, we cannot be sure. It may be merely a glomeroporphyritic belt. This may correspond to

T3b36, 1878-1905, in part amygdaloid. T3b37, 1905-1970, trap.

92 (72) Compare TJ2, 673.75-695.5.

T4b38, 2117.6-2145.7, amygdaloid, Sp. 16438. T4b39, 2145.7-2208.2, Sp. 16439.

90.6 (72)

Sp. 16439 is a coarsely mottled ophite, with olivine perhaps represented by serpentine. U. M. feldspar is andesite.

Sp. 16438 has calcite amygdules, but is of the same type as T4b22 and T4b25, a glomeroporphyrite, the whole flow being a feldspathic ophite, tending to differentiate. U. M. it shows somewhat agglomerated feldspar.

27. T5b42, 2374-2411, amygdaloid.

T5b43, 2411-2484, trap.

Thickness, 100 (79).....Total, (1893)

This has by some been correlated with the Pewa'bic amygdaloid.

T3b38, 1970-2018, amygdaloid.

T3b39, 2018-2039, trap, Sp. 16491.

Thickness, 69 (45).

T4b40, 2208.2 amygdaloid, Sp. 16440. U. M. trichitic marginal plagioclase, amygdules with yellow andgreen epidote and quartz.

T4b41, -2257, trap. Sp. 16441, dark, with a few large feld-48.8 (39) spar phenoerysts. U. M. verges on ophite,

rather scanty augite, with oligoelase.

The amygdaloid marking the top of this bejt varies so in position in the different sections, that it is hard to explain. Is it near the end of the sheet?

28. T5b44, 2484-2513.

T5b45, 2513-2569.

Thickness, 85 (67)..... Total, (1960) feet.

This may correspond to

T3b40, 2039-2068, Sp. 16492.

T3b41, 2068-2111, Sp. 16493, a very dark ophite.

Thickness, 72 (57). Compare with TJ2, 807-837. Also with

T4b42, 2257.5-2305.7, amygdaloid, Sp. 16442.

T4b43, 2305.7-2333.7, trap, Sp. 16433.

76.2 (60)

Sp. 16643 is a very dark, massive labradorite or porphyrite=Sp. 16493. U. M. feldspar is Ab3 An4, augite scanty.

29. T5b46, 2569-2630, amygdaloid, (71). T5b47, 2630-2684, trap, (54). Thickness, 115 (91).....Total, (2051) feet.

As the extra breadth of the amygdaloid belt indicates, there may be here two flows, or the porphyritic character of the two sheets may have led more of their contact belt to be classed as amygdaloid. Compare:

T3b42, 2111-2143, amygdaloid, Sp. 16494. T3b43, 2143-2164, Sp. 16495.

53 (42)

T4b44, 2333.7-2416.6= (83), amygdaloid. No samples. Compare TJbl, 500.4, TJb2, 2887.4, T3, 2111, and T4, 2333.7.

30. T5b48, 2684-2708, amygdaloid. T5b49? 2708-2753, trap.

69 (55)

Compare T3b44, 2164-2198, Sp. 16496. T3b45? 2198-2247, Sp. 16497. 83 (66)

This probably represents a small part of T4b44, 2333.7-2416.1; no Sp. and the whole of T4b45, 2416.6-2471.8= (55.2+), Sp. 16445. Of Sp. 16445 there are two pieces, one amygdaloid with thomsonite, possibly T4b44, mislabeled, the other, a fine-grained, dark purple melaphyre, a diabasic melaphyre.

The porphyry tuff, jasper bed (see Isle Eoyale report, p. 74), at 460 feet in Tl, seems not to have been noticed elsewhere.

U. M. 16444 is an ophitic melaphyre with large feldspar phenoerysts.

16445 shows low angled andesite.

Compare TJ1, TJ2, 1033, Bed Jacket or -Whiting shaft of Calumet and Hecla 1215, T3, 2247, T4, 2471.

31. T5b50, 2753-2796, amygdaloid. T5b51, 2796-2981, trap. Thickness, 228 (181) ..... Total, (2329) feet.

This is the great sheet known as the "Greenstone," which is the "backbone" of Isle Eoyale, (drill hole VI, 124-363. See Volume VI, part 1, pp. 74, 126, 128, 134, 244) and is also a prominent ridge, being there much thicker, probably several hundred feet, with proportionately coarser mottling of augite, just north of the Cliff, Central, Phoenix, and other mines. It is a type of ophite melaphyre, though in many places as coarse as many a gabbro. Yet the flow as a whole, contains glassy matter. This corresponds to

T3b46, 2247-2274. Sp. 16498 is a fine-grained ophite. T3b47, 2274-2513. Sp. 16499. Thickness, 266 (212). Compare TJ2, 1033.

Also to T4b46, 2471.8-2479.4. Sp. 16446, amygdaloid, fine-grained with small amygdules, zeolitic.

T4b47, 2497.4-2747.2, Sp. 16477. Fine-grained trap with small

amygdules.

Thickness, 265.4 (211). Sp. 16447 is not at all typical.

32. T5b52, 2981-3020 (or 3000 L. S. M. Institute report). Conglomerate. The Allouez conglomerate, one of the most important datum planes of the series, Marvines, No. 15, the Albany and Boston (Peninsula and Franklin Junior).

Thickness, 39 (31) .....Total, (2360) feet.

Corresponds to

T3b48, only 6 inches at 2513. Sp. 16500.

T4b48, 2747.2-2754.2. Sp. 16448. U. M. decomposed syenite pebble?

T2, at 1256.

Tl, at 876.

Calumet and Hecla, Bed Jacket or Whiting shaft at 1656 feet.

Isle Eoyale drill hole VI., 363-386 feet.

Tl, at 670 feet.

33. T5b53, 3020-3061, amygdaloid. T5b54, 3061-3114, trap.

94 (75) Corresponds to

T3b49, 2513-2588, amygdaloid. T3b50, 2588-2629, trap.

116 (92)

T4b49, 2754.2-2826.5, amygdaloid. Sp. 16449.

T4b50, 2826.5-2875.9, trap. _ Sp. 16450, an ophite. U. M. like

16414 olivine pseudomorphs. 121.7 The belt T4b49-50, also corresponds to the next belt.

34. T5b55; 3114-3158, amygdaloid.

T5b56, 3158-3181. trap.

67 (53) Compare

T3b51, 2629-2656 T3b52, 2656-2677

52 Also

T4b49, 2754.2-2826.5, amygdaloid. Sp. 16449. T4b50, 2826.5-2875.9, trap. Sp. 16450, an ophite.

121.7

%The upper belt of amygdaloid is much too broad to be one flow and corresponds to T5b53-54, and T3b49 and 50. T4, 2826.5, is nearly =T3, 2651=T5, 3061.

35 and 36. T5b57, 3181-3221, amygdaloid. T5b58, 3221-3320, trap.

139 (110)

This seems to represent two flows in T3, to wit: T3b53, 2677-2703, amygdaloid. T3b54, 2703-2720, trap.

43

T3b55, 2720-2742. T3b56, 2742-2819.

99=142 (113) Compare

T4b51, 2875.9-2973.8, amygdaloid.

T4b52, 2973.8-3050.4, trap. Sp. 16452, an ophite, medium coarse.

174.5

Obviously, in the smaller flows, less than 50 feet or so thick, the line between amygdaloid and trap is largely one of individual caprice, the upper flow in T5 and T4 is counted all amygdaloid and in the Red Jacket shaft the whole interval from 1700-1954 feet.

37. T5b59, 3320-3339, amygdaloid. T5b60, 3339-3594, trap. 274 (217) Compare:

T3b57, 2819-2834. T3b58, 2834-3114.

295 (234)

T4b53, 3050.4-3064.5, amygdaloid. Sp. 16453. T4b54, 3064.5-3334, trap. Sp. 16454.

284 (225) Sp. 16454 is an ophite, but has one large feldspar phenocryst, perhaps a pre-effusive, or "brotocrystal." U. M. a medium, coarse-grained ophite with chloritic interstices.

Compare the ophite (202) feet thick in the Eed Jacket shaft at 1754 feet depth.

This ophite is just here as large as the ".Greenstone," but it has not the same topographic prominence, which is another indication that the "Greenstone" (p. 263) is thicker to the north. This is, however, thick enough to be a fairly persistent bed.

38. T5b61, 3594-3630, amygdaloid. T5b62, 3630-3691, trap. 97 (77)

T3b59, 3114-3144, amygdaloid. Sp. 16509. T3b60, 3144-3212.6, trap. Sp. 16510.

98.6 (78)

T4b55, 3334 -3358.4, amygdaloid. Sp. 16455. T4b56, 3558.4-3444.9, trap. Sp. 16456.

110.9 (88)

Sp. 16455 is much decomposed, dark red with epidote and calcite. Sp. 16456 is a fine-grained melaphyre. U. M. rather fine-grained. Compare the belt at 1310 feet in the Calumet and Hecla cross-cut to Eed Jacket shaft.

39. T5b63, 3691-3730, amygdaloid. T5b64, 3730-3769, trap. 78 (62)

T3b61, 3212.6-3235 amygdaloid. Sp. 16511, laumonite. T3b62, 3235 -3270.3, trap. Sp. 16512.

57.7 (46)

T4b57, 3444.9-3458.7, amygdaloid. Sp. 16457, laumonite. T4b58, 3458.7-3500.7, trap. Sp. 16458, hard, fine-grained.

55.8

U. M. Sp, 16458 is slightly glomeroporphyritic; labradorite not high ex-angled; augite scanty, granular or patchy; olivine (iddingsite) scarce; iron oxides abundant.

Sp. 16457 seems to show melaphyre fragments with a red calcareous cement, and might cover a narrow scoriaceous conglomerate, (?) the Houghton conglomerate, of the ashbed type. Sp. 16458 is somewhat glomeroporphyritic.

Compare the amygdaloid at 1218 feet in the long Calumet and Hecla cross-cut to the Eed Jacket shaft, Plate I of Vol. V, Part I, and the feld-spathic melaphyre beneath.

40. T5b65, 3769 -3783 amygdaloid. T5b66, 3783 -3784 trap. Thickness, 78 (67). Compare:

T3b63, 3270.3-3312.4.

T3b64, 3312.4-3366.4, trap. Sp. 16514.

96.1 T4b59, 3500.7-3535, amygdaloid. Sp. 16459 hard. U. M. ophite

with feldspar not abundant. 34

T4b60, 3535-3611, trap. Sp. 16460.

110.3 This is an ophite, red, blotched with enclosures.

41. Houghton conglomerate absent (Marvine's No. 14) ?

42. T5b67, 3847-3861, amygdaloid. T5b68, 3861-3885, trap. Thickness, 38 (30).

43. T5b69, 3885-3912, amygdaloid (possibly a vein breccia). T5b70, 3912-3971, trap. Thickness, 86 (68). Compare:

T3b65, 3366.4-3385, amygdaloid. Sp. 16515. T3b66, 3385 -3500, trap. Sp. 16516.

133 8 T4b61, 3611 -3649.8, amygdaloid. Sp.16461, light green.

Sp. 16461A. T4b62, 3649.8-3719.7, trap. Sp. 16462, ophite. (March 16, 3860

feet). 108.7

Sp. 16461A appears to be a vein of breccia. Sp. 16462 is not so markedly ophite.

