

§ 35. MAMAINSE.

One further section with which I am familiar may have a word of mention. At the east end of Lake Superior north of the Sault Ste. Marie Keweenaw rocks are found. Here we find the thickest section perhaps at Cape Mamainse.¹ Here we find 2000 or 3000 feet of not very thick flows of ophitic type and conglomerates subordinate with a heavy 20 mm. ophite at the bottom. Under this is a set of beds with five important conglomerates and felsitic beds near the top. Next comes a very heavy conglomerate 680 feet thick, and then several thousand feet of not very thick flows with occasional diabase dikes, numerous amygdaloids, and no important conglomerates. Felsites occur from very near the top down and are often intrusive. In one place the upturned lower beds are overlain with an entire unconformity of strike and dip by sandstone that we may identify with the Lake Superior sandstone.

It seems as though the Central and Bohemian Range groups were represented.

This report has so extended that I will not try to give details of the section for which see Bull. 6 cited above. The important features for comparison are that we have here conditions very similar to those on Keweenaw Point or Isle Royale. The dips vary from about 24° to N. 35° W. at the top of the series to 42° or more toward the base. The formation is a good deal disturbed by faults which are, however, not so predominantly vertical as on Keweenaw Point. The main set strike nearly north, to east of north, and dip 45° to 65° E., thus making southward pitching troughs with which the occurrence of copper is associated. Not only are the beds as already mentioned similar to those of Keweenaw Point but they are markedly similar in the occurrence of copper. Native copper occurs in some of the conglomerates. It is more abundant in some cases, at any rate, near the cross-fissures as it was, for instance, at the Central mine on Keweenaw Point. It seems, however, to be rather more often a sulphide. In the cross-fissures both chalcocite and chalcopyrite occur. In one place one of these fissures had at the center nearly four solid chalcocites but masses of native copper also occur in the fissures.

Finally, in connection with the probably intrusive felsites disseminated pyrite occurs. We have practically the same secondary fillings of agates, prehnite, etc., that we have on Keweenaw Point. The occurrence of copper in so similar surroundings at the other end of Lake Superior suggests how intimately its occurrence is bound up with the Keweenaw formation itself.

¹See various reports of the Canadian Survey, and Ontario Bureau of Mines; also Bulletin 6, Department of Mines, Ottawa, Canada.

CHAPTER VI.

TEMPERATURE OF THE COPPER MINES.

§ 1. IMPORTANCE OF THE SUBJECT.

In Fernekes' and Stokes' experiments on the deposition of copper leading to the formation of native copper very analogous to that found in the mines, the solution was unequally heated, copper being deposited in the lower or hotter end. It will be quite fitting, therefore, to discuss what effect the fact that the mines are hotter at the bottom has had on the deposition of copper and for that reason alone to gather facts as to the temperatures prevailing in the copper mines, but these temperatures have also a bearing on the solubility of various substances, and on the probable circulation of water. From a practical point of view, also, they are of importance as they might limit depth in mining. Too great heat decreases the efficiency of men, though it increases that of compressed air machines. It might, therefore, involve an extra expense in ventilation, which might turn a proposition from a profitable to an unprofitable one. However, at what seems to be the actual rate of increase, 1°F for each 100 feet or more, beginning at a temperature of 43°F, it is probable that the increased cost of hoisting and keeping up the roof will be more vital factors.¹

§ 2. MEAN ANNUAL TEMPERATURE OF AIR.

The average mean temperatures of the Upper Peninsula, according to the map (Fig. 1) furnished by the State Weather Bureau for U. S. Geol. Sur., Water Supply Paper 31, would be 38° to 42° F. Calumet is about 1200 A. T. (See Pl. IX.) The record of temperature at Calumet is not quite so long as that at Marquette. The former runs only from July, 1887 to March, 1910 and the average for the various months and for the year are, as given by the State Weather Survey, C. F. Schneider, director, as follows:

¹See "Mineral Industry," 1895, p. 767, "How Deep can we Mine?" A. C. Lane.

MEAN TEMPERATURE AT CALUMET.

January	15.6° F
February	13.8
March	22.3
April	37.0
May	46.3
June	59.4
July	64.3
August	62.2
September	55.4
October	43.7
November	30.4
December	21.1
Year	39.4

If we assume that during December, January, February and March, owing to the snowy covering, the temperature of the ground is practically 32°. (as it is where covered on the level with snow, though of course, there are spots which are exposed and frozen much deeper where the wind has blown away the snow) and if we suppose also that during the month of April, when the mean annual temperature is 37°, the soil temperature is still kept down by the blanketing of snow to 32°, we shall have an increase of 4.10° to add to the mean annual temperature (39.4°) to get the mean soil temperature,—that is 43.7°. This is near enough in agreement with other observations and with the temperatures of the upper mine levels considering the rough method of approach. The temperature (43.3°F at 80 feet) of the flow of water from the Calumet and Hecla drill hole No. 10, would indicate a somewhat lower mean soil temperature, but it must be remembered that the covering of snow is quite irregular, and the correction due to it, which as we have seen is a very appreciable one, must be equally irregular. The thirty-three year mean for Marquette (which is only 600-700 A. T.) is 40.5 F.¹ The difference may be attributed to elevation and exposure. Jackson gives the mean temperature of Copper Falls as 42.11° F, but I do not know the length of time of the observations. It is true, however, that mean temperatures for one year as high as that are reported very frequently at Marquette. Foster and Whitney (p. 41) give the following mean annual temperatures:

¹U. S. Dept. Agr. Weather Bureau (Bulletin S) No. 408, April 1909.

Fort Brady from 36.6 to 41.6, average 39.82

Fort Wilkins 41.46

Mackinac 41.67

Numerous other data may be obtained from C. F. Schneider of Grand Rapids, chief of the State Weather service.

§ 3. MEAN ANNUAL TEMPERATURE OF UPPER MINE LEVELS.

If we wish to get the mean annual temperature of upper mine levels we may make direct observations which are liable to be affected by the ventilation of the mines. We are able to make better inferences from diamond drill holes, in case water flows from them,—as occasionally does happen. The temperatures of springs are also of importance.

Of especial interest are the observations made by C. T. Jackson in his old report¹ since they were taken before mines were deep and there was a chance for heating effect by warm air rising from below. We may make the following tabulation from his report.

JACKSON'S OBSERVATIONS, 1844.

Page	Mine	Depth	Temperature F	Remarks
412	Lac la Belle	100	44.6	Springs in drift
412	Lac la Belle	100	50	Drift July 10, air outside 77°
413	Lac la Belle	140	44°	
443	Lac la Belle	179	48	Air
			45	Water July 15, air outside 71°
		Upper	47	Air
			44	Water
447	Copper Falls	130	48	Air, air outside 64°
462	Copper Falls	120	44½	Air
		20	44½	Air
458	N. American	155	44	
		123	45	External air 59°
				Sept. 23
		95	43	Spring
459	Boston &	236	45	Rise of 1° in 88 ft.
	Pittsburg	180	43	
		120	44	
		60	44	

It may be worth noting that (p. 498) temperatures for Lake Superior ran from 9° to 2.5° C mainly about the maximum density of water which is 3.5° C or 38.3° F.

It is clear that the temperature at the "invariable depth" (that is to say a depth at which the temperature did not vary appreciably during the year) was 43°F to 44°. Jackson assumes 43° as the

¹Annual Message and accompanying documents, 1849-1850, Pt. III.

mean surface soil temperature. This is entirely confirmed by later observations. Prof. H. A. Wheeler gives a temperature of 43.3° at 112 feet. Smillie found 44.5° in the breast of a drift at the top of the Quincy mine 332 feet above Lake Superior, i. e., 200 feet ± below the surface. Wells and springs have temperatures from 43° to 45°—rarely below. See the data collected by F. Leverett in a recent Water Supply paper (160, pp. 30-44) of the U. S. Geological Survey.

§ 4. RATE OF INCREASE.

An article by H. A. Wheeler¹ gives observations on mine temperatures as follows:

	Gradient	—Depth—		—Temperature—	
		Upper	Lower	Upper	Lower
Atlantic	99.5	111	907	43.6	51.6
Central	101.	90	1950	42.6	61.
{ Conglomerate (Delaware) or (Manitou)	95.	90	617	42.8	48.3
Quincy	122.	111	1931	43.	58.5
Osceola	76.5	136	996	42.3	54.5
Tamarack	110.7	136	2200	43.	62.

In the 1901 report, page 245, I gave some tests at the Champion Copper mine, in 1902 at the Champion Iron mine and Freda, and I have other notes all tabulated below:

Depths in parentheses are vertical from surface; otherwise they are along the lode or hole, and may or may not be.

¹Am. Jour. Sci. (1886) XXXII, Art. 13, pp. 125-138. Also St. Louis Acad. Sci.

Mine	Depth	T. F.	Date	Remarks
C & H Hole d 10	80	43.3°	Aug. 25, 1908	Elevation 436 feet above Lake. Strong flow, alkaline, flowed when 80 feet deep. The hole is deeper. (See section, Fig. 36).
Lake Copper Hole d 5	110 to 186?	45°		Perhaps from first amygdaloid at 207 feet; cased to bed rock at 123 feet, 408 feet above Lake Superior. (See Fig. 51).
Freda well drilled by churn drill	100 480 550 636 770 730 700 to 950 }	45.5° 51.2° 51.5° 51.5° 50.° 49.° { 55° to 55°.6	during drilling	Sheldon. The drill house was warm and it was hard to set the thermometer and get it into the bailer without danger of its making observations uncertain.
Porcupine Mts., Union Spring Old laundry near Boston	0	43° 48°	Aug. 1908	
Spring		47	Aug. and Oct. 1908	Half way from Ontonagon to Porcupine Mts.
Champion Copper	(130) (250) (378)	44.5 45. 46. 47. 52.1	July 24 1901 1901 1901 1909 Aug. 4	1st level 2nd level Damp rubbish Air in 3rd level 13th level (water?)
Trimountain Victoria mine Nonesuch mine Isle Royale	1350 (270) (620)	46. 57. 42. 53. 57.	1906 1908 Sept. 1908	3rd level 18th level Near surface Section 12 shaft
Champion Iron	(465) (1335) (1500) (1650)	45.8 52. 55. 56.5	1902	9 L, 250 feet west of 7 shaft 24 L 140 feet west End of 26 L { End of 28 L 750 feet from 5 Shaft
Aragon Vulcan Iron	80-90 (1090)	44. 56.		Water Water
Republic Iron	1153 1435	55. 59.		Water
Central Copper	(2400)	61.	Dec. 6, 7, 8, 1894	J. F. Roberts foot of No. 2 shaft, 30th level
Centennial	3100 (1850)	69. 62.		Osceola lode on slope Level at foot of shaft Calumet conglomerate

Mine	Depth	T. F.	Date	Remarks
Ojibway 33 °dip	(680)	50.		
Wolverine	1225	48.		
Franklin Jr.	(520)	51.		
	400 level	45-46	Oct. 13, 1906	8th level cross-cut 13th level cross-cut Temperatures of waters (See Fig. 40)
	(200) ± (1600)	61.		21st level cross-cut from conglomerate to the Pe- wabic lode newly open- ed
Old Franklin	3200	62-63		On 32nd level, according to G. Pope
Tamarack N 18th level bottom	(4400) (5223) (5367)	84. 85. 88 to	July 13, 1909	R. M. Edwards
Tamarack 5 Tamarack 5	(4662) (4900)	91.4 82. 87.	Observations in A. C. Lane	damp mud W. E. Parnall J. Hall, mine inspector

We have also an interesting set of observations of temperature in the Quincy mine from S. Smillie, Engineer.

Temp. Fahr.	Elev. above Lake Superior	Remarks
		Surface runs from 480 ft. to 550 ft. A. L. S. at mine, but drops rapidly to south
44.5	+332	Breast of drift
50	-390	Breast of long cross-cut
55	-580	In diamond drill hole after 5 min.
57	-580	In diamond drill hole after 3 days
52.5	-580	Near top of cross-cut
52	-580	Near bottom of cross-cut
67.5	-2441	Breast of drift
64.5	-2441	In diamond drill hole 5 days
68.5	-2590	In breast of drift
74	-3120	Shaft in good circulation
75	-3120	In airway between 2 shafts
69	-2696	In breast of drift
71	-2903	In breast of drift
74	-3316	In cross-cut
79	-3316	In breast of drift
80	-3316	In another drift
76	-3375	In diamond drill hole cross-cut after 40 hours.

The observations in italics should be extra reliable.

The rate of increase of temperature according to T. C. Chamberlin, who has had the Calumet and Hecla observations from A. Agassiz to write up, is 1° in 103 feet for 4939 feet, assuming that at 50 feet the invariable temperature is 40°, or 1° F in 93.4 between 3324 feet and 4837 feet.¹ But as we have seen, the surface invariable temperature should be taken some 3° higher which would lower the rate of increase to 1° in 105 feet. Smillie's high-

¹Geology, Vol. I, p. 569.

est (80°) and lowest (44.5°) results at breast of drift give the same gradient (35.5°/3650) as Chamberlin's uncorrected figure; his drill hole observations (29°/2795) 1° in 104. There is, however, an uncertainty amounting to several hundred feet as to what should be taken as the mean depth of the lower stations, for not only the elevation of the surface directly above but also that of the surface all around for two or three miles should be considered and the Quincy mine stands at the brink of the Portage Lake trough.

Obviously, too, if any part of the surface is a relatively recent thing like a mine dump, it will have no effect on the temperature thousands of feet below. Indeed we may well ask (as we do below) if all the superficial and glacial deposits have not been deposited since the bottom of the mines acquired their temperature. While the general level of the country, from which the depth should be measured to warmer parts of the mine, is the same for the Calumet and Tamarack mines, yet the Tamarack shafts are 40 feet or so above the Calumet shafts so that really equivalent depths will appear that much deeper in the Tamarack. On the whole, plotting all the tests and weighing them, 1° in 105 feet seems to me the most probable average rate of increase but it might possibly be as low as 45° in 5000 feet, 1° F in 111 feet. This in any case is lower than in many places in Michigan.¹ In the Lower Peninsula, rates of increase of heat nearly twice as great are known (at Grayling and Alma) and rates of increase four times as great and more are found in other regions.

§ 5. EXPLANATION.

For explanation of this relatively low rate of increase at present we can not (as did Wheeler) appeal to the cooling effect of Lake Superior. The phenomenon is too wide spread. Moreover, the difference of elevation between the height of the range and the depth of Lake Superior (1105+834) is only 2000 feet and less, which in a distance of 20 or 30 miles (See Fig. 3) could make but trifling differences in the flow of heat,² for we must remember the difference of mean temperature is certainly less than 5° F. The temperature at the bottom of Lake Superior is that of the maximum density of water 39° F. A depth beneath Lake Superior as hot or hotter than the surface of Calumet would be only 2500 feet lower at a distance of many miles. The Freda well, near Lake

¹But not so low as that given in a "preliminary" note by A. Agassiz, which unfortunately, owing to its extreme character, has been widely cited and copied. Am. Jour. Sci. (1895) p. 503.

²See B. O. Peirce on the trifling effect the temperature of the sides of a cylinder whose radius is five times its height has on the temperatures along its axis. Proc. Am. Ac. Arts and Sciences, Vol. XXXVIII, No. 23, May, 1903, pp. 651-660.