The Houghton Conglomerate (Marvine's No. 14), is due here, and the blotched appearance of the overlying flow and the breccia may be signs of it. -

44. T5b71, 3971-3991, amygdaloid. T5b72, 3991-4049, trap. 78 (62)

An ophite, a well identified bed. Compare:

T3b67, 3500-3521, amygdaloid. Sp. 16517. T3b68, 3521-3578, trap. Sp. 16518, an ophite.

78 (62)

T4b63, 3719.7-3740.6, amygdaloid. Sp. 16463. T4b64, 3740.6-3794.4, trap. Sp. 16464, ophite.

74.7 In the Calumet and Hecla cross-cut this appears as flow (920-800).

45. T5b73, 4049-4085. T5b74, 4085-4137. Thickness, 88 (70). Compare:

T3b69, 3578-3619, amygdaloid. Sp. 16519, with copper. T3b70, 3619-3769, trap. Sp. 16520, an ophite.

10 1

T4b65, 3794.4-3837.1, amygdaloid. 16465. T4b66, 3837.1-3909.4, trap. 16466, ophite.

115.0

In the Calumet and Hecla long cross-cut, this appears as a flow (800— 674=128x.62=79 feet thick) of ophite with a laumonitic amygdaloid.

46. T5b75, 4137-4183, amygdaloid. T5b76, 4183-4232, trap. Thickness, 95 (74). Compare:

T3b71, 3679-3733 amygdaloid. Sp. 16521, small amygdules. T5b72, 3733-3797.8, trap. Sp. 16522, ophite.

117.8

T4b67, 3909.4-3927.8, amygdaloid. Sp. 16467. T4b68, 3927.8-3979 trap. Sp. 16468, ophite.

69.6

Sp. 16468 matches 16522 remarkably well.

In the Calumet and Hecla cross-cut we have a flow (674 to 660, and 660 to 557, i. e., 117) (73) feet thick of melaphyre, with a brecciated amygdaloid.

47. T5b77, 4232-4254, amygdaloid. T5b78, 4254-4358, trap. Ophite. Thickness, 126 (100)

T3b73, 3797.8-3818 amygdaloid. Sp. 16523. T3b74, 3818 -3898.2, trap. Sp. 16524, ophite.

100.4

Sp. 16523 has two pieces, one a well marked contact of two flows. A is the top of the lower bed, more amygdaloid.

The ophite is massive, chloritic, hard to break.

T4b69, 3979-4005, (26) amygdaloid. Sp. 16469. T4b70, 4005 trap. Sp. 164670, ophite.

This has a quartz epidote amygdaloid (Sp. 16469). In the Calumet and Hecla longest cross-cut it is an ophite with olivine well marked and a thickness of (539—361+18=196, which x .62=122) feet, the amygdaloid appearing dark red laumonite.

48. T5b79, 4358-4386. T5b80, 4386-4456.

98 (78) Compare:

T3b75, 3898.2-3920, amygdaloid. Sp. 16525. T3b76, 3920 -3970, trap. Sp. 16526, ophite.

72

T4b71. T4b72.

This in the Calumet and Hecla longest cross-cut is a belt with augite grains (mottled) at least 2 to 3 mm. across and a thickness of (361—220= 141x.62=87) feet.

49. T5b81, 4456-4525= 70, amygdaloid.

T5b82, 4525-4636=111, trap. A heavy ophite.

181 (144)

T3b77, 3970 -4008.7, amygdaloid. Sp. 16527. T3b78, 4008.7-4044 trap. Sp. 16528, called amygdaloid in other

records and really amygdaloid.

T4b79, 4044-4065, amygdaloid with copper. Sp. 16529. T4b80, 4065- trap. Sp. 16530, ophite.

This is the Calumet and Hecla cross-cut, an ophite with augite grains (mottles) at least 3 to 4 mm. in diameter, indicating a flow at least 80 to 120 feet thick, the belt with the amygdaloid being 220 feet wide (x.62=: 145 feet thick).

The amygdaloid is chloritic with a little copper.

50. T5bS3, 4636-4662, amygdaloid.

26 (20)

Not noticed in the Calumet and Hecla longest cross-cut, probably not present.

T3b81. amygdaloid. Sp. 16531.

T3b82, trap. Sp. 16532. A fine-grained black trap, appropriate to a thin flow.

51. T5bS4, 4662. Calumet and Hecla conglomerate. Marvine's No. 13. T3b83, at 4183, in T4 at 4393 feet.

The Rest of the Keweenawan Section.

From the Calumet and Hecla conglomerate down to the Kearsarge amygdaloid, which is the important belt worked by the Ahmeek, Mohawk, Wolverine, Allouez (new vertical shaft), Centennial, and Osceola which has also been recently opened up by the Calumet, there are a number of sections.

In Volume V, Part 1, will be found the sections of their long drift in the foot wall, furnished by the C. and H. Mining Co. In Volume VI, Part 2, p. 130, will be found a section of the Franklin Junior, which was furnished by Mr. Pope. The long drifts from the Tamarack vertical shafts over to the lodes also show the section down to the Kearsarge conglomerate and to within 200 feet of the Kearsarge amygdaloid. A lot of work has recently been done in developing the section below the Tamarack, which I trust to take up more fully in the future and will therefore give merely in abstract for convenience of reference here.

CENTENNIAL.

Calumet and Hecla in cross-cut, 2.33 feet.

1. Amygdaloid, 27 (17) feet and trap; Sp. 16545-16550; 187 (115).

2. Amygdaloid, 54 (33) feet; ophite; 16551-16559; 441 (271) ; coarsest about 174 feet above its base, where the augite mottles are some 6.5 mm. across; cut by a 2 to 3 foot slip about 266 (208) feetfrom its base. Comparing the various cross-cuts from the Calumet and Hecla, given in Volume V, we see that either this slip has been the cause of various interpretations of the section according to the degree of alteration produced, or really is crossing the formation obliquely, so as to give different sections at different points.

3. Amygdaloid, very much brecciated lamonitic and almost conglom-eritic in texture for 44 (37) feet,—then coarse ophite, 168 (103); Sp. 16561-16565.

Total from top of Calumet and Hecla to top of Osceola, (491).

In a cross-cut in the 13th level from Tamarack No. 1, it was, according to R. M. Edwards, 750 (461) feet from the bottom of the Calumet and Hecla to the top of the Osceola, the records being amygdaloid trap 35,

trap 145, amygdaloid 50, trap 220, amygdaloid (which is probably a pseudamygdaloid along a slip in reality) 20, trap 95, amygdaloid with copper 40, trap 145, to the Osceola, It is probable that strike faults produce some of this variety in sections.

Down to the Kearsarge-North Star conglomerate No. (11) are some four belts more or (412 at the Franklin Junior) — (481) feet!

This is about 1,000 feet below the Calumet and Hecla. The next 600 feet below the top of the Kearsarge are taken up by about four belts or flows, often heavy ophites, which are cut by the long cross-cut of the Calumet and Hecla. This is pretty w^ell down to the Kearsarge amygdaloid which is one of the most important lodes, being opened by the Calumet, the Kearsarge branch of the Osceola, Centennial, Wolverine, Mohawk, Ahmeek, Allouez, and is below the top of the Kearsarge conglomerate about (880) feet. It is not far, about 200 feet, from the bottom of Tamarack shaft No. 2.

The Kearsarge amygdaloid is the top of a peculiar bed of ophite characterized, as Dr. Hubbard has remarked, by quite frequent long porphyr-itic crystals of feldspar (labradorite phenocrysts), which appear to be quite early formed. At the base of this ophite which is about (180) feet thick, is a sandstone or conglomerate 40 to 60 feet thick, the Wolverine sandstone (Marvine's No. 9), so that the total from the top of the Kearsarge conglomerate to the top of the Wolverine sandstone is say (1060) feet; going south it may thin to (880) feet, and the whole thickness from the top of 11 to the top of 9 around Portage lake may be not over (875) feet.

Below the Wolverine sandstone comes a broad belt which has few notable sediments and no mines. One horizon has been denoted by Dr. Hubbard the "inclusion bed," about 461 feet below. There are some heavy ophites and coarse doleritic traps such as are associated with the Arcadian and Isle Eoyale horizon which is below the top of the Wolverine sandstone, say (2200) feet.

Not very far below this is an important sedimentary horizon, that of conglomerate No. 8. This is quite probably the same as the Bohemia-St. Louis conglomerate which Dr. Hubbard has traced quite extensively in Volume VI. It seems to mark the upper horizon of one set of acid fel-sitic flows, such as occur at a number of points and the interval between it and the No. 9, the Wolverine sandstone, is perhaps (2750) feet. It is about 5,000 feet up to the Calumet and Hecla.

Below the Bohemia conglomerate horizon comes the porphyry exposed on the Torch Lake E. K. (and shown in the map of Allouez Gap, given in Volume VI) which is probably at nearly the same horizon as the Mt. Houghton and other extrusive felsites which Dr. Hubbard has described out on the point, and the felsite found at the base of the Isle Koyale (Wendigo) section. We do not find these farther south, but we do find a group of conglomerates sometimes as much as 200 to 300 feet thick, corresponding to Marvine's numbers 5, 6, 7, and 8, with perhaps others intercalated, a more careful description of which may be left until later. However, between the top of conglomerate 5 and top of 8, are

about 10 belts around Portage Lake, included in a thickness of about (1000) feet.

Near Calumet the presence of irregular masses of porphyry makes it difficult to give any general figure.

Below the horizon of conglomerate (5) which probably does not appear at its ordinary level there is in the long cross-cuts of the Atlantic mine on Sec. 16, down to (No. 3), the Baltic conglomerate, (2050) feet. The

flows are mainly heavy ophites with seoriaceous amygdaloids that are liable to develop normal sediments at very short notice. The Baltic conglomerate is the one not far below the Baltic lode or shear zone in the mines of the Copper Kange Consolidated. Dr. Hubbard tells me that toward the south, the distance between the two increases. But this is not the base of the formation, which is nowhere visible. Toward the end of the point there must be exposed below the Bohemia conglomerate, faulting apart, not much less than 5000 feet, or below the Baltic conglomerate (No. 3) level, say (1400) feet.

East of Houghton to Marvine's conglomerate (1), there is some 2000 feet horizontally, or about the same thickness. There is no real indication even here that we are at the base of the series or beginning of the volcanic activity. To obtain any lower beds, however, wre must go elsewhere. I propose, in the coming year, to have prepared a section from the Gogebic range (where the Keweenawan is said to be more nearly conformable to the Huronian) north, and see if we can find comparable horizons, and any light upon the base of the Keweenawan. It is, of course, conceivable that the lowest beds of the Keweenawan exposed there, may be overlaps of beds far from the base of the series, but that is not my present belief. There is one comment that I think worth making. From the level of the top of Tamarack No. 5 to the Baltic conglomerate No. 3, is about 11,000 feet and there are at least 12,400 feet of beds. Now, the top of Tamarack No. 5 is by no means the top of the formation, though it is not far from the top of the main series of traps and the lake shore traps most likely do not appear here. There is perhaps 1,400 feet of mixed sandstone and trap above. Then there is the great conglomerate and the lake shore trap (probably absent), above which Irving draws the line between upper and lower Keweenawan, that are 700 to 2300 feet thick, so that there is not less than 13,000 feet of the lower Keweenawan.