Superior, shows no extra chill, and the Champion Iron mine far from Lake Superior shows an extra low gradient. Even if we suppose that the chilling effect of Lake Superior were so great as to make the temperature at the bottom of the mines the same as if the temperature at Calumet were that of Lake Superior, which of course is extreme, it would change the gradient only 10%. Thus Wheeler's, and more recently, Königsberger's suggestions¹ as to a topographic effect of Lake Superior upon the gradient appear to be wide of the mark. I doubt if the Lake Superior effect is appreciable.

More important in reducing the temperature may be some of the following causes.

- (1) Endothermal reactions, that is reactions that (like the solution of salt in ice) lower the temperature.
- (2) High diffusivity of the strata, permitting the early and free escape of heat.
- (3) Downward absorption of waters, carrying with them cooler temperatures of the surface.
- (4) Recent change of surface climate which presumably has grown milder since the ice age.
- (5) The recent deposition of surface drift.
- (6) Relative exhaustion of the internal supply of heat by the Keweenaw and earlier eruptions.

Let us briefly consider these in their order. (1) In the experiment by Fernekcs in which copper was formed in an unequally heated tube, it was found at the heated end. Then according to the principles of entropy and the second thermodynamic law, formation of copper must have been a chemical reaction that tended to absorb and use up heat and bring the temperature of the solution into equilibrium rather than accentuate the differences. It is a reducing action and tends to absorb heat just as oxidation gives out heat. This reason for low gradient is especially worth emphasizing if one is contrasting the gradients in western sulphide deposits that are partially leached, where oxidation and consequent rise in temperature may have taken place. I do not mean to say that the reduction of the copper in itself used up enough heat to produce the low gradient, but that it tends that way. Other reactions were of the same character. Brun has found silico-chlorides in volcanic glass. Reactions which start with calcium and chlorine in solid condition and wind up with it dissolved are strongly endothermic and changes which resulted in

¹See Report of International Geological Congress at Mexico, 1906, pp. 1127-1137, also Central Blatt f. Mineralogie Geol u. Palaeontologie, 1907, pp. 200-203.

calcium chloride in solution instead of ferrous or cuprous chloride would be in so far forth endothermic, and so would change from calcium chloride to sodium chloride which, in discussing the alteration of boulders in the Calumet and Hecla conglomerate², I have shown probably takes place.

Two of the commonest minerals associated with the copper in the Keweenaw rocks are epidote (Sp. Gr. 3.3 to 3.5) and prehnite (Sp. Gr. 2.8 to 2.95). They are denser and occupy less volume than average trap. The chlorite into which the Calumet and Hecla boulder² changes is probably denser than it. The decomposition of basaltic glass to epidote or epidote, calcite and chlorite would pretty surely not be an expansion.³ According to the principles emphasized by Van Hise⁴ then, these changes implying condensation of volume also imply absorption of heat.

It is true that light zeolites like analcite, natrolite, laumontite and others of that family are also produced. But they are *very largely in the upper levels*, and in the open cavities and veins. If we imagine relatively cool, though actually hot, waters working into a series of hot lavas and reacting upon them, the reactions forming these secondary minerals are such as would be thermally natural, being such as would tend to reduce the thermal differences.

(2) The conductivity of samples of trap, amygdaloid and conglomerate have been determined by B. O. Peirce⁵ as follows:

		Conductivity k	Est. diffusivity $a^2=k/c$.
Trap	11	0.0031	.0056 to
"Hanging?"	22	0.0036	.0045
Amygdaloid	1	0.0035	.0065 to
"Foot?"		0.0034	.0044
Calumet conglomerate	111	0.0047	.0061
	2	0.0052	.0066

The diffusivity must be obtained from the conductivity by dividing it by the specific heat capacity for unit volumes $a^2=k/c$. Unfortunately c was not determined, but the specific heat capacity for a number of minerals is as follows: (1) according to *Chemisches Taschenbuch* (2) according to White.⁶

¹Economic Geology, 1909, p. 158, (IV, No. 2, March).

²The decomposition which I described in Economic Geology, 1909.

³This decomposition is discussed in Chapter II, p. 87.

⁴Monograph XLVII, U. S. G. S., p. 185.

⁵Proc. Am. Soc. Arts and Sci., XXXVII, No. 23, May, 1903, pp. 651-60.

⁶See figures by W. P. White, of the Geophysical laboratory at Washington, Am. Jour. Sci. Vol. 28, (Oct. 1909) p. 342.

	(1)	(2)
Olivine	.189	
Orthoclase	.191	.257 to .279
Wollastonite		.251 to .261
Albite	.196	
Diopside		.262 to .278
Corundum	.197	
Hematite	.167	
Quartz	.191	.184 to .264
Calcite	.205	
Copper	.093	

If we multiply the specific heat capacity for unit weight by the specific gravity we shall get the specific heat capacity for unit volume. The specific weight of these rocks must be between 2.65 and 3, according to McNair's tests,—the conglomerate probably about 2.76, the others about 2.84 to 2.88. The resulting c will be about .51 to .77 for the conglomerate, and up to .8 for the amygdaloid and melaphyre. Peirce found for various marbles specific heats per unit volume from 0.567 to 0.586 and diffusivities from 0.009 to 0.013, the conductivities 0.005 to 0.0076. The conductivities are much like those observed on the Carlton Hill trap of Edinburgh, and they are more than those of some slates; less than those of many rocks and marbles, and can not be far from characteristic for the formation. They should imply a low, but not remarkably low, gradient and I do not think that the gradient can thus be wholly accounted for.

(3) We have elsewhere discussed the indications that the copper was deposited by downward working waters. Such a method of deposition is consistent with the chemical arrangement of the waters and with the absorption of the waters either by hydration or as a result of the cooling off of the formation. Such a circulation of water would also help to cool it off.

One point may be noted, however, for future research. If the cooling is produced by downward circulating waters, then the more pervious beds should be a little the cooler and the less pervious massive traps relatively warmer, so that the copper might tend to form between them, working toward the warmer part of the solution and the walls of the lode. This, indeed, it seems to do. The temperature difference would hardly be measurable with a thermometer now, but may have been marked when the copper formed.

We see, then, that we may have had thermometric conditions not unlike those of Fernekes' and Stokes' sealed glass tubes. So that it is perfectly possible to conceive copper deposition going on

without any other circulation than convection currents and ionic migration similar to that in those tubes. Of course, such reaction would be very slow, but its relatively coarse crystallization is exactly what gives Lake Copper its peculiar toughness as compared, for instance, with electrolytic copper. According to J. B. Cooper copper deposited in a week electrolytically is fine and short and can not be rolled. If four weeks are taken it is tougher and rollable, and a year might give a quality like that of Lake. Dr. L. L. Hubbard has a single crystal of copper $2\frac{1}{2}$ inches across and branching forms showing equally coarsely crystallized copper are not uncommon. The calcite crystals which are so closely associated with the copper are often many inches through and indicate very slow formation.

Lincio has described some quartz from Hancock¹ presumably from the Quincy mine, with calcite and native copper which showed new quartz faces.

Now it will be noticed that these quartz crystals showed trapezohedral faces, and Mügge has shown² (and the matter has been farther investigated by Wright and Larsen³) that while quartz in general only forms below 800°, such quartz only crystallizes below 570° C. Hence the copper which replaces quartz and comes later must also have formed at temperatures as low, and as its coarseness shows, in a fluid in which there were but slight differences of condition.

(4) Another possible cause of low gradient would be a colder climate in the past. In the not very remote past (perhaps less than 10,000 years ago) the Great Lakes covered practically all of Keweenaw Point. At a somewhat earlier date it was covered by melting ice. These two events might imply a surface soil temperature of 39° respectively 32°. A gradually increasing mean soil temperature amounting to 11° and beginning 14,500 years ago could cause a variation of less than half a degree (0.44° F) at a depth of 5000 feet. A gradient of 1° in 111 feet would be produced from one of 1° in 89 feet in 5000 feet. A change of 11° in surface temperature would change the gradient at the Champion Iron mine from 1° in 111 feet to the normal gradient of 1° in 67 feet. If the effect of the increase of annual temperature and milder climate had not penetrated the full depth the lower parts of the mine would tend to have the original gradient and that may account for the more rapid gradient (1° F in 93.4 feet) which

¹Neues Jahrbuch für Min., B. B., XVIII, p. 155.

²Ueber die Zustandsänderung des Quarzes bei 570°, by O. Mügge. Neues Jahrbuch für Min., Geol. and Pal., 1907, pp. 181-96.

³Quartz as a Geological Thermometer, Am. Jour. Sci., Vol. 27, (1909), p. 421.

according to Chamberlin is found in the Calumet mine between 3324 and 4837 feet. It may even be possible to work backward, and from the gradient at different depths estimate the date since the surface temperature ceased to be 32° F. But before doing this we should need to take into account also the next factor to be considered.

(5) There is a sheet of deposit of glacial or later origin. If the bottom of the mines are too deep to be affected by the post-glacial rise in annual temperature, they are also too deep to have been affected by any blanketing effect of this addition. Thus their temperature assumed to have been fixed by a gradient adjusted to a 32° F surface temperature, was also adjusted not to the present surface but the base of the glacial deposits. Not only this, but there are indications in kettle holes, etc., that considerable masses of ice were buried in these deposits, which slowly melting may have kept them at 32° F for some time after the departure of the ice sheet proper. Subtraction of the glacial deposits would, however, make less than a foot per degree difference in the Calumet district in the rate of increase. It might make more difference in the interval to be assumed between glacial time and the present milder surface temperature.¹

But if any effect of the ice age is in turn cause of the low gradient in the copper mines we ought also to find low gradients in the Lower Peninsula of Michigan, which was also at a geologically recent date covered with ice. In the Lower Peninsula the increase of temperature through the drift is very rapid and the gradient thence down is not unusually low.² This renders it very doubtful if any part of the low gradient of Keweenaw Point should be attributed to a climate that has recently grown warmer.

(6) It must also be true that in the immense outbursts of lava that accompanied the Keweenaw, and also occurred in earlier formations, there was a considerable exhaustion of the sources of heat from beneath and a lowering of a relatively cool basement, upon which this series of lavas was piled, down deeper into the earth's crust than it would otherwise have been. If, for instance, we consider (Fig. 57) a section of crust of three layers, (a), (b) and (c), and we consider the effect of the eruption as a geologically in-

¹If the milder surface temperature is supposed at once to have had its full effect and amount at the end of melting of the last enclosed ice block, then the increase of temperature at a depth x at a time t thereafter will be roughly $C(1 - P_{x/2a\sqrt{t}})$.
² C is the increase of temperature say 11° and P is the probability integral, the values of which for different values of the subscript argument are given in the report for 1903, page 222. And if, when $t=0$ $u=a+Cx$, and thereafter $u=C$ if $x=0$, then $u=a+cx+C(1 - P_{xy})$ where $y=1/2a\sqrt{t}$.

See Byerly on Fourier's Series.

²Report for 1901, p. 244 et seq. The Bay City and Grayling observations are most reliable except for water circulation.

stantaneous transfer of (b) to be piled up on (a)¹, the increase of heat from the surface to A will for a long time be much less than before.²

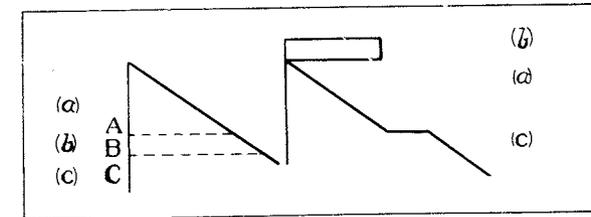


Fig. 57. Diagram to illustrate distribution of temperature in the earth's crust after the outflow of Keweenaw lavas.

The section (a) can be given some initial temperature between 1800° F and 200° to 400° F which lower temperatures the zeolites indicate were widely prevalent. Of course, there is little or no likelihood that it was anything like 1800° for 40,000 feet, but it is worth noting, that since after a million years there would be nearly half the original temperature left in the middle of the formation, but after 25,000,000 years the temperature in the middle dependent on the initial temperature would be but .0116 of the original temperature (supposing always that the formation is 40,000 feet thick), after 25,000,000 years there would even of this maximum temperature only be 4.5° left. The middle section (a) would have initially a gradient beginning with the surface temperature or zero at the bottom of the lava formation. At the point from which the lava was drawn between B and C there would have been a sudden jump up to a gradient as high as ever, reckoning from the top of the eruption rather than the bottom. (Fig. 57.) Such distribution is, of course, not exactly one that ever was really in existence but is sufficiently of the type to show the kind of effect that might be expected. Pages might be filled with computations of the various temperatures that might be obtained at different depths after different times and under different conditions. Suffice it to say, that if we assume a diffusivity of 203 in feet and years instead of 400 as used by Kelvin (since the former agrees better with the conductivity found by B. O. Pierce) we shall obtain the following results.

If we consider that the depth of the Keweenaw formation was 40,000 feet and the next layer 140,000, so that the third layer began at 180,000 feet and that the rate of increase of temperature was

¹Which it was not. No doubt a lot of heat escaped in the process.

²See Byerly "Fourier's Series" pp. 83-84.

one degree in 70 feet, then after the 25,000,000 years aforesaid the temperature at a depth of 5000 feet would be 53.8° F above that at the surface, plus a certain amount dependent upon the initial temperature of the Keweenaw formation which could not exceed 5.2° F. Thus instead of a gradient of one degree in 70 feet we should have a gradient of one degree in 85 to 93 feet, and if this were compared with a surface temperature which had recently been raised 11° above 32° it would give gradients as low as those we have. After 49,000,000 years an original gradient of 1° in 70 feet would still be 1° in 96 feet possibly increased by initial temperature to 82°. An original gradient of 1° in 60 feet would become 1° in 83 or 79 feet. It thus appears that while a recent change to a milder climate may have had something to do with the low gradient, which is promoted, too, by a rather high diffusivity of the rocks, this would also be promoted by something which had an equivalent effect, to wit, the tremendous loss of heat along with the outbursts of lava that took place at an early date and that these various factors are sufficient, if we make no unreasonable suppositions (in fact the most natural suppositions we can from independent data in regard to the thickness of the formation and the lapse of time since) to account entirely for the low gradient. And yet it seems to me that a downward migration of waters that incidentally produced cooling reactions, such as the solution of calcium chloride in water or ice, may also have been of importance.

Thus while I am not inclined to agree with the reasons for low gradient given by previous authors, we are not devoid of other explanations,—in fact we have an embarrassment of riches—and while as regards the effect of endothermic reactions we can not claim for them the importance which I frankly confess I had hoped (in beginning this research) I might have found, we can still say that the low gradient is not inconsistent with endothermic reactions and with downward working waters. It will probably be a long time before we have such an accurate idea of geologic time, of the thickness of the formation, and of other factors involved that we shall be able to say at all definitely which part of the low gradient must have been due to each factor.

§ 6. MATHEMATICAL SOLUTION.