Above this is an unknown amount of red sandstone and shale, certainly not less than 1000 feet, for which Irving estimates 9000 feet. Now is it likely that the base of the series could ever have been buried 22,000 or even 14,000 feet at an early date in geological time (when the rate of increase of temperature, unless we adopt Chamberlin's hypothesis, was higher than at present and then steamed) without having the augite altered to hornblende as it is around the Mt. Bohemia intrusion for a considerable breadth? It does not seem to me likely. It seems probable on this ground as well as on account of the basic pebbles found in the conglomerates that uplift and tilting took place at several times during the formation of the series. One I suspect is about the time of conglomerate 8, i. e.? the Bohemia; another about the time of the great conglomerate, and at the time of the basic (Nonesuch) black shales there must have been extensive erosion of the Keweenawan traps.

What the condition of the traps in the undisturbed center of the basin may be we can but guess. I suspect they will be much like many of the amphibolites (so-called diorites) of the copper country.

DEEP BORINGS

FOR

OIL AND GAS.

The position of the geologist relative to borings for oil and gas in Lower Michigan is trying. He cannot absolutely discountenance explorations with such confidence as he can predict the failures of coal explorations outside of the coal basin at Norwood or Petoskey, for instance. Neither can he promise favorable results with such confidence as he can promise brominiferous brines, or gypsum or salt. He can only say that the chances are generally unfavorable, but more favorable in some places than in others. Not a little of my time has been spent in examining borings and discussing prospects, and I thought of making quite a full report on recent borings something like that in the 1901 report. But a number of important records are not yet finished and I do not like to break up an elaborate record between two reports. The borings along the Detroit river should very soon receive exhaustive treatment in the Wayne county report and may therefore be omitted here. In this region the results so far are discouraging, as I have already mentioned, with this exception, that the quarries at Sibleys and at Anderdon, across Detroit river in Canada, dip to the southwest instead of the northwest or north, which should be the normal direction of dip. This may indicate that they lie on the northeast side of a synclinal or monoclinal to a fault, and that just northeast of them in turn is the axis of an anticlinal running and pitching to the northwest. The depth of the Sylvania sandstone in the various wells along the Detroit river indicates the same thing, the depth being less beneath Wyandotte than either above or below. This, then, would be the most favorable point to test, but the upward bend does not appear to be more than 30 feet or so, and the well of the Eureka Iron and Steel Co. (Van Alstyne) or that of the Fords (Michigan Alkali Co.) have not shown any noteworthy amounts of oil or gas. The line thus indicated produced northwest would, however, pass close to a field in Livingston county where some oil and gas has been found. Here also are oil horizons known as the Berea.

In previous reports (Volume V, and annual for 1901 and 1902) I have ventured to indicate other regions also as more likely to have the necessary structure, to wit: Khagashewing Point on Little Traverse Bay; somewhere near Manistee; an anticlinal through the city of Saginaw,

probably running a little west of north; one at Port Huron; an area north of Mt. Clemens, and finally coming up from Indiana a region east of Niles.

In regard to the Manistee district, Mr. T. Percy is going to do some testing upon which, with his knowledge of this region and oil wells elsewhere, we may depend so far as he goes. A disadvantage is that the drift is thick, and the oil horizons deep. At Eapid River on the other side of Lake Michigan, the newspapers report oil to have been struck in quantity,1

iThe following is given us as a test of the oil:

Milwaukee, Nov. 4, 1903. The Cream City Development Co., City: Gentlemen:—In accordance with your request I have carefully examined your sample of raw

35

(estimates ranging from 30 to 300 barrels a day) at 1,000 feet. But as I understand that the casing was not in order, and that 1,000 feet would be down in the preCambrian, and certainly could not be above the Potsdam, such estimates should be taken with great reserve. The oil may come by a leak from superficial strata.

In Muskegon, the Central Paper Co. put down a deep well and kept a careful set of samples, the results of which are as follows:—

Muskegon well No. 6. Central Paper Co., on lot 1, N. E. 14, Sec. 34, T. 10 N., E. 17 W., about 4% miles from Ryerson well.

petroleum from Delta county, Upper Peninsula, Midi., handed to me for physical and chemical investigation. In the following please find the results at which I have arrived.

1. The color of the same is a brownish black, the consistency is liquid though moderately viscous,

2. Specific gravity of your oil compared ivith that of other prominent fields:

Your Delta county oil, Michigan, 0.873; Pennsylvania Petroleum, 0.801 to 0.817; Ohio Lima field, 0.816 to 0.860; West Virginia, 0.841 to 0.873; Russia Bakerfield, 0.859 to 0.871; Beaumont, Texas, 0.904 to 0 926; California, 0.920 to 0.983.

3. The flashing point of your raw petroleum:

You will undoubtedly understand that petroleum coming from the well must be safe for transportation, handling and for storage. Very few petroleums as they come from the well have these qualifications. All contain a greater or less percentage of naphtha, or some lighter hydrocarbons which have a tendency to reduce the flash point and make the oil easily inflammable. The flashing point of the sample of your raw oil proves to be between 165 and 170 degrees F. which indicates that the same is perfectly safe for any kind of transportation as well as for the required storage.

4. Results of its fractional distillation:

Temperature. Percentage of distillate.Below 150° C. or 302° F..... 6.8

150-250° C. or 302-482° F..... 64.3

250-325° C. or482-617° F.... ..... 11.2

•8.6 Paraffin and vaseline, and

9.10 Residue, which later proved to be mainly asphalt.

The first part (the 6.8$) of the above distillates contained but a very small quantity of light resp. volatile hydrocarbons (gasoline, benzine, etc.) while more than 60$ of the raw oil proved to be first-class illuminants

From the foregoing it is clear that the oil is of excellent quality, partly of a paraffin but mainly of an asphaltic base.

Very respectfully,

FR. RUSCHHAUPT. Geologist, Mining Engineer and Chemist.

I wrote the Central Paper Co. the letter below, and I understand that further tests may be made. I sent also sample bottles for samples of the Black Creek or Fruitport well, but mischevious boys carried them off before I got them, and the drillers did not keep a record.

Lansing, Mick., May 1, 1903. Central Paper Co.,

Muskegon, Mick.

Gentlemen.—I send herewith blue print diagram of your well.

I presume the well is at about the same height above the lake as the Ryerson well and about 10 feet lower than the old Mason well. The bottom of your well extends down into the Traverse (Hamilton) series of blue shales and limestones. A small area of this is found near Milwaukee. Thus, the easterly dip from across the lake is some 20 odd feet per mile (1615 feet -f- 84 miles). From your well to the Mason well the dip continues about the same as that from Milwaukee (1700—11?—1615-f-4).1

The bed of red fossiliferous limestone which shows in your well at 845 to 870 feet is ignored in the old Mason record, but show^s well in the samples from the well recently put down near the old Mason well, but on lower ground, at a depth of 890 to 904 feet. The dip is still easterly but not so great,—only about 11 feet to the mile. This is quite what we should expect for we know that this series of beds thickens going east and thins out near Milwaukee, and this is just about the dip which would be expected. Now, although the Ryerson well is not absolutely in the line of the Central Paper Co. and Mason wells, it is so nearly so that we should expect the beds in it to be deeper than in the Mason wells. Tkis is not true. Tkis bed and otlier corresponding strata appear higher in the Ryerson well, than in tke new well near the Mason well,—No. V of my annual report for 1901.

Accordingly, if I wanted to try further for oil, I should go up the lake, —say on sections 15 and 16, and see if there might not be an anticlinal in that direction. The oil

sand is, however, so fine-grained that it is not likely to be a free yielder unless it is struck in some exceptionally coarse

i The difference in depth to the same horizon minus the difference in elevation divided by the distance between the wells.

spot. It is barely possible that oil or gas might be found at the point indicated as the Dundee,—2100 feet or so down, but this would probably be of the Canada quality.

I should like to know the record of the well and the sample of the Fruitport well put down not long ago, and with your permission, I should like to send a copy of this letter to Mr. Kirnball of Chicago. If we recognize that same limestone in the Fruitport well, it will be of considerable advantage.

Very respectfully yours,

ALFRED C. LANE.

In connection with the abnormal elevation of the Ryerson-Hill well above referred to, it is worth noting that as I have mj^self observed, it continually exudes some oil. The amount, according to newspaper1 report, probably exaggerated, is half a barrel a day.

DIVINING RODS.

There has been considerable activity in exploration near the Indiana line, not all of it on business principles. Wells have been located on the witch hazel divining rod plan worked up to an instrument supposed to be scientific, but which is beyond my science. Many would up and down denounce it as a fake and those who work it as fakirs.

I am inclined to think, however, in some cases the person using and having bought the instrument may be honestly deluded, and I think, therefore, that it may be worth while to give a description of the instrument and its working (the witch hazel and other water diviners are similar), to show how one may fool'one's self as well as others. It belongs to a class of instruments like the planchette, which are very sensitive to conscious or unconscious muscular action.2 The Assyria well was located by it.

Two flexible rods of whalebone about a foot long corresponding to the branches of the witch hazel, issue from a weighted disk corresponding to the fork or crotch of the witch hazel divining rod, to the other side of which is secured a tube (A) containing oil, or some substance which is

Fig. 8. Illustrates divining rod instrument.

supposed to be attracted by the substance in the ground. In working it the rods are bent until their ends are parallel, as shown in the diagram at C, and are held one in each hand, the palms turned upward, and the weight also being upward. In such a position it is clear that it is in a very unstable position, and that the weight (B) has a strong leverage against the grip of the hands which have only the thickness of the rods to

i Grand Rapids Herald, 11/1/1904.

2James' Psychology. My predecessor, Dr. M. E. Wadsworth, published in the American Geologist, January, 1898, an explanation of the mechanical action of the divining rod, which however, differs radically, in that the ends of the twig fork are supposed to " enter the closed fist on the exterior side of each fist," and the difference between wrist and finger action is not emphasized.

work on. Under such circumstances, by gripping it tight, one can keep the bob erect, but the least relaxation of grip, and ivhat I think is more important, a turn of the wrist so slight that I could not in watching my own wrists detect it, will let the bob over. In fact, the wrist has vastly greater and easier control than the fingers. Now it is easy to see from well recognized principles of modern psychology, that one thus holding it will from time to time either at points where he is otherwise led to expect oil, or from mere weariness, see it dip, quite unconscious of any cooperation on his part, if his attention is riveted on the grip of his fingers or on visions of oil, and may be led to believe the instrument full of magnetic power. So long as water is concerned and no special depth guaranteed, it is easy to see that here in Michigan, in almost all cases it will succeed. Possibly a little of that "horse-sense" by which animals are supposed to divine the presence of water may linger in some men yet and help them to guess good places to dig, which guess may be consciously or unconsciously recorded by the instrument.1 But in view of the fact that, generally speaking, the rocks below ground water level (say 30 feet depth at most), are saturated with water, it can hardly be believed that the rod can pick out what are known as veins of water, which are really merely more pervious places where the water will more readily flow, and be pulled by them, and not be strongly pulled by the general mass of water. The same thing applies to oil. There is more or less organic, oily, matter in most rock, especially black shale. Mr. Wood, for instance, made an analysis of a sample from the Assyria well at 1575 feet, under the direction of M. A. Cobb, in the laboratory of the Lansing high school, which, though it is only a student analysis, will illustrate the point. Others will be found in the coal report, Volume VIII, part 2, p. 105. It is as follows:— Analysis of shale from 1575-1700 of the No."2 Assyria well. Oct. 22, 1903.

How could a body of oil make itself felt through a belt of rock over 300 feet thick and so saturated with oil and gas as this, merely because it happened to be in a more pervious rock which would more readily yield it?