For solution of the problem we can consider an infinite solid cooling through one plane to the surface of the earth which is kept at zero, the mean annual temperature of the earth at the time being taken as zero. And taking the time when the lava was poured out

as a beginning of time at that time ($t=0$) the temperature was a function of the distance from the margin. Suppose, for instance, that it were 1800° down to a depth of $x=b$ (say 40,000 feet) for the Keweenaw formation. This is a much higher temperature than is probable but we will keep the term separate in our solution so that we can readily see by simple replacement what the effect of any other initial temperature would be. From the point $x=b$ on, suppose the temperature rises at a certain rate—say 1° in 70 feet. This ratio, too, we will keep by itself and treat as an algebraic expression so that any other ratio may easily replace it. Suppose this ratio to continue down to a 180,000 foot depth $=c$. From this the lava came with an initial temperature (assumed 1800° F¹). Then the solution of the temperature after a given time is given by Byerly (Fouriers Series, page 84, equation 7, etc.), and may be written in the following form. It will be convenient to write.

$$y = 1/2a\sqrt{t} \text{ and } \frac{2}{\sqrt{\pi}} \int_0^m e^{-m^2} \frac{P}{dm} = \text{the probability integral}$$

Then the temperature u is

$$u = \frac{1}{2} 1800^\circ (2 P_{xy} + P_{(b-x)y} - P_{(b+x)y}) \\ + \frac{1}{70} \left(x + \frac{b}{2} P_{(e+x)y} - \frac{b}{2} P_{(e-x)y} + \frac{(b-x)}{2} P_{(b-x)y} - \frac{(b+x)}{2} P_{(b+x)y} \right) \\ + \frac{1}{70} \frac{e^{-(b-x)^2 y^2} - e^{-(b+x)^2 y^2}}{2y \sqrt{\pi}}$$

Tables of values of P are found in Johnson's Theory of Errors, the report for 1903, etc., and of powers of e in Byerly and the Smithsonian mathematical tables just issued (Hyperbolic functions, 1909).

§ 7. PROPAGATION OF HOT AND COLD WAVES INTO SNOW.² BY H. L. CURTIS AND A. D. PETERS.

A solution of the partial differential equation

$$k \frac{d^2 v}{dx^2} = \frac{dv}{dt}$$

for the propagation of heat waves shows that $k = v^2 \pi T/4$ where k is the diffusivity, v the velocity of propagation and π the period; provided the heat wave is simple harmonic.

In the following we have in all cases assumed that the wave is simple harmonic. We have determined in two cases the Fourier Series representing the curves, but find in all cases that our data are too incomplete to make this desirable.

Two sets of data were taken, one from 9 p. m. January 27, 1905 to 9 p. m. January 29, the readings being taken every three hours. To secure satisfactory results we found that the readings should be taken oftener. The snow which was on the ground thawed,

¹This may not be the temperature which the rate of increase assumed would give for the depth C , for probably much of the heat would be dissipated in the eruption.

²I have to thank the Michigan Agricultural College for these data showing the low diffusivity and blanketing effect of snow. Letters, Aug. 4 and Oct. 21, 1905. L.

and a new fall of snow permitted us to get a second set of readings on February 14, 1905 from 7 a. m. to 6 p. m. In the first set of data the time temperature curves show well defined maxima and minima though the curves are far from simple harmonic. The velocity of propagation of two waves could be easily determined, one being a warm wave and the other a cold. In the case of the warm wave the period was taken as the time between the maximum temperature on either side of it, and the period of the cold wave was similarly determined. The velocity was determined from the time temperature curves.

In the second set of data the readings did not extend over sufficient time to obtain more than one maximum. The period could not be determined, so was taken arbitrarily as 24 hours. Other wise the computation is as above. The following table will be self-explanatory:

Time of maximum at surface.	Kind of wave.	Period.	Velocity in cm. per hour.	Diffusivity in cm. ² /hr.	Diffusivity in cm. ² /sec.	Conductivity in c. g. s. c. units.	% of volume of snow that is H ² O.	Depth of snow in c. m.
12 M. Jan. 29.	warm	15 hr.	3.3	13.3	0.0037	0.00041	22.1	29
6 P. M. Jan. 28.	cold	23 hr.	1.9	6.6	0.0018	0.00020	22.1	29
2 P. M. Feb. 14	warm	24 hr?	3.83	28.0	0.0078?	0.00055	14.2	17

Smithsonian

.00051

The conductivity was determined as follows. The specific heat of the air contained in the snow is neglected. The specific heat of ice is given in the Smithsonian Physical Tables as 0.5. The specific heat per unit volume is therefore 0.5 times the per cent of water in the snow.

As per your suggestion I have computed from our data the values of the diffusivity from the decrease in amplitude of the temperature wave. From the curves a table of the depths and amplitudes of each wave was made. The amplitudes were taken as the distance from a cold maximum to a warm maximum and the period as twice the time intervening. A curve was then plotted for each wave, of the depths as ordinates and logarithms of the amplitudes as abscissas. The points of this curve should then lie on a straight line and a line can be drawn giving a mean value. Then the difference between the logarithms of the amplitudes at any two depths can be determined from the curve and a value of the dif-

fusivity computed from this will be a mean value for the wave. The diffusivity was computed from the formula $\log a - \log a_1 = \frac{x \sqrt{\pi}}{1/\sqrt{Tk}} \log e$ where a and a_1 are the amplitudes, x the difference in depth, T the period and k the diffusivity. The following table gives the result:

DIFFUSIVITY FROM DIMINUTION IN AMPLITUDE.

Cold max. at surface.	Warm max. at surface.	Mean period.	Diffusivity in cm ² /hr.	Diffusivity in cm ² /hr.	Conductivity in c. g. s. C units.
6 A. M. Jan. 28, '05	12 M. Jan. 28	12 hr.	11.1	0.0031	0.00034
6 P. M. Jan. 28.	12 M. Jan. 28	16 hr.	20.0	0.0056	0.00062
6 P. M. Jan. 28.	12 M. Jan. 29	35 hr.	17.8	0.0050	0.00055
Mean values of above			16.3	0.0048	0.00050?
Mean former values			16.0	0.0044	0.00039
Final mean			16.2	0.0046	0.00044

35

CHAPTER VII.

MINE WATERS.

§ 1. HISTORICAL INTRODUCTION.

In our study of the chemical alteration and of specific gravity we have mentioned incidentally the fact that the mine waters had a peculiar character. While the fact that the deeper waters around Lake Superior were peculiarly salty has been known for over twenty years it was not known at the time of Pumpelly's study because the mines had not reached the depth where this feature became characteristic. The first published analysis of Lake Superior mine waters, showing their salty character at depth, that I know is that of the Silver Islet mine, within sight of Isle Royale but on the Canadian side of the boundary. This analysis should, perhaps, be included geologically with the iron country waters (since the mine is in Huronian rocks) but the salt content is very heavy and the water may derive its salt content from Keweenawan intrusives.

I am told by W. W. Stockly who at one time worked with Mr. L. G. Emerson, one of the most prominent early engineers and an assistant of R. Pumpelly during the time Pumpelly was preparing Volume I of the Geological Survey, that Mr. Emerson took samples of some salt water which was struck at about sea level at the Cliff mine. Johnson Vivian says that this water was 1800 feet down. The plan of the mine in the Mineral Statistics report (for 1880) shows the bottom of the mine at the 220— fathom level, 1680 feet below the top of the Greenstone. It was probably struck, therefore, about 1879, but I have found no printed references to it. The Silver Islet water, analyzed by W. M. Curtis, is described in the Canadian reports.¹ The analysis is also given in my papers before the Lake Superior Mining Institute.² The next analysis published and the first which called my attention to the matter was made by Prof. R. L. Packard when I was at the Michigan College of Mines.

It was not, however, until many years later that I fully realized the wide spread characters and the geological importance of these waters. It is obvious that if we find included in the copper country rocks three different kinds of water distributed in fairly hori-

¹Canadian Geological Reports, H. 1887, pp. 28, 58.

²Vol. XIII, p. 74.

zontal layers we can be reasonably sure that there has been no round and round circulation since these waters have been thus arranged. The question as to how thorough the circulation of water in the upper levels of the earth's crust has been is one which has been much discussed of late years, particularly by Van Hise and Kemp, and papers on this subject are listed and reviewed in Kemp's annual review of the literature of ore deposits in the annual volumes of Mineral Industry. I have given some preliminary results of my own work in a series of papers.¹ It was natural for me to do this because I had in mind the continuation of my study of the water resources of Lower Michigan by a study of the waters of the Upper Peninsula which naturally led me to take up the study of mine waters. I shall not repeat in full the data which I have heretofore given except where necessary to aid in the solution of the problem, but I shall summarize them, give new data which I have accumulated having a bearing on the problem and correct misprints. The more I looked into the matter the more I found it of geological and practical importance.

§ 2. SUMMARY OF RESULTS.

The study of these waters is of practical interest, in the first place, because the admixture with the upper waters of the lower, strongly saline waters affects the use of the mine waters in boilers. The study may lead to a different plan of pumping and other handling of the mine water. In the second place it seems fairly clear that the character of the waters has had a good deal to do with the deposition of the copper. It is a curious and significant thing that we seem to find traces of similar waters high in chlorides in other districts in which native copper occurs and it is interesting to notice that heretofore² in the discussion of ore deposits the importance of chlorides seems to have been little regarded compared with sulphates, in general.

Finally, the chemical character of these waters seems to also bring up very interesting questions as to possible changes in the chemical character of the ocean throughout geologic time and also the question whether the Keweenawan rocks were laid down in

¹Annual report to the Board of Geological Survey for 1903, see p. 141. Report of the State Geologist: "Salt Water in the Lake Mines," Portage Lake Mining Gazette, Mar. 8, 1906; Lake Superior Mining Institute, Vol. XII, p. 154-163; "Chemical Evolution of the Ocean," Journal of Geology, XXVI, April-May, 1906, p. 221; brief description of the Geology of Keweenaw Point, Lake Superior Mining Institute, Vol. XII, pp. 81-104; Mines and Minerals, Dec. 1906; "Salt Water in the Lake Mines," Lake Superior Mining Institute, March 18, 1907; "The Early Surroundings of Life," Science, August 2, 1907, p. 129; "Chemical Evolution of the Ocean," Bull. Geol. Soc. Am., Vol. 17; letter on Mine waters, Calumet News, Apr. 10, 1908; Native Copper Times, Apr. 21, 1908; Portage Lake Mining Gazette, Apr. 19, 1908; Mine Waters; Abstract for Proc. Lake Superior Mining Institute, June 1908; Michigan Miner, July, 1908, p. 13; Mine Waters, Lake Superior Mining Institute, Vol. XIII, pp. 63-152; Mine waters and their field assay, Bull. Geol. Soc. Amer. Vol. 19, pp. 501-512.

²A paper has recently been published by C. R. Keyes, Economic Geology II, p. 774.

the ocean or whether these waters may not have been derived from saline pools in the deserts. It may also be said that the study of these waters has its bearing upon all the theories of chemical alteration and change of these rocks and also upon the question of the temperature and the rate of increase of temperature which will be found going down. The facts and conclusions summarized below are those which are particularly important if true. I begin with those most firmly established and pass to others of which I am not so sure.

(1) In the copper country as in the iron country the surface waters are soft as compared with those of the Mississippi Valley and generally are more like those of New England. This is true also of the actively circulating waters.

(2) In the copper country, in the iron country and in the sandstone country of the eastern part of the Upper Peninsula, below the layer of soft waters, in which there is relatively active circulation, there is a layer of water in which there is a marked amount of sodium chloride. The chlorine rises steadily, the sodium rises and the calcium rises too, so that we may say that calcium chloride is present. Moreover, as we get to deeper waters calcium chloride predominates. This second or middle layer of water, however, contains sodium in greater quantity than we can imagine to have been produced by simple mixture of the surface waters in which there is a small amount of sodium carbonate and silicate with the deeper waters in which the calcium chloride dominates very largely over the sodium chloride. In other words there is a distinct belt of sodium chloride waters.

(3) Beneath the second belt will be found water extremely strong and practically saturated in many cases with calcium chloride. The ratio of calcium to chlorine becomes nearly 1 to 2. Such waters are extremely corrosive in boilers and pumps and, of course, hard.

(4) In this presence of calcium chloride they resemble waters which are found in connection with similar associations of copper, trap and red sandstone in Chili, in New Jersey and in the Sahe-Nabe region on the west bank of the Rhine. We also find similar waters in the older rocks all over the Mississippi Valley and in fact more or less all over the world. Such waters seem at least in part to have been buried with the strata now containing them and may be called connate waters.

(5) Flows of these deeper or connate waters when struck in mining decrease and soon drain off showing that there is no open connection with the surface.

(6) The exact level at which a given strength of water is found varies greatly, but below 1500 feet it is common to find them stronger than the present sea water (Sp. Gr. 1.028).

(7) The proportions of the different salts are very different from those in present sea water so that we must suppose that they are not derived from ocean water or that the ocean itself has changed in composition (which there is good reason to believe) or that these waters have also changed in composition since they were enclosed.

(8) I can explain the strength of the strongest of these waters only as that of the residue left after most of the water had been absorbed in hydration of the rock.

(9) The third or lowest kind of water not infrequently contains a measurable amount of copper chlorides.

(10) Similar chloride solutions may be made artificially to precipitate copper very much as it occurs in the mines upon prehnite and other minerals which tend to keep a solution alkaline, if such a solution containing copper is kept unequally heated.

(11) The mode of occurrence of the copper, the chemical character of the alterations of the rock, the character of the copper shoots, and the low temperature gradient are all consistent with the theory that the migration or circulation of water in the Keweenaw rocks is not mainly a mere up and down or a round and round circulation but an absorption or imbibition of water by the strata acting like a sponge in which process of absorption of the water the copper is formed and accumulated in a zone of relatively low oxidation in which as it replaces chlorite and prehnite and other minerals which tend to keep the solution alkaline or at least not acid, it tends also to accumulate with other positive ions at the alkaline or negative (cathode) or warmer end of the solution.

(12) This production of native copper may be associated with the production of ferric iron built into epidote from ferrous iron.

(13) The accumulation of copper is also associated with reactions by which the calcium of the calcium chloride is replaced by sodium derived from the rocks, sodium silicate being very largely removed in the process of decomposition, which accounts for the sodium of the middle zone of water.

(14) When the accumulation of alkalis becomes sufficiently high, alkaline zeolites, etc., may be formed, but this is toward the end of the deposition of copper and in the upper levels, where it may be redissolved and migrate downward.

(15) The ultimate source of the copper would seem to be the

formation itself, effusive as well as intrusive beds in the same, together with copper possibly originally dissolved in the water. But there is some indication that the sulphur came from intrusives or fissures.

(16) The general average of copper from extensive sludge analyses would seem to indicate that the whole rock formation ran something like .02% of copper and analyses of the stronger mine waters would indicate that copper in the strong chloride waters may run as high as eight to sixteen milligrams per liter.

In accord with the idea above developed that the copper forms where a chloride solution of the same is kept alkaline by sodium silicate in other alkali dissolved from the rock, we are not surprised to find the copper running into the hanging and foot wall of the porous bed proper, and so (if we may use the data of experiment and physical chemistry as a guide) we may expect to find the copper near pervious streaks, but in the part that was hotter,¹ that which was more alkaline and reducing,² that which was electrically positive³ (cathode).

§ 3. METHODS AND PRECAUTIONS.

Since in testing mine waters contamination by urine, etc., and nitroglycerine fumes might be expected, an analysis of urine was included in the Lake Superior Mining Institute paper. Both urine and nitroglycerine fumes contain other substances by which they may be easily identified, such as phosphates and nitrates.

While larger samples were taken where possible and convenient, a great many tests of the stronger waters like a series from the Calumet and Hecla and Challenge properties were taken in quantities from 30 cc. down, which proved ample, if the sample was accurately measured, when there were many parts per thousand of solids.

There were also made a great many preliminary tests of concentration with urinometer and refractometer. The latter enables one to get an idea of the concentration even to a drop.

DR. G. FERNEKES' ANALYSES.

In talking over the matter with Dr. G. Fernekcs, of the chemical department of the College of Mines, he expressed a very keen interest and willingness to take the matter up more systematically. His experiments in reproducing copper were his own free contribution

¹Near the less porous rock at bottom and sides in case of down circulation, at the center of the lode in case of up circulation.