The Assyria well went through the Dundee, but no oil to speak of was found. I did not expect it. A strong brine peculiarly free from sulphates (Mr. Ware wrote in a letter that he thought he detected a trace of barium spectroscopically, which would account for the absence of sulphates), was found, whose analysis was as follows:—

Ann Arbor, Midi., Oct. 31, 1903. Mr. Alfred C. Lane,

State Geologist,

Lansing, Michigan.

Dear Sir.—We have just completed the analysis of the salt brine sub-

iRemarkable successes have been reported to me. For instance, for Jacob Wood of Farmington, now living one mile from Grand Ledge; also for C. D. Woodbury of Lansing.

mitted to us by you, and find it contains strontium, bromine, and lithium (spectroscope anal.). A 40 cc. sample contained 1.044 grams CaO; .510 grams MgO; and 6.9482 grams chlorine (in form of chlorides).

Very truly yours, Chemical Laboratory, U. of M.,

Elmer E. Ware.

Mr. Alfred C. Lane,

Lansing, Mich.

Dear Sir.—We beg to report the following analysis of the sample of brine received from you, from Assyria, Michigan:—

Gravity ..... 24° Baume

Bromine..... 0.11$

We have no means of determining the potash. This being a very difficult matter to obtain on account of the presence of so much sodium.

Yours truly,

(Signed) THE DOW CHEMICAL CO.,Oct. 24, 1903.
Jas. C. Graves, Supt.

Of course, the believer in the divining rod said that the oil was there but farther down, in the Trenton, and I advised the secretary of the company to go ahead down to the Trenton, because they were a good deal over half way down, and they might as well make the test thorough while they were about it, in accordance with Prof. Blatchley's remarks.1

The one thing that I would urge with all my power upon those who want to take a venture with nature by testing for oil, is that they write to me or some other competent person, find out how far they are likely to have to go to meet the various oil bearing horizons, and how much water they are liable to meet, and accordingly how many times they will have to case, and reduce, and decide before beginning how deep they propose to go before quitting, and begin with a hole large enough. Otherwise, before they have reached the Trenton, if that is their goal, they may have so much water and so small a hole that progress becomes practically impossible ; a very unsatisfactory conclusion. It is much better to begin with a little too large a hole than a little too small, as there are a number of heavy flows in Michigan strata.

Then if they want to use divining rods or similar machines or spiritualistic media, to precisely locate their hole, which I do not pretend to be able to do, it is at their own expense, and they will at least have the satisfaction of finding out whether they are right or not.

I may, however, say in general, that so many holes have been put down in Michigan with such ill success, that testing for oil is no enterprise for people who have not money to spare, and that to test for oil and gas, planning only for a single hole, is about as absurd as for a farmer to organize a company to put down on his place one test hole for coal. The successful coal companies have put down holes by the hundred, only a small minority of which have shown workable coal. The state will be very fortunate if the results are .no worse in the matter of oil and gas. The following remarks of Prof. Blatchley are applicable equally to

iNext page.

Michigan, with the exception that a boring as far as the Corniferous (Dundee) may reveal whether or not the structure is favorable:—

"Shallow Bores in Central-Southern and Western Indiana.

"Investigations carried on during recent years in the central-southern and western portions of Indiana, and records of many bores which have been sunk in those regions, have led me to believe that the majority of drill holes sunk there in in search of gas or oil failed to reach Trenton limestone, the rock formation which produces the most of the gas and oil in this state. This failure to sink the bores deep enough was due to several causes, chief among which is the great difference in the strata overlying the Trenton limestone in these portions of the state from those overlying the same formations in the main gas and oil-producing areas. In the latter areas the Niagara limestone of the Upper Silurian age and the Hudson river limestone and Utica shales of the Lower Silurian, are the only formations to be pierced by the drill between the drift or surface and the oil and gas-bearing Trenton. In the central-southern and western portions, especially the latter, a number of formations which are wholly absent in the main gas and oil field intervene between the surface and the top of the Niagara limestone. The drillers employed during the gas and oil excitement of 1887 to 1895, to sink the bores in these regions were, for the most part, from the gas fields. Their knowledge of geology was small, and in many instances, after passing through a shale which resembled the Utica, and which they doubtless thought was that formation, they called the underlying rock "Trenton limestone," and soon abandoned the bore as barren. The shales which they had pierced may have been any one of a half dozen carboniferous shales, or, what is more likely, the black Genesee shale, no one of which occurs in the main gas field.

"In a number of instances in the southwestern counties, the Corniferous limestone, which in places is oil and gas bearing, was not even reached, though it lies 900 to 1,200 feet above the Trenton. ' Wherever a bore was

thus abandoned without reaching the Trenton, all the money spent was wholly wasted, there being neither negative or positive results. Moreover, much territory was condemned as non-productive without being given a fair test.

"If the earlier bores had of a certainty reached Trenton and proven barren, then negative evidence would have been available. The one fact which I do wish to impress upon the citizens of the regions mentioned, is that much of their territory has not been properly tested. Another and more important reason for the statement is to induce companies who gink future bores to see to it that nothing stops the drilling before the Trenton is reached, or, rather, before that formation has been pierced at least 75 feet. Beyond that depth there is little probability of finding either gas or oil. A contracting driller of experience can easily and without great expense case off any salt water which may give him trouble. An accurate record of the thickness of each formation passed through, together with a small vial of the drillings of each, will aid much in determining the horizon which the drill is piercing at any depth, and such records and samples should always be kept."

Another important feature in testing for oil and gas (or in fact anything), is to have enough capital to give a proper test. A weakness of many, if not most, developing companies is that the stock is sold so low

that after the promoters' and organizers' stock is taken out and selling commissions subtracted and allowance made for the fact that not all the treasury stock will be sold, there is not enough working capital to really do much, even if there are no salaries to the officers. Mr. F. A. Cook of the Xiles Star was good enough to keep a careful record of a well drilled at Xiles, by the Xiles Oil and Gas Co., the record of which is given below. The business record of the company will also be found in the files of that paper for March and April, 1903, (see especially issues of April 6, 11, and 14). but as it is not geological, even though there may appear to have been something subterranean about it, it will not be fit to introduce here. The only interest the geologist, as such, has, is in noting that explorations on that basis are not satisfactory to anyone. There has been no exploration of the ^ Trenton in the southwestern part of the state, with the" possible exception of one hole at Dowagiac.

Southwestern Part of the State.

This district was discussed and a sketch map given in the annual for 1901, and contours of the base of the Devonian black shale given. The

§fig. 8. Niles Well.

anticlinal indicated as running northeast from Grangers, is apparently the Kankakee uplift of the Indiana geologists.

The record of the Niles well is given in the cut above. It will be noticed that the elevation of the base of the Devonian black shale (the Corniferous or Dundee horizon is within the next 200 feet below) agrees with the map fairly. This well was on the Baumann farm, about a mile west of Niles. The elevation is probably about 660 A. T.—at any rate between 646 and 680 A. T.

Of this well a proper record has been kept (thanks to Mr. F. W. Cook), and returned to this office.

The following data on this district have been gleaned from newspapers and correspondence. A well at Dowagiac was recorded in Volume V of our reports, Plate XVI to 1760 feet. An interesting editorial in the Dowagiac Herald (9—18, 1903), says that it was ,continued to 2?200 feet by a stock company, i. e., probably to the Trenton and later put down 500 feet or more by Mr. Beckwith, and encountered only salt water, no oil, but on application to the Beckwith estate, we are informed that the record of Volume V is all there was. A good record of this well would be of great interest. We may summarize as probably:—

This is a little different from the division in Volume V.

The Umholtz Oil Co., Geo. S. Green, President, bored a well on the Um-holtz farm about 8 miles north of Niles and 4 from Buchanan, striking through black shale into oil and gas at 618 feet, stopping at 620 (or 625) feet/ close under black shale (amount unknown).

They started about Oct. 20th,2 and were down to 250 feet Nov. 12. By Dec. 1 they were down to 565 feet. At 138 feet it was reported that they went through 7 feet of what proved to be dolomitic pyritic rock. The brine, which followed the oil was analyzed at Northwestern University.

WHITE PIGEON.

Near White Pigeon a well was put down3 by the White Pigeon Oil and Shale Gas Co., cased as follows:—

It was shot at about 765 feet, July 15, without effect. It was down 250 feet on June 19, and was drilled about 800 feet in all. The last 80 feet were probably the Dundee (not Trenton) limestone.

I have to thank the treasurer, Mr. Ed. Roderick, for a careful and complete record and set of samples.

Elevation about 10 (?) feet above Lake Shore and Michigan Southern station at Constantine or about 800 feet A. T. Compare the well at Con-stantine reported in Volume III, Part 1, p. 93, and in Volume V, Part 2, Plate XI. The location is near the northwest corner of the northeast % of Sec. 22, T. 8 S., R. 12 E.

Calcareous and from the varied character of its grains, evidently a glacial sand, which must come in from some vertical fissure traversed by the drill, and yet is peculiar as being in very nearly the horizon of the Berea grit which yielded a strong brine and gas from 283 to 383 in one of the Constantine wells, while in the other it seems to have been represented by 15 feet of red shale, from 286 to 301, while in this well it is not to be recognized at all. This variety in record is probably due to an unconformity at the base of the Carboniferous, and the red shale which

iNiles Star, Dec. 12 and 14, Letters, Nov. 12 and 18, Buchanan Record, Dec. 15, 18, 1903, Feb. 2, 32, 1904, " Soo" Ev. News, 3/1/1904.

SBuchanan Record, 10/16/1903, Dec. 1, 1903.

3Saginaw News, 7/15/1903; Niles Star, 6/19/1903; Constantine Adv.-Record, 7/8/1903; Free Press, July 15, 1903.

appears in various records in this corner of the state may be due to the weathering and oxidation of black and green shales beneath an old land surface.

This apparently corresponds to the base of the dark shales at Elkhart between 375 and 350 feet down, and in the first Constantine well record the red calcareous shale immediately underlying is counted in, and 211 feet of shales given between 492 and 703 feet. Corresponding horizons are found about 82 feet deeper at Constantine.

This formation was apparently not separated off in the Constantine records, but its base and the top of the Dundee is probably nearly marked by the brine and sulphuretted hydrogen which occur at 790 feet and correspond to the horizon of the "salt sand" from 696-711 feet here. The red, gritty shale at the top may also mark a time between the Traverse and Antrim as here developed, when there was a land surface here. The pale-ontogist Schuchert1 assumes that there was a neck of land here at about such a time, and the more recent Niles and Dowagiac wells show a greater thickness of blue calcareous shale with no red shale mentioned, while from Coldwater and Elkhart no Traverse is reported. The Mles well in Volume V gives us from 415 to 500 feet very similar strata.

The well was torpedoed here, but as It was not a dry hole it was not a fair test.

An interesting thing is the irregularity of the Berea grit shown by this and adjacent wells. I think that a well might possibly strike gas in this formation, enough to be valuable, if placed so that it could be used near by.

The base of the black shale is at about 227 A. T. At Constantine it is about 137 A. T. At Elkhart it is perhaps about 205 A. T., but the record and elevation are uncertain. At South Bend the base is at 375 feet A. T. It is apparent that the dip from this well to Constantine is pretty sudden and that the contour of the figure below, repeated from the annual for

Fig. 10. Sketch of contours of the base of the black shale. [Repeated from annual for 1901 and not quite right.

1901, should continue on further to the east instead of turning sharply south, and then if the Elkhart record is right, there must be a sharp drop (fault?) along a line running between South Bend and Elkhart, and passing east of Constantine and White Pigeon. One or two more wells in the south part of St. Joseph county, ought to cost less than $2.00 a foot for less than 1000 feet and might develop something of interest and value. There has been some talk of a well at Sturgis. I do not, however, advise planning to go down to the Trenton until we know a little more about the lay of the upper formations.

At Granger, just over the line in Indiana, a well was put down over 350 feet.1 The Bridginan Oil and Gas Company,2 has started to put down another well at Bridgman. The old well put down over 20 years ago, went about 100 or 175 feet to rock, 50 to 130 feet in rock, probably the Devonian shales (compare the Berrien Springs record), when a pocket of gas which burned some time was struck. The new well has the following

^Niles Star, 6/19/1903.

SBenton Harbor News, 9/2/1903; Benton Harbor Daily Palladium, 8/31/1903.

South Haven Sentinel, 7/2/1903.

record, most of it reported through the kindness of R. J. Stahelin and G. W. Bridgman.

BRIDGMAN.

"Record of the Bridgman Oil and Gas Co.'s well, located about 40 rods south of depot, on ground about 3 feet lower than railroad track, i. e., 636 A. T.—May, 1904."

"The above report was given me today by one of the workmen who is still here. It may not be quite accurate, but think it is as near correct as it can be had, as there was no record kept while drilling."

A company was also organized to operate near Galien, but Mr. Loomis, who was also connected with the Mles Oil and Gas Co., above referred to, was interested in it, and nothing seems to have come of it. Mr. ,J. J. Gal-

lendar, the same who located the Assyria well with his "instrument," is reported to have located the oil.1

The Assyria well, 917 A. T., might be treated in this connection, though it is in some respects more allied to those of the central district. It is the one I referred to as having been located by a modified divining rod. Through Mr. Geo, D. Conner and J. J. Callendar I have received a good set of samples and I also visited the well to get the elevation and temperatures. It was to be put down further in the spring of 1904 and the record is postponed, so that it may be given complete. The Berea—Bedford red shale was from 1400-1450 feet, and the Traverse from 1810 to 1875 feet.

About 1% miles east of the corners another well was put down in 1899, of which, in spite of various endeavors, I never was able to get a satisfactory record. I did, however, meet the driller, Mr. John Brogan, at Mr. Stearns7 well in Ludington, and obtained some of the data from him. The bottom of the black shale, top of the Traverse or Dundee, was at 1875 feet. This is quite a little lower than the other well,—about 870 A T. on Sec. 14, T. 1 N., E. 7 W.

The Milan well reported in 1901 was deepened and the record now runs from samples as follows:—

iPort Huron Times, 6/6/1903; Detroit Journal, 5/16/1903; Buchanan Record^2/15/1903 cr^Lal|Sorcllestyiteeetl suggested by Kraus in Science that these gashes are due to dissolved

Of a well on the farm of Uriah Arnold near Clinton, Sec. 2, T. 4 S., E. 3 E., we have learned only that they struck little if any oil, but a strong brine at about 1000 feet.1

This seems to be as far south as the rock salt occurs and it is interesting to note that here, as in Ludington and other points, the rock salt at its greatest extent occurs close to the base of the formation, and the higher beds occur only near the center. The total thickness from the base of the Sylvania to the base of the rock salt is 722 feet, the brown, oily dolomite above being nearly the same as at 1500 to 1550 feet at Britton, and the Niagara, the typical white Guelph coming immediately below.

Around in that region shallow wells, as already remarked by Sherzer and myself, are very likely to find small amounts of oil or gas of local value only. At Britton, where a deep well was reported on in 1903, on the lot of John Wiggins a well for water at 90 feet struck a pocket of gas, the glow of which when lighted, could be seen in Tecumseh. How much was wasted before it was controlled I do not know, but the pressure is said to have increased since,2 from 35 pounds per square inch to 41, which is probably about the hydrostatic head. I would again call attention to the probable value of such modest wells, their relatively short life, and the possibility that in the ordinary way of accidentally striking them, thousands or even millions of cubic feet of gas may be wasted before they are controlled.3

In this connection it may be well to introduce a comparison of nearly equivalent formations and names in Michigan, Ohio, and New York, as used by Prosser4 and Clarke and Schuchert.5

^Detroit Free Press, 6/24/1903.

2 Adrian Times, 6/22/1903, Free Press, 5/27/1903.

3Such a blow out of gas was struck at Halfway near Detroit at a depth of 460 feet, News and Free Press, 4/9/1903.

4The Nomenclature of the Ohio Geological Formations, Journal of Geology, Sept.-Oct., 1903, Vol. XI, No. 6, pp. 520-521.

sAmerican Geologist, Feb., 1903, p. 118.

Port Huron District.

In regard to this district, C. H. Gordon has made the following report in addition to that which he prepared last year. We have also records from the Port Huron Salt Co. and the Diamond Crystal Salt Co., which will find an appropriate place in treating of the salt formations, and in connection with the Detroit river wells.

Valley Center, Mich., Aug. 9, 1903. Dr. A. C. Lane,

Lansing, Michigan.

Dear Dr. Lane.—Two wells have been put down in this vicinity, reports of which interested me, and I made inquiries, the results of which I send you herewith.

1. Brown City well. This well was put down recently to secure an adequate supply of water for the use of the village. It is located near the depot (Elev., 812 A. T.)1 and stopped in sandstone at a depth of 227 feet. The thickness of drift passed through was 180 feet, consisting of clay and "hard pan" to within a few feet of the rock. The space between the "hard pan" and rock was occupied by gravel as at Valley Center2 and elsewhere, but was not so full of water, which was found in abundance in the sandstone below. This shows that the drift is not so thick here as previously supposed. In our report, the only information we could obtain was to the effect that the Harrington well, located within a hundred yards of the new well, was sunk 212 feet without reaching rock.3 The papers reported that copper and silver had been struck in the new well. On inquiry I learned that what was regarded as copper was found in the gravel bed overlying the sandstone. It occurred in small particles associated with a white metal taken to be silver, the latter quite rare.4 My information was obtained from the president of the village board. Water stands within 11 feet of the surface in the well.

2. Graves well. This well is a drilling made for water on the farm of G. Graves, 1% miles south and % miles west of Valley Center in the N. E. % of the S. W. % of Sec. 34, of Maple Valley Tp., T. 9 N., E. 13 E. In this well it is claimed that hard coal was struck at a depth of about 114 feet which the drill (a light affair) would not penetrate, being broken three successive times. On losing the drill head the drillers attempted to break up the rock and get the lost drill out of the way by dynamiting, with the result that the casing was broken and the well lost. A second and third attempt, each at a distance of six to ten feet from the first met with the same result. The fourth hole is now down to a depth of 104 feet but no drilling is being done owing to a press of other work. The record of the drilling as given me by Mr. Graves, is as follows:—

*Report on Sanilac county, p. 5, Vol. VII, Part 3, Mich. Report.

sibid, p. 11.

3Report on Sanilac county, Vol. VII, p. 10.

*It may have been bronze and white mica.

Mr. Graves says there has been no hard coal about the place for a long time and he is of the opinion that it could not have been put in from the top. Each night the hole was covered and a heavy weight put over it. No motive can be suggested for "salting" the well. The loss of the wells rests * entirely on the driller who contracted to furnish a satisfactory well at $1.00 per foot. In one of the holes he says a coal seam was struck somewhat higher than in the others but the main bed, if such it is, was found at the same level. I send you specimens of the coal brought up by the drill. There seems to be no question of its being anthracite.

I give you the facts as he gave them to me. My impression is that someone is trying to ado" the driller, possibly to even up an old score.

Very truly yours,

(Signed) C. H. GORDON,

Central Part of the State.

It will be remembered that in previous reports1 I have mentioned anti-clinals as probably existing in the central part of the state, and pointed out that one probably passed through Saginaw (Wiley Brothers' well is near the crest), but was not able to give its course. The prosecution of coal mining and exploring makes it more and more probable that the Saginaw seam, 180 to 190 feet beneath West Saginaw runs up into the same mine at about 155 feet south of East Saginaw. Again, according to the reports of Mr. Chas. Page, the well of the Monitor Oil and Gas Co. on the S. W. 14 of the S. W. %, Sec. 26, T. 14 N., B. 4 E., considerably higher (605 A. T.), than the South Bay City well,2 582 A. T., ran some 30 to 40 feet less depth.

The Upper Marshall is said to have been from 800 to 930 feet. A sample of fine grained, red sandstone at 1050 looks like lower Marshall. The tools got stuck at 1700 feet, but this and other records bring out clearly in a section prepared by Mr. Cooper for his Bay county report, an anticlinal between Bay City and Midland. It is probable, therefore, that the Saginaw anticlinal ran rather nearly north, passing 3 or 4 miles west of Kawkawlin, at which town corresponding strata are much higher than in Bay City.

iVol. VIII, Part II, p. 176, Annual Report for 1901, pp. 211-237. 2Annual for 1901, p. 224.

LIVINGSTON COUNTY.

There have been pronounced signs of oil and gas discovered and quite an oil excitement recently in the northwestern part of Livingston county1 near Fowlerville. I have also some records of a well near Morrice, which, though incomplete, are interesting, and seem to indicate a well marked anticlinal at least down to the Berea grit. This occurs according to J. J. Mason, at Columbiaville,(764 A. T.) at 1500 feet, 90 feet of sandstone full of brine; at Flint (723 A. T.) possibly at 1200 feet depth; at Black-niar (610 A. T.) at about 1675 feet depth. On the other side of the basin it is absent, but its horizon apparently occurs at Jackson at 1400 feet depth, and at Assyria (917 feet A. T.) at 1400 to 1450 feet depth and at Charlotte at 1680 feet depth. But between we do not find the Marshall and Berea deepening as might be expected. It is possible that the deepest well at Lansing reached it at or before 1400 feet.

There was a well put down by C. W. Gale in the 1860's close to the Looking glass river (850 A. T.) on Sec. 25, T. 6 N., E. 2 E., of which we can get a record only from memory, that it was about 1100 (1135) feet deep, that at the bottom a strong brine was struck of which a sample was sent to A. Winchell, that it did not smell of sulphur, that this brine flowed and that a little oil used to show on the river, that much black shale was traversed and also a lot of "blue clay." The first casing was 45 feet to rock, which was sandrock. At about 100 feet a second casing was put in and at 600 feet a seed bag was put in so as to use the top water when it was decided not to use the brine. The top was drilled wet and water was never over 10 feet from the top at any time.

This sort of a record with so much blue and black shale suggests the Coldwater and Berea or Antrim shale, as does the Durand well given in Volume VIII. But if this sandstone and brine is the Berea there can be but little doubt that that of Jason and Shumway is also, who put down a well northwest of Fowlerville on the farm of Mr. Grill on Sec. 17, T. 4 N., K. 3 E., about 1000 feet A. T. The record of this is given as follows :—

Though full of salt and plugged there was a constant leakage of gas. This coarse sandstone full of a very strong and pure salt brine at so shallow a depth, must be either the Marshall or the Berea. But the Marshall

iPree Press, 5/17/1903; also 5/23/1903; 5/30/1903; Fowlerville Review, 10/16/1903; South Lyons Herald, 5/15/1903; Detroit Tribune, 5/26/1903, with photographs; Lansing Journal, 5/23/1903, 11/4/1903.

3SHKsSSSf|sr:.:'.:-t

"SJSSMSsaasSgK^j...;-

„, -«;|-|r«s.,-.&h

rifS^roS'^STan^ller well which is said to have had salt water. The record as given, is as follows :—

Fowlerville Oil Well

Two miles south and 2% miles east of Fowlerville in the N. E. % of Sec. 6, T. 3 N., E. 4 B.