²Associated with green colors, chlorite, epidote, prehnite, rather than red laumontite, etc.

³Perhaps, therefore, also on the north side.

to the advancement of science, and he also made a series of tests of mine waters, which went far beyond what he was paid for.

In all cases chlorine, calcium and total solids were determined. In many cases computing sodium enough to satisfy the acid, made solids enough by summation very nearly to agree with those obtained by "heating to incipient fusion," which latter is the way the total solids were determined for the lower stronger waters. This gave results a "little too low" as "some of the calcium chloride was broken up." This method was not employed for the upper waters that might contain large proportions of carbonates. In a number of cases other substances were determined, the bromine most commonly. When the bromine is not determined it is probably included in the chlorine. In a few cases exhaustive tests were made, and tests for copper and nickel more widely. Iron and alumina were measurable in the Quincy waters.

The results are given in grams per liter, oz. per cubic foot. The specific gravity was determined for about a dozen of the waters. As is shown by Figure 58 it pretty closely follows the rule that

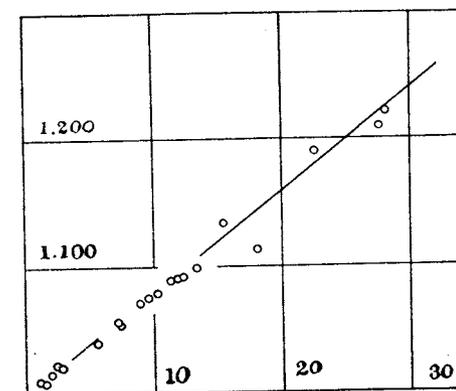


Fig. 58. Diagram illustrating connection experimentally determined between specific gravity and concentration of mine waters, the ordinates being the specific weight, the abscissas, the per cent of solids.

ten-eighths of the excess of specific gravity is the percentage of total solids.

It is quite clear that no serious adulteration with urine or nitroglycerine could be introduced without introducing quantities of nitrogen in some shape—it might be oxidized to nitrates—that should be recognizable. It is also clear that the tendency of such adulteration will be to increase the relative proportions of sodium.

No such adulteration can change our general results.

§ 4. IRON COUNTRY MINE WATERS.

The first definite indication of calcium chloride waters in the iron mines came to my attention in testing to see whence a flood of water in the lower levels of the Vulcan mine might have come. From the analysis of this water, page 155 of the annual report for 1903, taken in connection with the surface water analyses (p. 156) I inferred an admixture of a small quantity of calcium chloride water, and that there was no *direct* connection with the surface, or the alkalis would be higher. I suspected this flood to be connected with caverns in the Randville dolomite, and it is said (priv. com. W. Kelly) to come from the talcose underlying schists.

The temperature of the water at the 12th level, 1,000 feet from the surface, was: at the shaft, 57.°2 F.; at the first winze, about 100 feet west of the shaft, 60.°6; and the west end, almost 300 feet west of the shafts, 58.2°. (See annual report for 1901, p. 246). According to the observations there, the mine water at 1,210 feet was 56°, and at 270 feet, 45.°8. This water is then, abnormally warm—either from working up (?) or the heat from casing, friction and decayed timber.

The question arose whether it had any immediate surface source, and accordingly, analyses were made of the surface waters, which will be found in the annual report for 1903, p. 156. In them the chlorine is from 3.8 per million down, the alkalis high.

In a later flood¹ the output increased from 600 gallons per minute to 2,000, the increase being from a flow of water in the pump station on the 15th level. About Dec. 10, a sample was taken and analyzed, column (1). On March 19, 1904, it reached a maximum of 2,807 gallons and has since fallen off fairly steadily, being not much affected by the seasons. By March 26, 1907, the flow had fallen to about 1,000 gallons per minute when it was analyzed again by G. Fernekes with the results given in column 2. The decrease was principally in the flow in the 15th level pump station which "comes from the talcose slates underlying the north ore formation."² In the mean time at the west end of the 15th level a flow was struck "coming from the slates overlying the north ore formation," 1,300 feet west, about Sept. 1, 1906, amounting to about 250 gallons a minute, and this was tested, analysis 3.³ Comparing these Vulcan analyses 1, 2 and 3, it is clear that the hardness remains fairly constant, and there is always practically all the bicarbonate it can hold if there is no excess of CO₂,⁴ but with

¹Priv. Com. Agent W. Kelly, Mar. 10, 1907, and earlier.

²U. S. G. S. Monograph 46 by Bayley, pp. 221-2, 452.

³Analysed by G. Fernekes, May 10, 1907.

⁴Volume VIII, Pt. 3, p. 212, saturation is 95 parts per million Ca, 105 fixed, 210 total CO₂.

time and the addition of the new sources at the west end the chloride dropped, the alkalis rose and approached the amount in the surface waters. Judging from the analyses of the talcose schists given by Bayley (loc. cit.) the alkalis are not leached from them or the Randville dolomite, and the first water struck which had no alkali *seemed* to come from that direction. The abundance of potassium relative to sodium in column 2, may be connected with the fact (loc. cit. p. 379-389) that potash was found in 11 of 15 samples of ore analyzed, soda in but five and generally seems less abundant in the ore. The later analyses and the exhaustion of the flood which has come to pass show quite clearly that no mistake was made in inferring from the analysis that it was not directly from the surface and would run down.

Analysis (1) has the characteristic of the early connate waters, chlorine high relative to sodium.

VULCAN MINE WATERS.¹

	1	2	3
Insoluble matter, clay & SiO ₂	4.4		
Solid solubles	340.00	344.00	303.63
Organic matter	52.3		
Carbon dioxide	37.3CO ₂	163.00	171.00
Non volatile solids	250.4		
In solution.			
SiO ₂	5.8	9.8	11.2
Al ₂ O ₃	4.4	18.2	1.7
Fe ₂ O ₃	trace		
Ca	60.3	62.29	62.3
Mg.	37.7	28.20	30.5
SO ₄	43.0	13.14	11.2
Cl	61.	18.68	
K	trace?	13.	3.7
Na K	p. n. d tr.	6.	11.03
Sr. Li.	0		

Total by addition	209.2	332.31	
Diff., organic, and undetermined Li.			
Ba, etc.		11.96	

In the same way the Ishpeming mine water (loc. cit. p. 157), given below, shows a greater amount of chlorides than is at all normal to the superficial waters of the Upper Peninsula, though not so

¹Analyses in parts per million. Analyst, for 1 E. E. Ware for 3 and 2, G. Fernekes.—Location given above.

much that it might not be attributed to organic contamination, which however, the geological conditions render unlikely.

An Ishpeming mine water, collected by A. Formis, coming out of a diamond drill hole at a depth of 825 feet, gave the following results in parts per million.

1	2.
Lime as carbonate.....	55.8
Oxide determined	31.3
Magnesium as carbonate	17.0
Oxide determined	8.1
Iron and alumina carbonate .....	.5
Oxide determined .....	.7
Requiring CO ₂	33.2
CO ₂ actually determined.....	34.3
Total encrusting solids	73.3
<hr/>	
Chlorides as sodium chloride.....	56.2
Chlorine determined	34
Sulphates as sodium sulphate (25 Na).....	67.0
S O ₃ determined	33.4
<hr/>	
Total corrosive solids	123.2
Silica	10.5
Water of crystallization ¹	3.2
Excess of CO ₂	1.1
Combined CO ₂	33.2
Sodium chloride	56.2
Organic matter by difference from ignition loss.....	19.9
Ignition loss	113.6
<hr/>	
Total by computation	229.1
Total by evaporation at 105° C.....	232.2
Difference (minor errors, extra weight of potash over soda and undetermined)	3.1
Analysis by Kirschbraum, computation by A. C. L.	

I took, myself, with Mr. E. A. Separk, the chemist, a sample of water from the Aurora mine, Gogebic range, 200 feet west from A shaft about 900 feet down, on the 5th level at a point which had been opened five months. The temperature of the water as taken

¹The sulphates are probably in large part calcium sulphate, etc., and the soda correspondingly carbonate, reducing the amount of crystallization water.

was 67° F.; of the drift at a dryer place 57° F. The water was coming down on top of the 60-foot kaolinized dike which crosses the formation there.

The analysis is as follows:

December 8, 1904.

Sample marked—Oliver Mining Co., Aurora mine water, Ironwood, Michigan.

	Grams per liter.
Total solids .....	.1420
Loss on ignition.....	.0544
Silica .....	.0122
Iron and aluminum oxides.....	.0012
Lime .....	.0354
Magnesia .....	.0150
Sulphuric anhydride .....	.0044
Chlorine .....	.0160
Sodium oxide .....	.0037
Carbon dioxide .....	.0510
Organic matter .....	.0034

F. K. Ovitz, Analyst.

Upon evaporating fifty cc. of the water to which a few drops of hydrochloric acid had been added to three or four cc. the spectro-scope showed no test for potassium. No phosphorous was found. The organic matter is taken as difference between loss on ignition and carbon dioxide.

Here again while the total solids are not greater than might be found in any surface water, and the chlorine not greater than might have been artificially introduced, the amount of chlorine is more than twice what can be combined with the alkalis (Na : Cl :: 23 ; 35.5 :: .0037 : .0057) and the presence of calcium chloride and the admixture of a small quantity of water containing this in solution must be inferred.

Sometimes the amount of residual chlorine is so great as to affect the use of the mine waters in boilers. This instigated tests of the Hurley (Superior and Ottawa) mine waters which will be found in the L. S. M. I. paper.¹ These mines are just over the line in Wisconsin, and not very deep—5th to 12th levels.

Through H. H. Smyth I was enabled to get a very much stronger water from the Germania mine of the Harmony Iron Company at Hurley, Wisconsin, an analysis of which will be found in the Cana-

¹Proc. Lake Superior Mining Institute, Vol. XIII, p. 71.

dian Mining Institute paper.¹ In it Ca (.205) : Cl (.638) = .345 and there was sulphate. It was found in a huge vug, a solution cavity which is 700 or 800 feet east of the shaft on the 14th level, close to it on the 11th and 12th and pitches therefore flat to the east, like the dikes, but seems to follow a big crack or fissure that comes in and dips to the south against the foot wall which dips north. The vug was full of the salt water (1.585 per thousand at 110°, after ignition at low heat 1.005) and of a gas that put out the candles, hence was probably CO₂. I visited this great cavern with water corroded sides in June 1909. The water from the bottom of the shaft gave Ca 1.426 and Cl 3.793. Ca : Cl = 0.376.

These salt waters occur all along the range to Sunday Lake. Through Mr. George H. Abeel, Jr., I was enabled to get tests of the deepest mine, the Newport mine (north half of Section 24, T. 47 N., R. 47 W., just east of Ironwood), which is looking, I am told, as well as ever at the bottom. At 1750 feet a dike came in carrying lots of ore, and it will be noted that the water is relatively fresh. This dike may possibly be a split of the one in the Aurora mine. Mr. Abeel's tests of chlorine show that the water is less saline just on the dike than below or from a diamond drill hole in the hanging, and much less saline than at the Yale which is not so rich. His results are:

Number.	Grams per liter Cl.	Position in Newport mine.
22	.105	On 15th level about 1180 feet from surface.
21	.14	16th level, under dike.
14	.14	17th level, under dike.
25	.07	On 17th level, on dike.
24	.14	On 17th level, 20 feet in foot.
23	.07	Diamond drill hole in hanging.
27	tr.	Above dike, about 1300 feet from surface.

The Newport is under a hill. The next, the Yale, is in a transverse valley farther east on the range, in the S. ½ N. W. ¼ Section 16, T. 47 N., R. 46 W. Here again down (863 feet vertical) to a flat dike cutting the formation at the 10th level no trouble was found in using the mine water as boiler water. Then the trouble began. A sample of water pumped from the mine when at the 15th level (1200 ft. vertical) gave E. B. Smith 13.12 grains per gallon Cl.

as against, from the adjacent Colby, $\frac{0.227 \text{ " " " "}}{12.8 \text{ grains}}$

¹Vol. XII, pp. 124 and 126.

I took two samples, (1) representing the whole mine, which yielded 125 gallons of water a day, about 50 gallons coming above the 10th level and practically fresh, the balance (75 gallons) below that level gave in grams per liter

	(1)	
		.0710 Cl
	to	0.568
		0.781
	Hardness =	0.260 Ca
(2)	representing that below the 10th level	1.070 Cl
	to	1.170
		0.429 Ca
	Hardness =	0.540 Ca

It is apparent from these tests compared with the tests of George H. Abeel, Jr., that the bulk of the water below the 10th level is that coming above the dike at the 20th level or like it. We may also infer that the water above the 10th level will run about 0.18 grams per liter which is more than that above the 5th level, and less than the average water in the cross-cut. Arranged in order of concentration Abeel's field tests gave.

Number.	Chlorine.	Position in Yale mine.
9	.07	Above 5th level.
2	.35	10th level cross-cut, raise above 3rd dike.
5	.14	10th level cross-cut above 2nd dike.
1	.14	10th level cross-cut below 2nd dike.
17	.28	10th level cross-cut above 1st dike.
8	.14	12th level on dike.
10	.14	14th level above dike.
20	.42	17th level diamond drill hole in hanging.
18	.49	17th level above dike.
19	.84	19th level above dike.
16	.84	19th level below dike.
15	1.33	20th level on dike.
11	.84	21st level below dike.

To explain the references to dikes we remark that the iron bearing formation of the Gogebic range is cut across by Keweenaw dikes, and that the iron ore lies in troughs made by them and by an impervious foot wall. Most of the water of the mines comes in along these dikes which are kaolinized as described in a previous chapter. So it was of interest to see if any connection between the chlorine and these dikes could be obtained. A long cross-cut cut into the hang-

ing at the 10th level gave a chance to test that. There is but slight difference. The iron ore bodies seem to have a little fresher water, and so on the dike it is sometimes a little fresher, but on the whole the circulation was so long ago that the inequalities in concentration seem to have nearly spread out horizontally. Indeed, it is not sure that the slight effect observed may not be due to circulation started in mining. It must also be remembered that there are faults nearly parallel to the strike, which act like another foot wall to make with the dike a trough for the accumulation of iron ore. These faults, (though strike faults) can be recognized by the way they displace the dikes. As these dikes are of Keweenawan age it is conceivable that they introduced the chloride waters after the iron ore bodies formed, for pebbles of the latter are found in the Keweenawan conglomerates. Salt water is also reported farther west around Sunday Lake in the Brotherton mine and near Wakefield, but has not been farther studied.

REPUBLIC MINE T. 46 R. 29.

Captain Peter W. Pascoe reported a salt water coming at a vertical depth of 1153 feet from the surface in the 16th level, 600 feet northwest of the No. 9 shaft. With Messrs. Siebenthal, Slaughter and Pascoe I visited several places in the deeper part of the mine where saline waters came in, testing with total reflectometer and urinometer, and taking a sample of the strongest.

At 1153 feet down, 600 feet northwest of the No. 9 shaft a drip from a drill hole and fissure which has a temperature of 55° to 56° F. and precipitated iron freely on the floor of the drift, seemed fresh and showed an index of refraction near that of fresh water. This was from an east-west seam. A seam with quartz and coarse hematite ran N. N. E. and dipped 45° to S. E. The ore body dips 80° and pitches 45°.