.SSSISS'SSSK:

S^W«X2ETSJSJr«?±SS IcKin ^

The temperature varied from 67.6 degrees at 1450 feet to 49 degrees at 200 feet. The rate of increase is not absolutely uniform.

In closing my notes on the subject of boring for oil and gas this year, I take pleasure in referring to the elaborate reports issued by Prof. W. S. Blatchley, State Geologist for Indiana, from Indianapolis and the auspicious resumption of the publications of the Geological Survey of Ohio under E. Orton, Jr., by Bulletin No. 1, containing a report on the occurrence and exploration of petroleum and natural gas in Ohio, by J. A. Bownocker, published at Columbus, Ohio. This contains in Chapter V, a good review of the theories of the origin of oil and gas, which will save my going into the subject now. I may also say that so far as lower Michigan is concerned, oil and gas seem to arise from the decomposition (very likely bacterial, most decay is) of buried animal and vegetable matter.

If the deep well at Rapid River strikes oil or gas down in the preCam-brian, I shall begin to believe there may be something in the theory of inorganic origin of petroleum as applied to the commercial product.

PEAT.

Dr. Rorninger closes Chapter II of Volume III of these reports with the following prophecy, "fuel is too cheap yet, but the time will come when peat will be appreciated at its true value." With the exhaustion of our forests, which has caused the development of the coal? cement and brick resources of this state, the time seems at hand for the fulfillment of this prophecy. The problem of the utilization of the peat is one for the mechanical engineer as well as the geologist. But fair questions for this board to help solve pertain to the properties of the different kinds of peat as they lie in the bog. How stringy is it and how does this factor depend upon the plants that made it or upon the variations of water level ? What liability is there to be logs of wood, stumps, and other obstacles to easy working scattered through the swamps, and what kind of swamps are most free? What is, the effect of a certain admixture of mud and silt? Suppose a peat thoroughly dried, how much will the different kinds re-absorb from the air (for they will take up some) ? These are some of the questions upon which we have obtained data. I had hoped for a report ready for this year. I think we shall certainly by next year have something worth while to add to our brief statement in the 1902 report.

Prof. C. A. Davis has been at work for us, and writes as follows:— "I had a chance to spend some days in the camp in Eoscommon county where the Bureau of Forestry party is at work and availed myself of it and am very glad I did so, for it took me into a country where peat bogs are really a feature of the surface geology, and not simply an incident or accident. I found there that the plants are the same that occur at Ann Arbor in bogs and that they occur in the same relationship to each other and to the water level and the shade that they do there, and that the bogs pass through the same stages of development, reaching a climax which is practically permanent so long as the water level is constant or rising only as fast as the bog builds up, but if anything occurs to cause decided elevation or depression then a change occurs, which, if the water level is raised, is in the nature of a rejuvenation, in which the bog goes back to the marsh or even pond stage, and begins over again, or if it is lowered then the bog plants are crowded out by more aggressive species from the higher land around. Thus around the camp where I stopped, were numerous bogs which had been rejuvenated by the building of dams by the lumbermen, and it was easy to see that the rising of the water level had killed out the old plant covering and had given the sedges and grasses a chance to come in again and there were numerous "hay marshes/' as they call them up there, which had evidently been cut out of the older cedar and tamarack swamps by fire, the peat burning down to the level of the ground water, after which the same sedges and grasses which build out over the lakes here have gained possession and have started in a new cycle which will progress from sedge to grass, to heath-sphagnum, and finally to cedar-spruce-tamarack and possibly to elm and ash swamp. In my studies of the bogs north, I have been interested to see that the plants which south all huddle in the bogs and keep at about the same distance above water level, are, as we go north, separated by degrees, until it is practically certain that several of them are not bog plants at all in the north, but occur only on the deeper levels of rather poor soils, and even some species, which botanists are inclined to call bog plants exclusively, do not get down into the bogs, but are simply confined to their margins and the indications are from the analogy of the plants which get away entirely from the bogs, that most if not all of the bog plants down in this part of the state, get into dry situations to the north and give place to other species from farther north in the bogs. This is an interesting discovery from the point of view of the ecologist, and from our point of view as well, for it opens up a way to form a hypothesis that the northern bogs grow more slowly, or possibly more rapidly than the southern. I think it is likely that I shall decide that it is more rapidly, for if the broad leafed shrubs and trees cannot get into the bogs until a relatively great elevation of surface has occurred, then sphagnum, which is probably a rapid peat maker when once it is established, has the longer chance to grow and build before the higher plants shade it out. On the other hand, if it is true that the higher plants make the most rapid accumulations of peat then the northern bogs would grow more slowly. At any rate it seems certain that the more northern the bog the longer it will remain open so long as the water levels do not change. It is also possible to tell the present condition and stage of development of a bog by the flora of the surface of it, but evidently from the foregoing, it is not possible to tell anything about the quality of the peat, for present conditions may be the result of very evanescent conditions which have not been in existence but a short period of time. So much for

this side of the investigation, which is one of much interest. The region south of Koscommon which, by the way, Leverett has mapped with some care1 is full of extensive peat bogs, probably of varying depth, but some must be quite deep. The aggregate area is large and from the configuration of the country and the nature of the soil the peat must be of good quality. I did not bring samples back as I had my grip full of stuff and had such long distances to travel by carriage, but they can easily be obtained if wanted. The peat I examined up there was mainly fibrous and not thoroughly decomposed, a kind hard to handle as the Capac people are finding out; it does not cohere in the compressors, so that the bri- -quettes are not durable. I may say that seems to be true of all the northern peats I have examined. I have worked up the Ann Arbor R. E. to Frankfort and looked around quite a good deal on other roads, and near the railroads there are not many large areas of peat that I have seen. The deposits near Jackson, I went over with Thompson and from Jackson

on down the old drainage channel to Kalamazoo and beyond, there is a great area of peat, which is more thoroughly decomposed than that north, and which is also more compact, as would be expected. This grade is of course, higher in ash, but it can probably be put into form for consumption without much compression and possibly by some drying, so it is well worth trying. There seems to be an abundance of this sort of material in the region, and in fairly large areas, but much of it is still covered with bushes and trees so it is not so easy to get at as the open bogs. Thompson says that he went into the Upper Peninsula and prospected a number of bogs but found them full of submerged tree trunks and stumps so that he could not get his sounding rod down in them, and I presume he is right about the matter, since I had the same difficulty in the bogs around Cadillac and in Koscommon county. Such bogs, of course, add materially to the cost of getting the peat out, since they have to be handled individually and cannot be scooped up by machinery. They are having some trouble with such material at Capac, although the amount of it there is not very large. In Eoscommon county I learned that in some places where bogs had been cleared, the buried logs and stumps were so thick that when they were logged up and burned down to the level where the land could be plowed, the surface was lowered so that the attempt at cultivation was abandoned because the water stood on the surface and the cultivation plants were drowned out."

Alma, Mich., June 10, 1903.

Dear Doctor.—I herewith transmit copy of notes on peat analyses of samples taken from near Ludington.

You will notice that about ten per cent, of the wet substance is combustible matter, and that the amount of sand is very large. Sample No.

'SeeLivingston's map in this report, Plate III.

6 when dried in oven gave 8633 B. T. U., so I calculate a ton of thoroughly dry peat of this quality is equivalent in heating value to an equal weight of beech and maple wood.

Yours truly,

A. N. CLAEKE.

Prof. E. T. Jackson of Harvard University made a not profitless trip to some of our chief later paleozoic localities, from which we had hoped for paleontological light. The report has not been received in time for incorporation here.

RELATION TO OTHER ORGANIZATIONS.

Eelations with the U. S. Survey have been as close as heretofore not only in cooperation in the topographic survey leading to the publication of the Ann Arbor quadrangle and preparation of three-fourths of the Detroit quadrangle, but also in the continual interchange of information, in the preparation of the Ann Arbor topographic and geologic folio, by Messrs. Eussell and Leverett, in the study of water powers, in charge of Mr. E. E. Horton and W. M. Gregory, and the water supply through Mr. W. F. Cooper and M. L. Fuller and Alfred E. Schultz, and in the study of the sedimentary section of the Upper Peninsula by Mr. Alden.

Mr. Chas. S. Prosser, working for them mainly in Ohio, has recently published a classification of the Ohio column1 elsewhere given, in which he has adopted our term Monroe, after discussion with us and the U. S. authorities, and we expect to use his terms Lucas and Sylvania. I would call attention to a pamphlet recently issued by the U. S. Geological Survey2 on cooperation with the state surveys.

Another similar pamphlet of interest3 relates to cooperation in the collection of statistics between the various bureaus.

I endorse the recommendations thereof and repeat my suggestion of past reports that there be more uniformity in the gathering and publication of statistics. Changes in the method of gathering or even of presenting these is a very great detriment to their value. Statistics form a science by themselves, and though, as the paper shows, in many states some statistics are handled by boards which also conduct geological investigations, I am not entirely convinced of the wisdom of this. I think the mineral statistics and reports of inspectors of mines, etc., should be published in connection with the other industrial statistics, though there may be friendly cooperation in gathering information. Mr. Hanna, the present commissioner, has started some very valuable tables which should be kept up continuously and systematically.

I do not think that this board should gather such statistics. There are, however, two other extensions of the work of your board which seem to me more desirable. For some years the Michigan Academy of Science has recommended a biological survey of the state. This has been carried on in connection with the geological survey in a number of states. An abstract of the reasons for, and utility of, such a survey is given by them as follows, and has been the theme of Prof. Newcombe's presidential address:—

1 Journal of Geology, Vol. XI, No. 6, 1903, p. 519.

^Extract from the 22d Annual Report of the Director.

3Cooperation and unification in Federal and State Statistical Work, a paper read at the 19th annual convention of the Commissioners of State Labor Bureaus, Washington, D. C., Apr. 28, 1903, toy S. N. D. North, Washington, D. C., 1903, pp. 5, 6, 7, XI.

38

Reasons for a Biological Survey of the State of Michigan^ Prepared ~by the Michigan Academy of Science.

I. States making or having made such surveys.

New York, Pennsylvania, Ohio, Indiana, Illinois, Wisconsin, Minnesota, and California.

Various other states not appropriating funds directly for a biological survey, empower various boards to do such work. Thus the health board of Massachusetts makes biological surveys of rivers and lakes used as water supply for cities.

Michigan, in connection with the geological survey, began a biological survey in 1837, which, for lack of funds, was discontinued in 1840.

II. Reasons for making a biological survey.

1. To add to the sum of human knowledge.

2. To furnish data for nature study in the schools.

3. To furnish data on the past and present resources of the state in timber, fish, game, forage plants, fruits, peat, marl, etc.

4. To furnish a scientific basis for practical work in preserving and replenishing these natural resources. (Forest are to be grown again in Michigan, and peat can be made to reproduce itself. One-half the area of the state is water or land unfit for agriculture, but can be made a source of wealth on account of its forests, fish, and game. The commissioners of fisheries and game in Maine estimate the amount spent in 1902, in that state, by those coming from other states to hunt and fish, at f 6,000,000 to 112,000,000.)

5. To secure the introduction of new plants and animals of economic value.

6. To restrict the spread of plant and animal diseases.

7. To furnish data for just legislation on forestry, water-supply, and the taking of game and fish.

III. Lines of work to be followed in a survey.

1. The collection into accessible form of the scattered publications on the plants and animals of the state, and the completion of the examination of the whole state, so that every school and everyone may know the plants and animals of his neighborhood.