On the 1435-foot level, say 700 feet from No. 9 shaft, was another flow, temperature 59° and there was a more appreciable amount of salt. On the 1710 level near the Pascoe or south end of the mine the strongest water was almost drained off¹ from a fissure making an angle of 32° with the drift, dipping 24° or so north of west. The temperature was 57° to 57.5°, the Sp. Gr. by urinometer 1.025 to 1.027. The analysis by Dr. G. Fernekes is as follows:

¹It is characteristic of the *strong* calcium chloride waters that they appear in limited quantity. More than once I have been told of one by a mining captain, and upon going to the place found not enough to test. Somewhere lower we might find it.

	Grams per liter.
Ca	7.902
Na	7.290
Mg .....	.566
Cl	25.360
SO ₄	1.045
CO ₂	not determined
Al ₂ O ₃ .....	.700
Mn	tr
Fe	tr
Sum	42.863
Total solids	45.590

CHAMPION IRON MINE T 48 N., R. 30 W.

A sample was sent in by the agent, W. H. Johnston, which came from the 28th level, 800 feet east of No. 5 shaft and was taken with great care by Harry R. Hulst. It was a *slow* drip.

It gave the following results:

Sp. Gr. 1.0037. This would correspond to about .5% CaCl₂ and .51 NaCl.

	Grams per liter.
Total solids by evaporation, including combined and crystal water	7.100
Chlorine Cl	3.050
Calcium Ca	0.810
Sulphate ion SO ₄	0.370
Alumina Al ₂ O ₃	present
Carbonates CO ₂	very low
Iron	0

M. A. Cobb, Analyst.

The ratio of Ca : Cl = .27 is not very far from that of the Republic sample just cited (.313).

Salt water is also said to have come out of a drill hole in the foot wall south from the 17th level No. 4 shaft and no doubt traces of calcium chloride water could have been found higher up if tested for.

This mine shows well the contrast between the upper circulating waters and these lower ones. Very little water is said to come in below the 800 to 900-foot level. The salt water is said to come mainly on the 28th and 30th levels. A pump at the 1000-foot level takes care of practically all the water. When I visited it, July 2,

1909, they had done no pumping below that level since August 21 of the previous year, at which time it was bailed out in one day in about 50 skips. This mine is an unusually interesting one owing to the metamorphic change. Grunerite, chloritoid (masonite) and tourmaline are found. The latter occurs down in the 20-23rd level and some more was recently found about 2000 feet from No. 7 shaft in the 3300-foot level. I mention these facts as they might have some bearing on the composition of the water.

§ 5. COPPER COUNTRY WATERS.

The first published analysis of Lake Superior mine waters of which I know is that of Silver Islet, within sight of Isle Royale but on the Canadian side of the boundary which should perhaps be geologically included with the iron country waters as it occurs in Huronian rocks, but it is very strong and may be associated with a Keweenawan intrusive.

The water in the Silver Islet mine¹ was noted also for the presence of combustible gas, which came in vugs penetrated by drills with salt water below 500 feet.

The calcium chloride water, I am informed by W. M. Courtis, who was employed as chemist there, came in a bore hole on the north side of the shaft at 560 feet from the surface.

We calculate from the original figures given in the L. S. M. I. report.

Cl ²	22.53
Na	6.45
Ca	6.23
K .....	.25
Mg .....	.34
SO ₄ .....	.047
CO ₂ .....	.177
Na : Cl	0.275

PEWABIC LODE.

The next analysis published and the first I personally heard of was the one made by Prof. R. L. Packard, of water reported by an error as from the Huron mine, in Wadsworth's annual report for 1892, p. 174.

¹See Canada Geological Reports, H. 1887, p. 28, 58.

W. McDermott, Eng. & M. J., Feb. 3, 177, p. 53.

T. Macfarlane, Trans. A. I. M. E., VIII, 1880, p. 226; XVII, p. 296, and earlier volumes, i. e., IV, V, IX, XV, p. 671.

Data of Geochemistry, U. S. Geol. Survey, Bull. 330, p. 144.

²In all the mine waters there appears to be bromine which is presumably included in the chlorine when not given separately.

I was assured by Capt. J. Vivian that the sample was really from the Franklin.

The full figures, both of the analysis of the general mine water and of the boiler water are given there and in the L. S. M. I. paper.

Attention was first called to it and the analysis made because of the trouble it made in the boilers. This was when the mine was down to the 25th or 26th level (1610' on the lode) about 1300' below the surface.

Another analysis of the general mine water made in Chicago at about the same time is given also.

Cl	4.739 per thousand
Na	1.583
Ca	1.378
K .....	.086
Mg .....	.030
Fe, Al, Si p.n.d. compare following analysis.	
Organic	
CO ₂ .....	.088
SO ₄ .....	.174
	<hr/>
	8.078
Undetermined	0.437
	<hr/>
Total solids	8.515
Na:Cl .....	.33
Ca:Cl .....	.29

The second analysis was as follows:

Cl	2.694 per thousand
Na .....	.763
Ca .....	.784
Mg .....	.056
K .....	.077
Fe .....	.012
Al .....	.016
Si .....	.134
CO ₂ .....	.046
SO ₄ .....	.213
Organic .....	.027
	<hr/>
Sum	4.827
Na : Cl	.283

It comes from the same general lode and horizon as the Quincy mine waters analyzed by Koenig, Fernekes and Steiger below, and the water from seams in the Franklin Junior cross-cut and their work on the Pewabic lode is also from geologically a similar horizon and depth. The relatively greater amount of sodium as compared with them is marked. But these are analyses of a composite water.

QUINCY MINE.

The Quincy mine was of especial interest as offering the deepest mining on the amygdaloid, and as being the one in which copper in the mine water first attracted attention. It was not easy to obtain satisfactory samples in the upper old workings.

I am informed by Prof. J. Fisher that in the Quincy mine flows good to drink were found on the 13th level, and on the 26th level, but that on the other hand a drill hole in the hanging between Shaft 1 and 2 just N. E. of the old man engine shaft on the 26th level was too salt to drink. This is about 2,000 feet deep on this lode, which at a dip of 53° is 1600 feet vertically. This would bring the salt water in at about the same depth as in the Franklin—a little deeper possibly. It should be remembered that the Pewabic lode worked by the Quincy Mining Co. is in the "Ashbed" group, a series of extra feldspathic traps containing unusually much sodium.

The upper water of the Quincy mine is said to have contained 35 parts per million of calcium carbonate and sodium silicate with no free CO₂, reacting alkaline when reduced to half volume.

It is difficult to get the exact vertical distance of these samples as the contours of the ground differ several hundred feet and the lode itself varies in dip from 52° to 54° at the surface to 37.5° at the bottom of No. 2, 5500 feet deep in 1908.

To S. Smillie, then engineer of the Quincy we owe a significant series of tests of the chlorine in the mine water with notes on the copper bearing character of the adjacent ground. The figures are in grams per liter.

No. 7 shaft lies farthest south and was 5,162 feet deep in 1908. It is 860 feet southwest of No. 4 which is 585 feet southwest of No. 2.

In the 13th level, ground carrying no copper.....Cl	.07
In the 16th level, ground carrying no copper.....Cl	1.00
In the 36th level, ground carrying no copper.....Cl	47.25
The well at his house 350 ft. northwest of No. 2 shaft gave.Cl	0.20

At the 7th and 9th levels near No. 2 which is near the top of the hill in fair copper ground in cross-cuts over to the west vein	0.20
In the large band of barren ground extending down to the 40th level 2300 feet, the chlorine is only.....	0.07
to	0.14
The water is very copious and abundant, running freely, the ground hard. One drill hole in fair copper went as high as 0.160.	
In the 18th level, No. 2 shaft, the ground carrying little copper, there was.....	0.04
In the 40th level, No. 2 shaft ground carrying no copper..	84.61
In 63rd level, No. 2 shaft, ground carrying excellent copper.	175.
In the 64th level No. 2 shaft, ground carrying excellent copper	146.67
No. 6 shaft is 200 feet south of the Old Franklin line. It was 5500 feet deep in June, 1908.	
In the 63rd level, excellent copper ground.....Cl	195.13
In the 64th level, excellent copper ground.....	146.67
Mr. Smillie also makes the significant observation that deeper down in the mine the amygdaloid belts are much better defined and much less disturbed.	

There is in the Quincy a fissure with "dragged copper" and faults (the south side dropped?) running near the west quarter post of Section 26 a little north of east and dipping to the north with a slight hade. The big calcite vein which strikes N. N. W. to the north part of the Quincy shown on the report of the Commissioner of Mineral Statistics for 1889 is not slickensided.

The Mesnard shaft, No. 8 is at the extreme north 4,168 feet north of No. 6 which is 1928 feet north of No. 2, and was 4500 feet deep, the 24th level corresponding to the 42nd level of No. 6. The levels are at 135 feet intervals. From poverty in the upper levels it is said to have improved beginning at the 10th level but markedly at the 20th level, and best at the south end.

In the 13th level, ground carrying no copper.....Cl	1.11
In the 20th level, ground carrying no copper.....	32.25
In the 20th level, ground carrying no copper.....	31.75
In the 21st level, drainage, good copper.....	21.05
In the 23rd level, drainage, fair copper.....	130.65
In the 24th level, excellent copper.....	100.30
In the 46th level, excellent copper.....	147.00

Dr. Koenig made some tests on a deep water from the 47th level of the Quincy running into a sump on the 50th level, given in our annual report for 1903, p. 243, and in the L. S. M. I. paper No. 7.

The Sp. Gr. would indicate 216.27 grams per kilo of CaCl_2 . We may compute this as:

Cl	132.5
Na	11.7
Ca	64.5
	208.7
Fe .....	.004
Cu .....	.009 ¹
Ca : Cl =	.485
Na : Cl =	.0885

This is essentially the same as the water obtained by G. Fernekes from the pump at the 62nd level, and as tested by Geo. E. Steiger, U. S. G. S. Bulletin 330, page 144, and the discrepancies are due to the difficulty of the determining small quantities of other things beside such large quantities of calcium chloride. After running along the level the copper dropped to 7 grams per ton.

Certain of the Quincy samples were tested for CO_2 by distillation, and also for ammonia. A very small amount of the latter was found on which no stress can be laid as it might come from organic contamination or dynamite fuses.

Dr. Fernekes' first test was from drippings in the 49th level north of No. 6 shaft, as follows:

Cl	142.173 grams per liter
Ca	70.072
Na	12.064
Br	1.891
Cu	tr
	226.206
Sum	226.206
Difference .....	.320
	226.52
Total solids determined	226.52
Sp. G.	1.19
Whence we compute:	
Na : Cl =	0.083
Ca : Cl =	0.494

This is practically as strong as it gets.

¹.007 after it has run along the level.

Dr. Fernekes also made the following tests (analyses 89 to 97 of the L. S. M. I. paper) of waters which all had from 8 to 16 mg of copper per ton and are all of the lowest type of water.

From water running from the walls on the 53rd level, north of No. 6 shaft.

Cl	174.287 grams per liter
Ca	86.500
Na	14.068
Br	2.180
Cu	tr.
	277.035
Sum	277.035
Difference .....	.465
Total solids determined	277.500 ¹
Sp. Gr.	1.21

We compute:

Na : Cl = 0.081

Ca : Cl = 0.496.

Quincy mine. 53rd level N., stream near No. 6 shaft.

Cl	177.380 grams per liter
Ca	87.478
Na	14.920
Cu	trace
Br	2.240
SO_3 .....	.123
	282.141
Sum	282.141
Difference .....	.359
	282.500

We compute:

Na : Cl = 0.0843

Ca : Cl = 0.492

This analysis was published by Dr. Fernekes in Economic Geology II, page 584, with a slight misprint.

Quincy mine. In stope 10 feet below 53rd level N. of No. 6 shaft—a running stream.

Cl	173.735 grams per liter
Ca	87.380
Na	13.470

¹Solids when not heated quite so hot 281.900.

Br	2.272
Cu	tr.
<hr/>	
Sum	276.857
Difference .....	.243
<hr/>	
Total solids determined.....	277.100

We compute:

Na : Cl .078

This sodium ratio is abnormally low—an error in analysis is possible but not probable.

Dripping on 55th level N. of No. 6 shaft, Quincy mine.

Cl	176.027 grams per liter
Br	2.200 ¹
Ca	86.478
Na	15.188
K .....	.411
SO ₄ .....	.110
Si O ₂ .....	.020
Fe ₂ O ₃ and Al ₂ O ₃ .....	.010
Mn .....	.004
Cu .....	.016
Ni .....	.006
Sr	trace
Ba	none
Li	none
Mg .....	.020
B	trace
CO ₂	none
<hr/>	
Sum	280.489
Difference .....	.011

Total solids determined..... 280.500

This is the most complete analysis made of the deep water and may be taken as the standard. It is worth noting that calcium and sodium chlorides form 99% of the total salts, and calcium and sodium bromide three-fourths the remainder.

¹Cf. test of Dow Chemical Co., .17 per cent or 2.13 grams per liter.

Na : Cl .0865

Ca : Cl .49

N. of No. 6 shaft, running 10 feet below 55th level Quincy mine.

Cl	176.400
Ca	85.200
Na	17.580
Br	2.460
Cu	tr
K .....	.450
<hr/>	
Sum	282.090
Difference .....	.310

Total solids

282.4

Sp. Gr. 1.22

Boiling point 104°.5 C.

We compute:

Na : Cl = 0.099

Ca : Cl = 0.483

This higher ratio of sodium might be due to urine, etc. A sample at about this level gave the Dow Chemical Co., .17% Br with a Sp. Gr. of 1.293 or 2.190 grams per liter. The same sample gave Fernelkes 2.390, which is a pretty close check as bromine analyses go.

Pool with good drainage on 57th level N. of No. 6 shaft, Quincy mine.

Cl	113.7	grams per liter
Ca	57.33	
Na	7.70	
Br	1.2	
<hr/>		
Sum	179.93	
Difference .....	.270	

Total solids determined..... 180.2

Sp. Gr. 1.13

Na : Cl = .068

Ca : Cl₂ = .504

59th level, Quincy mine, said to be a fine slow drip.

Cl	166.56
Ca	82.486
Na	13.129
Br.	1.92
	<hr/>
Sum	264.035
Difference	1.165
	<hr/>
	265.2

We compute:

$$\text{Na} : \text{Cl} = 0.0785$$

$$\text{Ca} : \text{Cl}_2 = 0.495$$

Quincy mine. 62nd level, N. from pump.

Cl	131.46	grams per liter
Ca	65.35	
Na	10.56	
Br	2.004	
	<hr/>	
Sum	209.374	
Difference .....	.426	

Total solids determined..... 209.8

We compute:

$$\text{Na} : \text{Cl} = .08$$

$$\text{Ca} : \text{Cl}_2 = 0.496$$

In Bulletin 330 of the U. S. Geological Survey, page 144, is an analysis of the water from the "lower level of the Quincy mine, Hancock, Michigan," by Geo. E. Steiger for C. K. Leith. From it we have

Salinity 212.3

$$\text{Na} : \text{Cl} = .0885$$

$$\text{Ca} : \text{Cl}_2 = .485$$

On the whole the analyses of the lower waters are singularly constant in their peculiar composition. The ratio of calcium to chlorine by weight is almost exactly one to two.

When we consider the possibility of admixture from above and from other horizons by cross-fissures, and of contamination in the course of mining operations, the result is the more impressive. The absence of magnesia compared with surface or iron country rocks is the more striking in rocks so chloritic.

The Franklin Junior mine is now running the same Pewabic amygdaloid horizon also a few miles north but not at so great a depth. Water on the 21st level 1000 feet or less north had a Sp. Gr. of 1.010. In the 23rd level the Sp. Gr. was 1.038. A sample was taken, but the vial cracked and most of it leaked out. Ca : Cl was 0.35. In a pool right in the shaft between the 27th and 28th levels it was much over 1.080 (estimated 1.150). Dr. Fernekes tested three samples:

Sample No. 1, 2100' down on the dip, 1600' deep is in a cross-cut over from the Allouez conglomerate (See Fig. 40) to the Pewabic lode on which the Quincy mine is working. It was slowly dripping from a seam dipping 50° to S. E., i. e., about at right angles to dip of bed.

The distance from the Allouez conglomerate No. 15 is 192'4 (about 100' above the Mesnard epidote).

(1) Sp. Gr. by urinometer in mine 1.045. Temperature 61° F. Taken by A. C. L.

Dr. Fernekes determined (on about 30 cc).

Cl	7.912
Ca	2.926

Whence we may compute:

Na to satisfy Cl.....	1.764
Sum	12.602

Difference SO₄, Mg, etc..... .298

Total solids at 160° C..... 12.900

Ca Cl₂

(To satisfy Cl) Na Cl..... 4.486

12.602

$$\text{Na} : \text{Cl} = 0.223$$

$$\text{Ca} : \text{Cl} = 0.368$$

(2) Franklin Junior. Dripping from cross-cut on 21st level S. Taken by G. Fernekes later.

Cl	8.580
Ca	3.289
Na	2.349

Sum

Difference

Total solids determined..... 14.260

Na : Cl = 0.272

Ca : Cl = 0.384

These two check fairly. It is notable that this which is nearer to the conglomerate is less strong than the next following analysis.

I cannot very well account for the high Sp. Gr. of this and the next, unless we assume that the water gave off little bubbles of gas that clung to the urinometer, which I did not observe or that evaporation tends to very rapidly concentrate the water in the puddles on the floor where the urinometer was floated. The sample was caught in a small vial from the roof.

(3) Another sample was flowing much more freely down the side of the level from a similar seam 386 feet above the Allouez conglomerate and dipping 40° into the foot from the hanging. It must pretty nearly represent the Pewabic lode.

Sp. Gr. 1.055.

	In grams per liter
Total solids at 160° C.....	46.100
Cl	28.680
Ca	12.290
Whence we compute:	
(To satisfy chlorine Na).....	4.45
	45.42
Ca Cl ₂	34.09
Na Cl	11.33
	45.42
Other substances by difference, SO ₃ , Mg, etc.,	.68
Na : Cl = 0.156	
Ca : Cl = 0.43	

A very small sample from the 23d level, all that was left of a larger sample that had Sp. Gr. 1.038, gave F. W. Durkee:

Cl	45. grams per liter
Ca	15.6
Na	11.8
	72.4

Whence we compute

Na : Cl = .248

Ca : Cl = .212

Evidently comparing this and the Quincy mine, in the Pewabic lode, at any rate, there is vastly more difference in composition between the 15th and 20th levels than between the 21st and the 62nd. See result in 14th level cross-cut. It will be interesting to compare the Allouez conglomerate only 460 feet away.

ALLOUEZ CONGLOMERATE.

On a visit to the Franklin Junior, May 24th, 1906, I found in the 14th level cross-cut 270 feet above the Allouez conglomerate a drip with Sp. Gr. 1.000. The long 4th level cross-cut also had Sp. Gr. 1.000 wherever tested (see Fig. 40).

On the 15th and 16th levels I did not find enough water to test. There was more in the north end of the 15th level and the south end was very dry.

On the 17th level the water on the floor seemed to have Sp. Gr. 1.000.

400 feet north of shaft it was dripping freely and seemed to have increased in gravity (1.002?).

On the 18th level S. a dripping tested had Sp. Gr. 1.000.

At the reservoir for drill water near shaft Sp. Gr. was 1.003.

On the 19th level I could only find a drop to taste—quite salt. The 20th level was dry. The 21st level water of drift has Sp. Gr. 1.003.

The change from fresh to salt was according to Capt. J. Doney between 14th and 17th levels and his observation was later fully confirmed by Fernekes' tests. He also thought the rock became richer at that point.

The Allouez conglomerate has a straighter "hanging" top than "foot" bottom, and where it is thin is generally barren. There was good copper bearing conglomerate in the 22nd level. Some of the basic pebbles are quite decayed.

The dip flattens from 48.5° down to 46°¾ at the bottom of the mine.

Mr. Rickard in his book on the copper mines of Lake Superior has some notes on the distribution of copper in this lode.

On Oct. 13, 1906, I again visited the Franklin Junior mine.

We failed to get any water at crevices on the 17th and 19th level where Captain Doney had noticed it. Fernekes in 1906, took samples from the No. 1 shaft, on the Allouez conglomerate.

From a drip in the 15th level¹.

Cl	0.416
Ca	0.134
Na	0.115
	<hr/>
Sum	0.665
Difference	0.085

Total solids determined 0.750

We may compute:

Na : Cl = 0.277

Ca : Cl = 0.322

The high ratio of sodium to chlorine and of difference not chlorides show the mixture of upper water quite plainly. This is just on the line.

From a dripping 1,000 feet S. of No. 1 shaft on the Allouez conglomerate, 17th level, Franklin Junior.

Cl	0.858
Ca	0.211
Na	0.313
	<hr/>
Sum	1.382
Difference .....	.313

Total solids 1.695

Na : Cl = 0.1382

Ca : Cl = 0.247

This seems to be fresher than that on the same level north. It is said that No. 2 shaft 1200' S. of No. 1 is better than No. 1 and better than at 1200' or so than higher up

At the old Rhode Island mine² further north and not so rich Mr. A. P. Frapwell found at 1,000 feet, 0.0760 Cl.

Reservoir 100' north of No. 1 shaft, 17th level on Allouez. Franklin Junior.

Cl	1.066
Ca	0.249
Na	0.404
	<hr/>
Sum	1.719
Difference	0.281

Total solids 2.000

¹Analyses are in grams per liter, parts per thousand unless otherwise stated.

²Now part of the Franklin Junior.

Na : Cl .39

Ca : Cl = 0.234

Water dripping 1200 feet S. of No. 1 shaft on 18th level, Franklin Junior.

Cl	3.621
Ca	1.516
Na	0.609
SO ₄	0.040
	<hr/>

Sum 5.756

Difference274

Total solids determined 6.030

This is a *good deal fresher* than the next analysis, the 19th level north, but stronger than the previous one.

Na : Cl = 0.167

Ca : Cl = 0.420

Franklin Junior from a dripping on the 19th level 200 feet north.

Cl	8.320
Ca	3.166
Na	1.750
	<hr/>

Sum 13.236

Difference224

Total solids determined 13.560

Na : Cl = .21

Ca : Cl = 0.406

From pump on 23rd level near bottom of mine.

Cl	7.540
Ca	2.493
Na	2.032
	<hr/>

Sum 12.055

Difference295

Total solids determined 12.350

Na : Cl = 0.269

Ca : Cl = 0.330

On the whole the Franklin Junior tests show clearly (1) that the

amygdaloid waters are stronger than those of conglomerate. This confirms the widespread impression of the miner. (2) That the change from fresh to salt is relatively sharp beginning in this case below the 14th level and well established at the 23rd. (3) That the salt water when first struck is relatively high in sodium, and low in calcium, so that no mixture of the strongest water with fresher waters could produce the intermediate waters. We find these inferences confirmed over and over again. (4) That the line between fresh and salt was perhaps higher at the north and leaner end of the Allouez conglomerate corresponding to the surface rise of ground is faintly indicated. A surface launder nearby contained water that gave 0.058 Ca.

Outside the Franklin Junior few tests have been made at or near the horizon of the Allouez conglomerate. I made a test of the Old Delaware mine as it was being pumped out. This is close under the top of the Greenstone and two or three hundred feet above the valley, and was no salter than wells nearby (.030 to .040 Cl).

A sample of water from the 13th level of the Medora shaft of the Keweenaw Copper Company gave

Cl	0.248 grams per liter
Ca	0.151
Total solids	0.560
Ca : Cl =	0.608

This is a hard surface water, the lime mainly that of a hard water. It was still in the upper level. Owing to the flat dip of only 25° or so the mine depth would correspond to only half the vertical distance.

We might assume we had

Na ₂ Si O ₄	0.018 grams per liter
Ca CO ₃	0.150
Ca Cl ₂	0.253
Na Cl	0.143
Total	0.563

CALUMET CONGLOMERATE AND ADJACENT BEDS MIXED.

A good chance to compare tests in amygdaloid and in conglomerate is furnished in the Calumet and Hecla, Tamarack and adjacent mines. A test of water from the Tamarack Pond will be found in the Proc. L. S. M. I., and the report for 1903, p. 78, also one by G. L. Heath from the Red Jacket shaft. This is a vertical shaft and the exact horizon of the water doubtful. The original figures are given there. Computing to uniformity we have the following.

(The water was slightly alkaline, and owing to difficulty in weighing a hygroscopic brine residue like this Mr. Heath thinks the sum of constituents as reliable as total solids, since it is impossible to drive off the water without volatilizing other things.)

Cl	3.2660
Na	1.740
Ca	1.2496
Mg .....	.0216
K .....	.0388
Fe .....	.0026
Cu .....	.00213
Zn .....	.0134
CO ₃ .....	.149+
SO ₄ .....	.0392
SiO ₂ dissolved .....	.0032
Na : Cl =	0.543
Ca : Cl =	0.260

The amount of sodium is relatively very high.

A stronger but yet mixed water derived by tapping the water that had accumulated in the Tamarack Junior mine was given me by Mr. G. L. Heath, July 27, 1905.

This mine was mainly outside the rich shoot of the Calumet and Hecla conglomerate. (Pl. IX). At the east end of No. 2 shaft (See Fig. 37) the conglomerate was only 6 inches of black amygdaloid conglomerate, I am told.

The very small amount of sulphate is noteworthy, and the presence of strontium may be connected with it, for strontium sulphate is but very slightly soluble in salt solutions.

Very rarely barite (and celestite?) are found in the Calumet mine.

Cl	6.421
Na	0.776
Ca	2.875
Mg .....	.009
K .....	.019
Fe .....	.006
Cu .....	.00144
Zn .....	.00076
Sr .....	.01742
Li .....	.00063
CO ₃ .....	.084
SO ₄ .....	.001
Illuminating gas	p. n. d.

Na : Cl = .121
 Ca : Cl = .448

OSCEOLA LODE.

Prof. James Fisher reports salty water that was popularly supposed to be depositing copper at the 26th level of the old Osceola mine following down the foot.

Tests of waters from the upper levels are given in connection with the Calumet conglomerate, and are all relatively fresh. These were from the Osceola lode back of the old Calumet and Hecla mine.

In collecting the samples from the 30th level cross-cut of Tamarack in connection with President McNair's gravity work, I had a chance to get a sample of water from the Osceola lode. The results are as follows: (See Fig. 37.)

Water from Tamarack mine, 4,300 feet down at 1,794-1,800 feet from shaft No. 2. Taken by A. C. Lane, Sept. 14, 1905. Analyzed by F. B. Wilson—letters of Oct. 8, 9, 28 and Nov. 22.

Sp Gr.	1.135	
Total solids at their melting point.	157,411.5 grams per ton	
Cl	97,963	
Ca	47,166	
Mg	tr	
CO ₃	0	
Ba & Sr by flame test on precipitate.	0	
Na	8,278	
K	837	
SO ₄	226	
NH ₄ Cl by distillation.....	2,456.7	
NH ₄	829.8	
Total determined solids.....	155,299.8	
<hr/>		
Undetermined (organic matter crystal water traces of Fe, Mg, etc.).	2,111.7	
Excess of salts, shortage of Cl, perhaps replaced by organic acids..	1.169	.589

Organic matter leaves a small residue of carbon in the total solids and there is plainly some contamination.

The Sp. Gr. agrees quite well with the total solids. The ratios are:

Na : Cl .0846
 Ca : Cl .482

A ratio of Na : Cl like this (cf. Wolverine No. 3 shaft at the 30th level S.) seems to be that normal to the deep waters.

I also made urinometer tests of the waters at other points in the 29th and 30th level cross-cuts but in every case noted they were stronger than 1.060 the limit of the urinometer scale. In particular is this true of water dripping from a winze up to the 29th level, about 400 feet from No. 2 shaft, which seemed to be between 1.08 and 1.16. As reported in Volume V, in the Tamarack No. 3 shaft salt water was struck at 1,267 feet depth (about the horizon of the Pewabic lode) in an amygdaloid horizon much above the C. & H. lode. One of the specimens, too, from Tamarack shaft No. 4 from an ophite close above the Calumet & Hecla conglomerate—No. 16,472, T.4672, though kept in our collection from 1894 to 1906 was still damp and bitter with calcium chloride.

On July 13, 1909, visiting the North Tamarack shaft No. 3 with Prof. J. F. Paull, I took a sample (No. 7) in the 18th level cross-cut at 790 feet from the Osceola lode again which gave

Cl (Br).....	179.5542 per thousand	
Ca.....	88.582 = Ca Cl ₂	245.815
Na.....	14.893 (14.46 Na=NaCl)	36.782
Sum.....	283.019	6 H ₂ O 237.
Total solids at 105°C.....	400.	Cf. 519.6
Whence Ca : Cl = .493		
Na : Cl = .083		

This is somewhat deeper (5223.5 feet vertical) and much stronger but the proportions are the same. The dilution of the 30th level sample is due to contamination. Another small sample (No. 11) from an amygdaloid 50 feet from shaft (hence about 1450 (900) feet from the Calumet conglomerate) in the same cross-cut gave

Cl .....	.0023mg
Ca .....	.0010mg
i e. Ca : Cl = .044	

The amount of water was not closely measurable.

A sample of rock from this same lode was extracted four times with distilled water. The sample weighed 851 grams and was not cupriferous. The successive extractions (500 cc. of distilled water were used, except 690 cc. the first time) yielded Dr. A. A. Koch

	Cl	2.5577 gr.	Ca	1.2414 gr.	Na	.2191 gr.	Ratios	
							Ca : Cl	Na : Cl
1.							.487	.086
2.		0.5339		0.2591		.0501	.485	.094
3.		0.3828		0.1866		.0285	.490	.075
4.		0.2283		0.1054		.....	.485	.....
		<u>3.7027</u>		<u>1.7925</u>		<u>.2977</u>	.....	.....

Total actually extracted at least..... 5.7929

The irregularity in extraction of sodium may be due to solution, but the rock was in coarse pieces, not crushed fine, and was left to soak over night only. The first extraction was as the rock came damp from the mine wrapped in paper bags. I think probably that the total chlorine would be about 4.000, and total calcium perhaps 1.940, i. e. Ca : Cl = .485. If then we assume Na in the water to be 0.360 we shall not be far out. This would make total solids in solution 6.3 mg

The first extraction gave 4.272 (grams solids at 110°) as against a sum of 4.0182, the balance being perhaps crystal water. Part of this may be charged to adherent moisture but I think not much. If the water is as strong as any known (No. 7) and has 180 grams per liter of chlorine (and that is also about the strength of the deep Quincy water) then the 4.000 grams chlorine would mean 22.2 cc. of brine (about 27 grams) of which 20.7 cc. would be water. This would imply about 3.18% of rock moisture by weight, which as amygdaloids are always damp is nothing surprising, or it would mean 22.2 cc. of water to 290 of rock, that is 7.8% of pore space filled with water by volume, which figure should be reduced somewhat for adherent moisture.

The close agreement of the H₂O here found as probably present in the amygdaloid with that we found necessary to convert a fresh basalt glass into chlorite and epidote (Chapter II, § 9, p. 86) is entirely undesigned and accidental, and too much stress should not be laid on it. It is, however, fair to call attention to the apparent presence as quarry moisture of enough water to be a large factor in hydration and chloritization.