2. The study of the habits of plants and animals, their food, their migration, their reproduction, and their beneficial or injurious effect.

3. The study of the relation of plants and animals to soils, to climate, to rainfall, etc., so as to enable one to know where agricultural plants, fruits, etc., may be raised.

4. The special study of rivers and lakes to determine the food of fish and the means of propagating fish in waters now furnishing no support to them.

5. The especial study of the habits and propagation of game birds and animals.

6. The especial study of problems in reforestation of waste lands.

7. The study of the water supply of cities.

8. The especial study of insects, fungi, and bacteria, and the means of combatting pests and diseases, for instance, distribution of malaric mosquitoes.

Granted its advisability, the reasons for its being conducted by the board are three-fold:—

(1.) The precedent of other states.

(2.) The economy of administration, over having a separate board of survey.

(3.) The unifying of the scientific research of all the higher schools of the state, rather than having such a survey conducted as it is in some states, solely by the university. If the board of regents of the university were in this state, as in New York, the center of all the educational interests of the state, this argument would not apply.

Feeling that the arguments for a biological survey as above given, were weighty, I favored an appropriation to that end, introduced as a separate bill, which passed both houses though it failed to become a law. My experience, however, with another separate appropriation which did pass, to aid the topographic survey, has, as below mentioned, not been entirely satisfactory. The keeping items charged to different petty accounts means much more work, both in my own and the auditor's department, and one great advantage of having the biological survey attached to the geological survey,—the ability to attach a biologist to a geological field party— would very probably involve us in bookkeeping snags. Would it not be better simply to provide in one act for the extension of the work of your board to cover this field, and then to provide separately for such increase in your general appropriation as might be deemed advisable, trusting to your board to apportion the same fairly, or directing that not less than an average fixed sum be expended in certain directions?

The same thing applies in regard to the topographic survey which has been urged by the Michigan Engineering Society as well as the Academy of Science, and was favored by the late Senator McMillan. The utility of the joint topographic survey is unquestioned, and I append Col. Muenscher's report to the Michigan Engineering Society.

Report of Committee on the Topographical Survey of the State.

To the President and Members of the Michigan Engineering Society:—

Your committee on the Topographical Survey of the state would respectfully report that they have done nothing as a body the past year in furtherance of the object for which they were appointed. The indifference with which their memorial to the state legislature of 1901-2 was received, was very discouraging, and would seem to indicate that the people of Michigan are not yet sufficiently informed of the value of such a survey to make it for the interest of their representatives to promote it.

It is gratifying, however, to know that a commencement

of this work has been made, for which we are indebted almost entirely to the zealous efforts of our member, Mr. Alfred C. Lane. By devoting to this purpose a portion of the appropriation for the state geological survey for 1902-3 he was enabled to obtain the cooperation of the United States Geological Survey so far as to secure the survey of the quadrilateral enclosed between the parallels of longitude 83° 30' and 84° west and of latitude 42° and 42° 30' north, and including the cities of Ann Arbor and Ypsilanti, most of Washtenaw county,, and portions of Livingston, Oakland, Wayne, Mon-roe, and Lenawee.

Mr. Lane also succeeded, with very effective assistance from the Michi-

gan Academy of Science in persuading the last legislature to appropriate the meager sum of f 1,000 to be expended during the year ending June 30th, 1904-5, for the continuance of this work. It is hoped that by means of this appropriation, with the aid of the United States, the survey of another quadrilateral, including the city of Detroit will be accomplished. The map of the first quadrilateral has been completed, but has not yet been published. A very few moments' inspection of this map ought to be sufficient to convince any intelligent man of the immense value of this survey, not only to engineers, but to all persons owning property or interested in public works or industrial enterprises of any kind in the state. It is reported that by the use of a single sheet of the Topographical Survey of Ohio, the locating engineers of the Wabash railway were recently enabled to change their previous location so as to save 2,300 feet of distance, and a summit termed 800 feet long, at an estimated money value to the company of more than |70,000.00. If such an amount can be saved by a single sheet by a single enterprise, how much can we not fairly hope for from a complete survey of the state.

Possibly a copy of this completed sheet placed in the hands of each member of the legislature to be elected next fall, would be the most convincing argument that could be used to advance the object which we have in view.

It would be, perhaps, too much to hope that this legislature can be induced to make any large appropriation, or to enter upon any general plan of survey, but it is not impossible that the members of this society from those sections of the state which are most largely represented, such as Grand Rapids, Saginaw, Kalamazoo, Battle Creek, etc., could, by personal efforts with their representatives, induce them to combine to carry through an appropriation which would cover the survey of those sections, and thus carry on the good work which has been begun.

E. W. MUENSCHEE,

Chairman.

Prof. E. E. Bogue of the Agricultural College wants a similar survey as soon as may be to cover the college area. It is in the line of work which the board can do with limited means but very slowly. To aid in the work the legislature of 1903 made an appropriation, which was cut down before passage to |500 per annum,—not even enough to make one-half of the smallest unit of mapping without supplement.

In the course of the summer I found out by expensive experience from the auditor general that having had an appropriation for a specific purpose, the general appropriation could not be used for that specific purpose, though the same object be covered by it, and the only way I could aid was by doing a certain part of the work entirely at our own expense.

But it caused me a good deal of anxiety of mind and I also had personally to carry something like a thousand dollars worth of expense for a month or two. I would therefore recommend that any further additions which the legislature may see fit to give to hasten the work of the topographic survey may be either in the shape of additions to the general fund, or in sums of not less than f 2,500 per annum.

The schoolmaster's club, and teachers' association as well as the Academy of Science are showing more interest in the work of the survey as the equipment of the teachers improve. I am not inclined to urge the study of geology as such into the grades. Too much preliminary knowledge is required before beginning its scientific study. What is advisable

and useful can best be given in connection with a good physical geography. One can hardly describe the earth as it is, without some reference as to how it came to be so, especially when the agencies are still at work.

I would also urge that mineralogy is a very interesting subject, giving play to the collecting instinct, and of peculiar interest to many boys. In the boulders or hardheads scattered over our fields almost any mineral may occur. Practical experience shows that it tends to hold boys in school better than biology and I should recommend that mineralogy be allowed as an alternate to botany or biology, where the teacher desired and the local conditions made it advisable.

A committee of the teachers' association have prepared a handbook for the use of teachers. If possible it would be well to have this widely published and distributed among the teachers.

By an arrangement with the university, needed analyses have been made for the board under the direction of Prof. E. D. Campbell at half the usual rate, mainly by E. E. Ware and L. Kirschbraum. Many, such as those of the Lighthouse point quartz diabase, and those of a series of clays for Prof. Sherzer, are inserted in appropriate places.

A piece of fusible slag from our Michigan coal was sent me. Such slag occurs rarely but occasionally in connection with the Saginaw seam. It seemed to me worth while to have it analyzed to verify my suspicions that it was due to black band ore. The following is the result:—

This was tested for ZnO but the chemist could find no appreciable trace.

of it.

In the notes turned in by W. M. Gregory for the gypsum report, Volume IX, Part 2, on the Alabaster region, there were some remarks on recent changes of the Lake Huron shore which seemed hardly pertinent to that report but were of such interest in themselves as to deserve insertion here.

EECENT SHOEE FOEMS.

BY W. M. GREGORY.

Outside of the glacial region and between the lake level and the Nipis-sing beach is a strip of land which is due entirely to recent lake formations, some of them within historic times. The general shore structures of the eastern edge of this area show the direction of the adjustment of the beach to the lake currents by the smooth curves, convex to the lake, present in the outline of the shore, both in the larger features and the smaller ones. The most interesting place where these recent formations

have been more rapidly built, is at Tawas point. This formation is spoken more of at length below. The places in the "bight" of Tawas Bay show how the building out of this point is gradually weakening the building effects of the waves on the shore in its shelter.

One of the familiar features along the shore are the sand dunes; in many places arranged by storm waves and wind action into lenticular dunes with the longer axes northeast and southwest. These are often cut later into several smaller ones by wind action, or perhaps the entire top blown off, forming a dune which resembles the crater of an old volcano.

The cutting of the lake shore is going on very extensively in regions which may be located as in general above prominent points. ^The erosion of the lake bank a mile and a half above Tawas point, has carried the bank inshore some 50 feet within the memory of the fishermen living there and as shown by recent surveys. Cutting has also taken place below Tawas City, and this is due to an eddy current which is traveling in the bay, and its effects have been very extensive. A large amount has been expended in building a revetment and otherwise lessening the erosive action of this current which is often aided by the northeastern storm waves. In this same region the Detroit & Mackinac R. E. once ran in front of the old Presbyterian church, but because of the extensive cutting, thus causing the caving of the bank, the track was moved a distance back of the church and at the present time where the track stood the bank has been cut out some five to ten feet, almost wholly through wind action. This has been done within the last 15 years. Very extensive cutting has also taken place in a long stretch of this shore from Harmon City down nearly to Point Lookout. In this region, the average height of the bank varies from 10 to 20 ^ feet All of the points below these regions of extensive cutting are building spits and are otherwise rapidly enlarging, thus showing where part of the material being removed is being placed.

FORMATION OP TAWAS POINT.

This has been spoken of as Ottawa Point, Tawas Point, or Whittemore Point, and is located some two miles directly east of Tawas City in losco county, and it is so excellent an example of the formation of "cuspate forelands" that it is deemed worthy of a rather careful consideration. It has long been known by the settlers of this region that the point has been in process of rapid building. The bay has always been one of excellent refuge for ships in the case of storms and a lighthouse has always been maintained for aiding navigation. The trouble with the location of these lighthouses has been that they were built on the end of the point and by its rapid growth needed to be moved from time to time not to be misleading. There have been two of these lighthouses and also a fog horn, built in recent times. This of course, has been due to the action of the currents in rapid building and similar phenomena have been discussed by different people in other regions, but this particular point, excellent as a type of formation of cuspate foreland, has been overlooked. It has been used by the writer as a practical exercise in geological excursions (field) in school work and has been a source of excellent results to the pupils who have lived in this vicinity.

A few notes may now be given pertaining to the building at this point The first lighthouse which was located in this region was built in 1856. The light was located on the end of the point at that time and the water's

edge was only 15 feet away, and there was no land to the southeast. At this time there were several small ponds in back of the lighthouse. This was 1800 feet northeast of the present light, which was built in 1876. Thus in 20 years a stretch of land some 1200 feet in length and 1000 feet wide in average was added. This enables somewhat definite estimate of the power and the rapidity of the point building forces of this region.1

The building action is largely due to waves throwing up the sand and the wind blowing the sand out of the water and piling it up in dunes, thus slowly adding to the land already in place. The water coming down the shore is supplied with plenty of sand and what is not extracted from the waves by the winds is carried to the point where the waters of the lake meet the waters of the bay and at this dead water triangle between the two currents opposite in direction, it is utilized in prolonging the length of the point. These normal conditions are often disturbed by a change of wind which introduces changes of the currents.

The new lighthouse, as has already been stated, was built in 1876 and was entirely surrounded by water, being built on a firm area of land between which and the mainland there wTas a passageway from the bay to the lake through which fishing boats of large size often passed, and through which the surf boats of the life-saving crew were taken from the station to the bay to

work in the lake. At the present time this passageway has been closed at the ends and is only a swamp between two high ridges of sand. The old shore lines on the point are marked by faint beaches of well worn brown, sandy, shelly pebbles. The surface of this point has been made over almost entirely by wind action where many forms of dunes are seen covered with very little vegetation. It is possible to see the dunes in the embryonic stage, its fullest development with a smooth full top, and in the stage when the top becomes blown off, which is characteristic of its old forms.