A water sample (No. 5) from a winze 650 feet back from the Calumet and Hecla conglomerate is perhaps from the Calumet amygdaloid, but very likely to be contaminated with organic or conglomerate water (to that probably is due the low Ca:Cl ratio) and total solids 360 instead of 400):

Cl	165.5155
Ca	70.8638
Mg	0
Na	not determined

Total solids at 110°..... 359.6000

Ca : Cl = 0.44

These samples are strikingly like the deep Quincy samples both in proportions and strength, though miles away and in a different group even.

CALUMET CONGLOMERATE.

None of the above analyses represent the pure lower mine water or the Calumet & Hecla conglomerate. They represent either the upper mine waters more or less contaminated with the lower, or other horizons. A sample taken for Prof. H. L. Smyth of Harvard, at 3,000 feet depth, was analyzed by Robert Forsyth. The figures are:

66.94 grams per liter solids of which—

Ca	24.77 %
Mg	0.06
Na	12.14
Cl	61.97
SO ₄	0.22
Si O ₂	0.09
Br .....	.15
Al .....	.17

Determined 99.57 per cent of solids

Na : Cl = 0.199

Ca : Cl = 0.403

This seems to be more likely the pure conglomerate water.

Another analysis of the Calumet and Hecla mine water from the 24th level, No. 7 Hecla shaft, an inclined shaft on the Conglomerate lode, taken December, 1901, and furnished us by G. L. Heath is as follows:

Total residue in thousand parts of water....	.0204
Si O ₂ .....	.0029
Fe ₂ O ₃ .....	.0020
Cu .....	.00094
Zn	tr. ¹
MgO .....	.0267

¹.02 or less.

Na Cl (&Br?)	2.9875
KCl	.0175
LiCl	.0175
CaO (reduce to Ca with trace of Sr)	1.96
SO ₃	.1057
Total Cl (and Br)	4.499 ¹
Loss on ignition	.5056
CO ₃	hardly any ²

Total solids	7.65610
Difference	.0583

Na : Cl is about 177:450 = 0.26 (distinctly of the middle rather than of the lower type.

Ca : Cl is 0.31

Fernekes took a sample from an inclined winze on the conglomerate lode near Tamarack No. 5 shaft, which gave

Cl	57.550 grams per liter
Ca	25.429
Na	8.032
Br	1.070
Sum	92.081
Difference	.419

Total solids determined..... 92.500

We compute:

Na : Cl = 0.14

Ca : Cl = 0.443

When we compare these with the previous analyses they agree in being less strong than analyses from the amygdaloids and the ratio of Na : Cl is higher. This agrees with the miner's impression reported by Mr. J. T. Reeder and others, which is confirmed by other tests for chlorine only, that amygdaloid water is stronger than that of the conglomerate.

It is somewhat stronger than Smyth's water at 3,000 feet. The ratio of sodium is lower too. The ratio of Na: Br is about the same.

I also took samples of copper bearing conglomerate and soaked

¹The poor check in bases (for the chlorine calculated to bases is 4.2833) may be due to the Br.

²Corrosive effect about the same as that of the mine water from the Red Jacket or Whiting vertical shaft. Experiments on corrosion showed that there was little effect if the iron was entirely covered with the water, but that otherwise considerable scale was formed on iron pipes.

them in distilled water changed four times. Nos. 1 and 6 in 500 cc. and No. 2 in 250 cc. the first time. No 6 was mainly copper from 20th level of.

Number	1	2	6
Weight	555 grams	500	242
Cl successive extractions	1. 3.6514	3.4209	.3438
	2. .4786	.3155	.0482
	3. .1489	.1064	.0319
	4. .0851	.0523	.0177
	4.3640	3.8951	.4416
Ca successive extractions	1. 1.773	1.6597	.1357
	2. .2266	.1442	.0220
	3. .0882	.0606	.0157
	4. .0384	.0235	.0063
	2.1262	1.8880	.1797
	= .487	.585	.41
Na	1. .2975	.265	
	2. .059		
Na : Cl	= 1.2 to		18 ? to .09
Total solids	6.750	6.190	.646

in first extraction.

It is clear that the Ca : Cl ratio approaches 0.49 in the successive extractions, and that the conglomerate water has at this depth, essentially the same kind of water as the surrounding amygdaloids. But the amount extracted is greater. One may estimate in No. 1 the total chlorine as

	4.40
Calcium	2.15
Sodium	.40

6.95 grams

or about 1.25% of the rock is soluble solids and probably (if we take water sample 6 below as a key) about 35 cc. of brine, i. e., 42 grams which is to 100 grams or about 7.5% by weight,—about three times as much as the amygdaloids. This would mean about 16.4% of pore space as a maximum. Specimens 1 and 2 came 600 feet from the cross-cut at the northeast end of the 18th level. No 3 was a drop of water only from the shaft at the 19th level, and no tests were made of it.

In the same trip in 1909, above mentioned, I took a sample of mud scraped from a damp spot near the bottom of the mine at the

northeast end about under No. 4 shaft, at the same place that the rock was taken (1); also a sample of mud baled out of a drill hole (2); also some mud from the hanging of the 20th level (4); also muddy water trickling down along foot of inclined shaft at same level very likely to be contaminated (6). These were of value mainly in showing proportions. A. A. Koch obtained

	1 ¹	2 ¹	4 ¹	6
Cl	.716mg.	1.098mg.	.0383mg.	124.784 grams per liter
Ca	.344	.546	.0127	57.111
Na				14.972
Ca : Cl ₂	.482	.495	.332	.457
Total solids				255.550

The damp ground is said to be better copper bearing. The main good shoot of copper ground coming in from the Hecla (or "Black Hills") end of the Calumet comes in according to Captain Rosevear in the 15th level at 1300 feet; on the 18th level at 600 feet.

Tamarack No. 4 shaft about 600 feet northeast of No. 3 was much poorer. On the whole the samples (1 and 2) run a little higher in Ca than those at the bottom (6).

I owe to Mr. E. S. Grierson, chief engineer of the Calumet and Hecla, some 33 small samples running about 33 cc. or less, put up in vials I sent. They were mainly tested by Dr. A. A. Koch, but also by Karl S. Meuche, Hore and myself. They include samples from the Kearsarge hole on the Tecumseh (La Salle) and Calumet and Hecla property, the Baltic lode on the Superior property and the Osceola and Calumet lodes. We have the following results on the Calumet conglomerate.

Number	Depth ²	Position	Cl	Ca	Ca:Cl
1 cc	-1608	90 feet N. of No. 4	3.268 or 2.524	.920	.365
2 cc	-2028	500 feet N. of No. 4	9.571	2.412	.254
3 cc	-1848	2100 feet N. of No. 5	2.127	0.939	.45
5 cc	-1488		2.920K 2.9822L	0.908	.312
Whereas in the amygdaloids we have:					
4 cc	-1668	First amygdaloid east of conglomerate 400 S. of No. 5	55.00K 55.17L	24.907	
6 cc	-472	Shaft 16, 40 feet above 24th level	3.2L		
			3.459	.860	.352

¹Very small samples result in milligrams not parts. Specimens of rock and water 6 were very nearly from the bottom of the mine at the time, 5367.5 feet deep, where the temperature was 87°. No. 6 has less chlorine than Nos. 5 and 7 and on the whole confirms the miners' impression that the conglomerate has for the same depth less salt than the amygdaloid.

²Referred to the level of Lake Superior; + means above, - below.

On the Osceola amygdaloid we have:

10	+850	.071	.004
20	+858	1.418	.008
30	+923	1.064	.014
40	+923	1.418	.014
50	+663	1.418	.004
60	+885	1.418	.031

These show much more strikingly than the analyses at great depth the relative freshness of the conglomerate, which seems also fresher at the north end near the barren ground in that direction. The water from the South Hecla, perhaps at the lower side of the shoot or below is very bad even above the 24th level. It is this region where the salt crystals are found.

Our general conclusion is, then, that the Calumet conglomerate water is relatively fresher than the amygdaloid rocks around it on either side but that this difference seems to disappear somewhat at great depth or at least that the ratio of Ca:Cl becomes about the same. The copper is richest in the middle water and becomes very slowly less rich as the lower water is reached, but continues good long after the lower water is well established, and the Ca : Cl ratio has become 0.485.

KEARSARGE.

Proceeding next in order to a lode where a large number of tests are available we come to the Kearsarge lode, and we take the analyses in order from the north end.

The Ojibway struck salt water quite early, it is said, at 500 feet (the 4th level). In opening the upper levels some fine specimens of crystallized cubes and dihexahedra of copper are found. One specimen Hubbard showed me has copper upon, and later than, quartz prisms and pyramids, then later yet a zeolite in white prisms with oblique terminations supposed to be laumontite.

The Mohawk mine was tested by Fernekes as follows:

Shaft No. 1, 10th level dripping.

Cl	.357 grams per liter
Ca	.067
Na	.154
Sum	.578
Difference CO ₂ , SiO ₂ , etc.	.122
Total solids determined	.700

Na : Cl = 0.43

Ca : Cl = 0.183

This is a typical upper level water like the S. Kearsarge, but only half as strong.

Shaft No. 1, 11th level, Mohawk dripping.

Cl .....	.285
Ca .....	.057
Na .....	.1198
Sum .....	.4618
Difference .....	.1382

Total solids determined .....	.600
Na : Cl = 0.42	
Ca : Cl = 0.20	

Note how sharp the change is at the next level.

Shaft No. 1, 12th level Mohawk dripping.

Cl	3.172
Ca .....	.993
Na .....	.914
Sum	5.079
Difference .....	.276

Total solids determined	5.355
Na : Cl = 0.294	
Ca : Cl = 0.314	

This is fairly in the middle zone. The sodium ratio is dropping.

Shaft No. 1, Mohawk 13th level, pool.

Cl	3.299
Ca	1.241
Na .....	.711
Sum	5.251
Difference .....	.349

Total solids determined	5.600
Na : Cl = 0.216	
Ca : Cl = 0.282	

Shaft No. 1, Mohawk, 20 feet S. of 14th level, dripping.

Cl	21.546 grams per liter
Ca	10.560
Na	1.824
Br .....	.124
Sum	34.054
Difference .....	.346

Total solids determined	34.400
Na : Cl = .085	
Ca : Cl = 0.48	

This is quite characteristic of the lower zone in proportions if not in concentration.

The features of a splitting of the copper of the lode is, I am told, shown in the Osceola lode on the Calumet property. Near the margin of the amygdaloid there is always a little copper, then again in the foot where it is more massive, more irregular and perhaps 30 feet away.

The Kearsarge lode in various mines including the Pewabic has an east vein and a west vein. How far is this in a way the same phenomenon? The Osceola lode seems to run from 11 to 19 lbs. of copper per ton, *in selected* parts.

In this mine, the amygdaloid has two forms of alteration, one brown and soft, one hard, greenish gray, quartzose and epidotic. Cross-fissures contain Mohawkite and Keweenawite. Shaft 2 is especially poor, and on the whole the rock is not as rich as in the Ahmeek, or in the Shafts 5 and 6 near the Ahmeek, and the rock near them is of the grey, not the brown type. The intersection of the nearly vertical fissures with the lode which dips 36° or so, inclines 50° to 80° to the north. They seem to guide somewhat the shoots of copper.

H. V. Winchell was inclined to believe these Mohawkite veins genuine fissure veins filled from below. The cracks in which they occur are certainly of that nature.

The North Kearsarge directly abuts the Ahmeek and is deeper than the Mohawk. From this we have Fernekes' test (L. S. M. I., Vol. XIII, analyses 117 to 120).

North Kearsarge mine. 26th level. 700 feet S. of No. 3 shaft.

Cl	83.400
Ca	38.667
Na	9.826
Cu	p.n.d. ²
Br .....	.905

Sum	132.798
Difference .....	.202

Total solids determined.....	133.000
Sp. Gr.	1.099
Ca : Cl	.465
Na : Cl	.118

This is much stronger than any of the Wolverine waters but the Na : Cl ratio is similar to that on the 26th level.

N. Kearsarge, 300 feet S. of No. 3 shaft, on the 27th level.

Cl	71.240
Ca	31.822
Na	9.822
Cu	p.n.d. ²
Br .....	.945

Sum	113.829
Difference .....	.371

Total solids determined.....	114.2
Sp Gr.	1.089
Ca : Cl	.457
Na : Cl	.1375

This is less strong than 119 at the N. end or than No. 117 on the level above, but has just about the same amount of sodium.

¹All samples from N. Kearsarge are estimated to contain from 2 to 8 mg per liter of copper.
²Estimated from 2 to 8 mg per liter.

N. Kearsarge 450 feet N. of No. 3 shaft, 27th level.

Cl	76.363
Ca	32.937
Na	11.597
Cu	p.n.d
Br .....	.725

Sum	121.622
Difference .....	.178

Total solids determined.....	121.800
Sp. Gr.	1.091

We compute:

Ca : Cl	.43
Na : Cl	.151

These are running a good deal higher in sodium than the Wolverine at the same levels and concentration.

N. Kearsarge, 28th level, 150 feet S.

Cl	60.480
Ca	25.618
Na	9.722
Br .....	.675

Sum	96.495
Difference .....	.245
	96.740

Sp. Gr.	1.074
Na : Cl	= 0.161
Ca : Cl	= 0.425

As we go south from the Allouez gap the relative amount of sodium at about the 26th to 28th levels seems to decrease, the calcium to chlorine ratio increases, perhaps, but it is notable that it is lowest in this last analysis—the only case of the sort I have met.

Adjacent to the North Kearsarge is the Wolverine. It is on the Kearsarge lode but there have been a number of exploratory cross-cuts. See Chapter V.

The Sp. Gr. of the water (at 48° F.) in the 8th level cross-cut was 1.000 by urinometer; 13th level cross-cut was 1.000 by urinometer; 17th level cross-cut was 1.017 by urinometer;

The sample from the 17th level was tested by F. B. Wilson with the following results:

Sp Gr.	1.022
Cl	15.2287 grams per liter
Na	2.731
Ca	6.300
Mg .....	.013
SO ₄ .....	.0724

Sum 24.3451

Na : Cl = 0.181

Ca : Cl = 0.413

This total agrees with Sp. Gr. which I found.

This agrees pretty closely with Fernekes' tests at the 20th level south, Wolverine No. 3.

At the 24th level (possibly some water working down through the slopes) Sp. Gr. was 1.012 by urinometer, and in the 29th level cross-cut 1.033.

The sharp change in the composition of the water in the Wolverine at the 17th level as at the Franklin Junior is clear. G. Fernekes made additional tests as follow:

Wolverine No. 3 shaft, 300 feet S. on 20th level.

Cl	17.395
Ca	7.321
Na	2.852

Sum 27.568

Difference (Mg, SO₄, etc)252

Total solids determined..... 27.82

Sp. Gr. 1.021

Na : Cl = 0.165

Ca : Cl = 0.42

Wolverine No. 3 shaft, 300 feet S. on 22nd level, drip.

Cl	11.705
Ca	5.071
Na	1.784

Sum 18.560

Difference800

Total solids determined..... 19.360

Sp. Gr. 1.015

We compute:

Na : Cl = 0.153

Ca : Cl = 0.433

This is apparently somewhat diluted of the same type as above.

Wolverine No. 3 shaft, 300 feet S. on the 24th level, dripping.