In addition to the lighthouses above mentioned, there was built in 1900, because of the point's rapid growth, a fog horn .6 of a mile southwest of the present lighthouse, being at the present end of the spit. The land between the fog horn and the lighthouse has a width of some 600 to 800 feet, spindling down to some 200 feet at the fog horn and turning off sharply to the northwest where it forms a hooked spit. The average height of the land between the present light and the end of the point is some three to five feet. On the lake side of this formation at the water's edge, are many small pebbles, well worn and making a distinct beach. Going lakeward these increase in size. Out 100 feet from the present shore line, there is a distinct bar or ridge formed, which is the predecessor of the point which is to pome. On the off shore side of the point the water is very shallow in this region, being from one to four feet deep, out for a distance of more than three-fourths of a mile, where it drops off very suddenly to a depth of 15 feet. In the inside curve of this spit or as it is locally known, the "bight" of the bay, there is no distinct shore line ^ as along the outer edge of the point. The sediments here are very fine silt, mud, bark and floating debris, and it is a place much loved by ducks, the mollusca and other fresh water shells. Here are many good examples of ripple marks, wave prints and the tracks of different animals. A large

*It is adding say 1,200 feet in 20 years. 3,168 feet in 24, say 60 feet a year, or in area 1,200 X 1,000 in 20 years or 3,168 X (700 to 200) in 24 years, or almost exactly 60,000 square feet a year. The area of the point proper from section 13 to section 21 is only about 1.6 square miles, projecting perhaps four miles from the normal coast contour, so that figuring by length it would only take some 350 years or by area 460 years to have produced the whole point.—Lane.

part of the bottom is exposed by the water when the level of the lake is lowered by reversed currents of water due to wind action.

The currents which cause the building have been carefully observed throughout a period of several years by the writer and some explanation of the facts may be attempted on the data attained. The currents are dependent upon the direction of the wind. The prevailing direction of the wind for one-fourth of a mile out from the life-saving station is to the southwest^ but this direction is reversed during a heavy southwest wind. The general current has been shown to be as above stated by the drifting of boats, floatwood and a series of tests with bottles. The objects when placed in the lake from small fishing boats, located off the life-saving station, were found to take a course to the southwest which brought them to a point near Alabaster. In heavy storms from the northeast a very strong current runs down this shore and strikes the shore of Saginaw Bay at Harmon City and Alabaster. This was shown to be the case when the steamer Baltimore was wrecked above AuSable, which occurred in 1900. Some of the wreck material was thrown on the beach just below Alabaster and the course of the wrecked boat was in this direction, which the current takes during heavy northeast storms. At such times there is formed an eddy in Tawas Bay, this eddy current having a direction on the shore opposite to that of the lake, and thus where the eddy current and the lake current come together at the end of the point, there will be formed a dead water triangle, and in this triangle the addition to the land will take place. The prevailing direction of the currents are as indicated above and have been tested several times to prove the correctness of the theory. During the use of the dredge at Tawas City, the muddy water was carried in the direction of the eddy referred to, and W* O. Emery of the custom office has observed these currents for a number of years and believes that the eddy's general direction is to the northeast along the shore of the bay, while outside the point the prevailing current is to the southwest. In considering these currents in this discussion, we must remember that these directions can be reversed during a storm.

The ridges which are formed and which are the most prominent feature of the point, are believed to be the result of big storms. At Tawas beach there are as many as a dozen of these ridges nearly parallel with a decreasing elevation as they reach the water. The heaviest storm of the season builds the highest beach, and thus when the water stands at the same level there are a series of beaches commenced. The sharpness of these storm ridges which have been formed during the building of the point decreases as we pass up the bay under shelter of the point. The old ridges which are prominent and extend entirely across the point and are being cut by the lake waves at present, were built before the point was formed and resulted from the formation of a similar point before the present one, for if the present point were to build rapidly across the bay and close in a body of water, we should have exactly the conditions under which Tawas lake was formed and later Lake Solitude. Some of the members of the U. S. L, S. station have observed the formation of these storm ridges which have been built in a single night's storm to some 5 or 6 feet above the lake level.

The water of Tawas Bay varies in its level considerably, being dependent upon the direction of the wind and its strength. In November, 1901, the wind from the northeast raised the level of the water some three feet, according to the authority of Engineer Black of the East Tawas Water

Works, and on April 14, 1901, in four hours the level of Tawas Bay was lowered 1.64 feet by a southwest wind.

Lake Solitude, which is located on the "bight" of the bay, is a shallow lake with muck and silt in the bottom with a large sandy ridge nearly dividing it into two distinct parts, and with an elevation of 2.5 feet above Lake Huron. This lake had two outlets at one time, or more properly was connected with Lake Huron, being merely a passageway between two sand ridges. When the level of the lake fell the water was partly drained oft, and because of the sand bars which choked the entrance, a considerable area of water was left behind forming a lake, which in time demanded an outlet, and this was accomplished by cutting across the places where the wave action was slight under the protection of the building spit, and thus making a small outlet to the lake, while the older became clogged by the action of the waves on the Lake Huron shore. This is a rapid sketch of the formation of many of the lakes along this shore.

Tawas lake, which lies to the northwest of these smaller lakes just described, has the same general characters, being nearly filled with silt, muck, and abundant growth of vegetation. It evidently was formed between the Algonquin and the Mpissing beaches, and was evidently the first point formed in this region by the action of the currents in building off the shore bars and spits, as its western border in many places rests on the eastern edge of the Alcona moraine.

From Au Sable all along the shore to Au Gres, the tendency of storm waves to build ridges has formed heavy ridges running parallel to the shore line, having between them swales and swamps, rendering the drainage very much obstructed, and in many places where the distance between the ridges is large, cranberry marshes have been formed. These large ridges in many places have been cut away and now the old cranberry marsh is being cut into by the waves. There are several places along the shore where this is shown and also places where the sand has been duned and carried in shore by the wind, exposing a section of the cranberry marsh at its base as the waves cut away.

The Tawas river and other rivers of this section have a tendency to build deltas where the force of the river currents is less than that of the lake currents. This has taken place at the mouth of Tawas river. The building takes place in the spring and fall. The current of the AuSable is much stronger than the prevailing lake currents and the sediments are carried some two miles down the shore where, according to Captain Small of the U. S. life-saving- station, there is a large shallow area, some one-half mile off shore, and this is being converted into an island whose sediments are derived from the river. The Kifle river has built a large delta at its mouth, some five miles square in area, and the Au Gres river has a current which is so sluggish that the channel to Sagi-naw Bay is kept open with difficulty, and a long area of land in front of the river mouth is slowly forming the river delta. 39

PUBLICATIONS.

In publication this year lias been signalized by the completion of Volume VIII of our reports, containing three papers bearing on the raw materials of cement. (We are still at work upon the limestones, concerning which many facts have been given in our annual reports.) This report has elicited such comments as this from Municipal Engineering (Aug. 1903, p. 121) : "The most valuable work on the manufacture of cement from clay and limestone or marl which has yet appeared." See also the letter from Mr. Wentz. I also quote from the Indiana State Chemist:—

"Lafayette, Ind., Xov. 21, 1903.

"Having had some experience in cement manufacturing in your state, it is evident to me that you-have made a very broad and comprehensive treatment of the marl question and I wish to thank you very much for bringing Part III to my attention. "Very sincerely yours,

"(Signed) CHAS. S. McGOVNEY."

Dept. of Geology, Drury College,

Springfield, Mo., Aug. 10, 1903.

Dear Sir.—I thank you for Volume VIII of the Michigan Geological Survey, and also for the annual reports for 1901 and 1902. They are of great value in my library, and I congratulate you on the character of the publications sent out by your Survey.

Very sincerely vours,

(Signed) EDWAED M. SHEPARD.

East Tawas, Midi., July 3, 1904.

Gentlemen.—I have received the Geological Report of Michigan and am very much obliged for same. I find it a very valuable book and shall enjoy reading it.

Yours very truly,

(Signed) TEMPLE EMERY.

Union City, Midi., July 14, 1903.

Dear Sir.—Please accept my thanks for Volume VIII of the Geological Survey of Michigan. The work contains just the information I was in search of.

Respectfully yours,

(Signed) E. G. ARDAGH, Of the Peerless Portland Cement Co.

I have also issued as Part 1 of Vol. IX a paper which otherwise would have been included in the annual report, but was needed by the attorney

general's department as soon as possible, on the "Growth of the St. Clair Delta/' by Leon J. Cole.

Part 2, of Volume IX, a report on the gypsum of the state by G. P. Grimsley will probably have appeared before this report i^ printed.

The expense is given in the financial statement below.

Our present system of distribution, which involves sending to none but college libraries and exchanges, except upon especial application, and to very few other than teachers outside the state except upon payment of a fair price, makes small editions sufficient. Possibly in some cases a more liberal distribution would be worth while as advertising the resources of the state more, and possibly in reaction against a too lavish distribution of public documents I may have been niggardly, but I do not think so. The press usually announces such publications, and those who do not care enough for them to write, will probably get along comfortably without them (and never know what they miss) and can better be reached by the periodical press. Large parts of our reports, at times practically the whole, are reprinted in magazines and technical periodicals, in particular the "Michigan Miner" and "The Gateway." I believe that your policy of extending the widest opportunities to editors who desire to use our material is a wise one.

The above is the financial statement of the expenditure of the annual appropriation. Money spent in conjunction with the U. S. Geological Survey in the topographic survey of the Ann Arbor sheet (you allotted |27000)7 is included under field expenses. Salaries and office expenses are less than usual. This does not include the expenses for printing, which are given below. We have used up the appropriation of Act 78, session of 1899, for printing, and start on that of Act 231, session of 1901. The completion and binding of Volume VIII, which is now in press, and the printing of this report, if you so order, will use most of that.

iIncluding in part pay of temporary field assistants and payments on chemical work, etc., by contract.

2 Including most of the salaries of assistants hired by the month or longer, and some payments on contract, e. g., $200.00 for gypsum report.

The above statement of expense follows the usual form. It is not always practicable to draw a consistent line between field expenses so far as temporary assistants are concerned, and salaries. The salaries of the permanent staff really amounted to about $300 00 per month.

I would call your attention to certain requests for new work which have come into this office, although it really seems to me we have all we can do for a year to finish work on hand and keep up with current explorations.

The American Institute of Mining Engineers, Mr. Merrill, one of the Smithsonian curators and others, are anxious that we should reprint the earlier reports. Inasmuch as they can no longer be obtained even from second hand book dealers, I think it would be wise so to do. The Academy of Science would like a natural science hand book for teachers published. The I. Stephens estate and the Upper Peninsula experiment station people are anxious for a map of the Upper Peninsula surface geology.

The Waverly Stone Co. and others would be glad to have a report on the building stones of the state like that recently issued by Wisconsin.

I cannot close this report without a reference of honor, respect, and regret to the departure from this life of Jacob Houghton, Esq., brother of Douglass Houghton, the first State Geologist of Michigan, who was, I believe, the last survivor of that survey. He also contributed to Volume II of the present series of reports, and to the end of a long life never lost interest in geology and faced camp life even when past the allotted three score years and ten.

Very respectfully,

(Signed) ALFRED C. LANE.

BOARD OF GEOLOGICAL AND BIOLOGICAL SURVEY, 1903.

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