Cl	33.640
Ca	15.600
Na	4.088
Br .....	.868
SO ₄ .....	.130

Sum 54.326

Difference174

Total solids determined..... 54.5

Sp. Gr. 1.039

We compute:

Na : Cl = .122

Ca : Cl = 0.463

The lowest water is nearly established. Note as compared with the other levels the sudden rise in solids, almost double, while the sodium ratio drops.

This is about the same concentration as the 30th level Centennial, No. 108 of the L. S. M. I. paper.

Wolverine No. 3 shaft, 300 feet S on 26th level, dripping.

Cl	55.765
Ca	26.800
Na	5.912
Br .....	.930

Sum 89.407

Difference393

Total solids determined..... 89.8

Sp. Gr. 1.071

We compute:

Na : Cl = 0.106

Ca : Cl = 0.48

This is the lower water.

Wolverine No. 3 shaft, drip 300 feet S. on 28th level.

Cl	75.231
Ca	36.347
Na	7.367
Br.	1.085
Sum	120.030
Difference .....	.270

Total solids determined..... 120.3

Sp. G. 1.092

We compute:

Na : Cl = 0.098

Ca : Cl = 0.483

Wolverine No. 3 shaft, 300 feet S. on 30th level dripping.

Cl	64.390
Ca	31.271
Na	5.756
Br .....	.940
Cu	p.n.d.
Sum	102.357
Difference .....	.143

Total solids determined..... 102.5

Sp. Gr. 1.079

The last three are of nearly the same kind of water varying slightly in concentration. In this:

Na : Cl = .0895

Ca : Cl = 0.485

The varying concentration may be partly due to evaporation and partly to very recent circulation of fresh water incident to the mining.

The Centennial 30th level water is about as strong as the Wolverine 24th level water and the Na : Cl ratio is the same.

Centennial mine. At the 11th level "no shaft" was reported, i. e., not enough to make analysis on a small sample. Fernekes estimates that a gallon would have been needed.

At the 13th, 15th and 20th levels.

	13	15	20
Cl	1.711	3.549	5.780
Ca	0.626	0.880	1.880
Na	0.389	1.287	1.584
Sum	2.726	5.716	9.244
Difference	0.232	0.264	0.216

Total solids determined 2.958 6.0 9.460

We compute respectively:

Na : Cl = 0.228 0.357 0.275

Ca : Cl = 0.368 0.248 0.326

At the 25th level it is much stronger, and the Ca : Cl ratio gets above 0.40. The lower water is well established.

Cl	27.114
Ca	11.6
Na	4.22
Cu	p.n.d.
Sum	42.934
Difference .....	.266

Total solids determined 43.200

We compute:

Na : Cl = 0.156

Ca : Cl = 0.428

Centennial 30th level.

Cl	34.263
Ca	15.700
Na	4.140
Cu	p.n.d.
Sum	54.103
Difference .....	.377

Total solids determined..... 54.480

Na : Cl = 0.121

Ca : Cl = 0.457

Note that the most rapid rise in saltness comes between the 20th and 25th levels. Later tests of Centennial waters came through E. S. Grierson.

Mark	Depth	Cl	Ca	Location and remarks	Ca:Cl
1 c	-1128	53.53	24.90	27th level, 200 feet north of No. 2	.465
2 c	-1191	59.202	26.52	28th level, 200 feet south of No. 2	.448
3 c	-1252	58.493	26.34	29th level, 100 feet north of No. 1	.456
4 c	-1328	68.064	29.46	30th level, 200 feet south of No. 1	.43
5 c	-1409	77.99	36.50	31st level, 300 feet north of No. 1	.47
6 c	-1487	84.371	40.16	32d level, 200 feet north of No. 1	.475

The two shafts are close together but diverge going down. No. 2 is the farthest north. This set, later than Fernekes, is much stronger. Is it a question of evaporation of the water before or after it was taken as a sample, or is a stronger water actually coming in from the wall rock? I think the latter is quite probable. The earlier tests were not as strong as those at the Wolverine at the same depth, but the last set are quite as strong.

South Kearsarge No. 2 shaft, 9th level, drippings collected by F. W. McNair and C. D. Hohl.

Cl	.842
Ca	.111
Na	.418
<hr/>	
Sum	1.371
Difference	.61

Total solids determined..... 1.432

This is essentially a duplicate of the next. Cf. the 10th and 11th levels Mohawk.

Na : Cl	.495
Ca : Cl	.132

South Kearsarge No. 1 shaft, 9th level, dripping collected by F. W. McNair and C. D. Hohl.

Cl	.702
Ca	.0912
Na	.414
SO ₄	.075
SiO ₂	.035
Fe ₂ O ₃ } Al ₂ O ₃ }	.030
<hr/>	
Sum	1.3472
Difference	.0028

Total solids determined..... 1.350

This is a complete analysis intended to show the character of the middle water in the upper levels, before the calcium chloride becomes conspicuous, though even here there is chlorine, which may be considered combined with calcium. There is even here little or no CO₂ and the Ca is not abnormal for any water.

Probably the iron and alumina may exist as chloride.

$$(\text{Fe}_2\text{O}_3 = .030) = (\text{Fe} = .021)$$

We have:

Na : Cl	.58
Ca : Cl	.13

We may combine this as

Water glass Na ₂ O 4 SiO ₂	= .0067+.0023+.034	= 0.044
Salt Na Cl	= .4083+.630 Cl	= 1.038
Fe Cl ₃	= .021 +.039	= .060
Ca Cl ₂	= .019 +.033	= .052
Ca SO ₄	= .0312+.075 SO ₄	= .106
<hr/>		
Total Ca combined	.0502	
Ca combined with CO ₂ ?		.041
		<hr/>
		1.3411

Note the tendency to alkalinity, both in the water glass and the excess of lime. The sodium is more than could be obtained by dilution of a deeper water with a surface water.

From the Calumet shafts 19 and 20 on the Kearsarge we have no tests. They were barren and did not go deep. Small samples from No. 21 shaft, through E. S. Grierson gave A. A. Koch

Number	Depth	Cl	Ca	Ca:Cl	
1 K	556 A. T.	.177	.018	.010	9th level, 20 feet south of fissure
2 K	427	.213	.025	.012	100 feet below 10th level
3 K	347 A. T.	.675	.110	.015	10 feet above 12th level as strong a stream as drill hole No. 10

These show the middle water just coming in. This shaft is on the whole richer than No. 19 or 20 (or the south part of the Centennial?). At about the 10th level a considerable flow of water came in under a seam and the lode was thought to be better.

The next property south is the La Salle. From the Tecumseh No. 1 shaft we have the following tests of the Kearsarge lode.

Mark	Depth	Cl	Ca	Ca:Cl.	Notes on location
1 T	At 900 feet.	.035	.004		71 feet south, 9th level
2 T	At 1010 feet.	.052	tr		300 feet south, 10th level
3 T	At 1120 feet.	.071	.014		40 feet south, 11th level
4 T	At 1230 feet.	.142	.004		174 feet south, 12th level
5 T	At 1340 feet.	.177	.012		69 feet south, 13th level
6 T	At 1450 feet.	.248	.185		in the shaft itself.

These waters with their very great softness are largely the upper water,—like the South Kearsarge but containing less salt. They show in their rapidly increasing chlorine a steady admixture of lower water. On the whole, however, the La Salle has not been rich and the shafts farther south, the so-called Caldwell shafts, have shown even less stamp rock. On the Franklin Junior the Kearsarge was cut in a cross-cut at the 4th level, but very close to the surface and the water was of course, fresh.

The next lower horizon from which we have many tests is that of the Isle Royale-Arcadian lode. An analysis of surface water from the Arcadian shaft is given in the annual report for 1903, page 243.

Isle Royale Consolidated Mine. Arcadian, i. e. Isle Royale amygdaloid epidote, and possibly Grand Portage lodes. This is close to Portage Lake just back of Houghton, and is 400 feet or 500 feet above it, i. e. above Lake Superior. It is the old Huron mine re-opened. This went down about 16 levels or 1000 feet.

On the Grand Portage lode shafts to 500 feet were sunk. This opened on many levels by cross-cuts, but is about 200 feet (above) west of the Isle Royale lode on which the shaft is sunk.¹ This is worth mentioning since dripping from the levels might well have been affected by surface water standing in the levels a good while.

300 feet N. of No. 2 shaft 15th level, dripping. (Cross-cut to Portage lode, at 14th level?)

Cl	9.204 grams per liter
Ca	4.321
Na	.994
Sum	14.519
Difference	.581
Total solids determined	15.1
Sp. Gr.	1.007 low!

We compute.

$$\text{Na : Cl} = 0.0925 \quad \text{Ca : Cl}$$

This is a dilute deep water.

¹N. B. This is not on Isle Royale but back of Houghton.

18th level, dripping, 300 feet N. of No. 2 shaft.

Cl	34.920
Ca	16.751
Na	3.058
SO ₄	.179
Cu	p.n.d. ¹
Sum	54.908
Difference	.792

Total solids determined..... 55.70

We compute:

$$\text{Na : Cl} .089 \quad \text{Ca : Cl}$$

This is a typical dilute deep water.

19th level, N. of No. 2 shaft, from a pool from dripping.

Cl	45.178
Ca	22.201
Na	3.837
Br	0.320
SO ₄	.234
Cu	p.n.d. ¹
Sum	71.770
Difference	.330

Total solids determined..... 72.1

$$\text{Sp. Gr.} \quad 1.057$$

We compute:

$$\text{Na : Cl} .085 \quad \text{Ca : Cl}$$

Dripping 50 feet S. of No. 2 shaft on 20th level.

Cl	7.626
Ca	3.249
Na	1.204
Cu	p.n.d.
Sum	12.079
Difference	.241

Total solids determined..... 12.32

$$\text{Sp. Gr.} \quad 1.009$$

¹Estimated 2 to 8 mg per liter.

Here is lower down a distinctly weaker water with
 Na : Cl .158 Ca : Cl

The contrast between this and that above at the 5th level is worth noting. Though they have about the same strength the deeper water is in one case diluted with fresh water that has found its way rapidly and directly down, while in the other case there is much sodium, presumably derived by decomposition of the rock.

The 21st level was the bottom of the old Huron mine on the same lode (2500 feet deep) shafts 6 and 8, of the Report of Commissioner of Mineral Statistics for 1888.

WINONA AND KING PHILIP MINES.

These waters were tested by Dr. M. L. Holm in connection with the Challenge waters. They are distinctly salt at the 5th and 8th levels respectively. They are newly opened compared with the Mass and Adventure. On the whole the water appears to be weaker to the north which is the poorer end. Winona shaft No. 2 farther north was of little value for 200 to 1000 feet though there was some copper rock in the 6th level south and Shaft No. 3 was poor on the 3rd and 4th levels, but improved from the 7th to 12th levels. All the drifts north to No. 4 shaft are said to be in poorer ground. In that direction we seem to find the upper type of water exclusively while only one, that is that from King Philip shaft No. 1 at the 8th level is the lowest type. This is said to be particularly good in copper from the 6th to the 9th levels. This is brought out by arranging the analyses thus:

Winona No. 3 shaft, levels north	3	4	6
Number of analysis	429	422	424
Chlorine	tr	tr	100

Ratio Ca : Cl more than 1, i. e., surface waters in a region of hard water. Limestone Mountain is not so far off, but here the glacial movement was from the northwest over the traps which are limey.

No. 3 shaft levels south..	5	7	8	9	10
Number of analysis.	423	425	426	427	428
Chlorine	2.050	.225	.125	.250	.300
Ratio Ca : Cl	.13	.427	.39	.42	.40

No 423 is evidently abnormal, urine contaminated?

King Philip No. 1 shaft levels..	5	6	7	8
Chlorine	.406	.900	2.85	15.25
Ca : Cl ₂	0.29	0.29	0.3	0.45

The Mass and Adventure mines of Ontonagon county are at about the horizon of the Winona lode.

Prof A. P. Frapwell, then assistant in chemistry at Ann Arbor, 1906-7, was with us in the summer, and I had him make the following tests with the U. S. G. S. field assay outfit. The Ca runs from 19 to 60, though the results are not very reliable. The same comment applies to SO₄ determinations, as the electric cells were old. Still that would tend to give SO₄ too high, and we may be sure that SO₄ is at least as low as the low figures shown.

The water of the Mass mine, C shaft, for the first thousand feet was fresh and down to and including the 8th level gave him the result below, and water from a seam on the 17th level gave (analyses 50 and 46 of the L. S. M. I. report):

	8th	17th
Cl	.050	22.476
Ca (hardness as)	.082	.044?
Alkalinity as Ca CO ₃	.263	.015?
Alkalinity as Na ₂ CO ₃	.000	.021
SO ₄	.110	.135
Sp. Gr.		1.041

They are said to have lost their copper when they struck salt water. In the A shaft a seam in the 10th level gave water with only

Cl	.006
SO ₄	.038
Ca (hardness)	.016
Alkalinity as Ca CO ₃	.225
Alkalinity as Na ₂ CO ₃	.000

This is distinctly an upper water, but it must be remembered that the mines are old and circulation started by mining operations may have a great effect. He also made tests of the Adventure mine of water down to the 6th level in No. 1 shaft (54), the 8th level in No. 4 shaft (51), the 12th level in No. 3 shaft (56) also of the Michigan mine B shaft, of the water down to the 10th level (50). They are all very fresh and run between 30 and 6 parts per million of chlorine. He also made a number of tests of surface waters, tabulated in the L. S. M. I. paper.

Victoria mine, Rockland district. A sample was taken by Dr. L. L. Hubbard from the 19th level cross-cut, about 600 feet from the shaft near the top of the "Forest" conglomerate. It is from prac-

rically the same location as No. 20 taken only three years before. It gave

Cl	3.159
Total solids	6.465
Sp Gr.	1.004

Additional samples were collected late in 1908 by Mr. Schultz and myself and tested with the following results. See Figure 60 in Chapter VIII.

Mr. Schultz suggests that there may be more calcite in the upper levels, more epidote in the lower, just as in the Baltic mine, epidote comes only in depth. At any rate the Forest conglomerate in the 19th level is full of epidote. If the carbonate radical does replace the chlorine of Ca Cl_2 in the upper levels, it would leave chlorine ions to travel and attack the rock.

1. 4th level cross-cut north from seam at about 45° dip and strike a little more north. Cl 0.013
2. Five paces from breast Cl 0.015 Ca 0.030 H
3. East end of 4th level in shattered lode Cl 0.025
4. From percussion drill hole a little north of shaft, 12 paces east of Plug 132 Cl 0.028
6. Floor of west end 4th level Cl 0.003
8. 5th level west near Plug 156 Ca 0.033
9. 5th level west, quite a fair flow which blackens the rock, from a cross-seam dipping to southwest, five paces east of Plug 158.
10. 6th level east, 10 paces west of Plug 161, slow drip into bottom of level. Cl less than 0.017
11. 6th level west, near a seam 5 paces west of Plug 176 where there is a drift to north. Cl less than 0.066
12. West end of 6th level, in this level it was mainly dry. Cl less than 0.188
In the 7th and 8th levels it was dry to the east.
13. East 10 paces of Plug 24 steady stream Cl less than 0.007
14. A slow drip from a west dipping seam 6 paces east of Plug 31 Cl less than 0.014
Location is supplied from an underground reservoir in the 4th level Cl 0.102
The 10th level was dry.

15. The 12th level east had a very slow drip about 800 feet from the end near a plug. This continues as a bar of damp ground, with slow drip nearly to the shaft. Cl 0.019
Ca 0.010 to 0.021
Hardness 0.030
Then to the shaft and the first few hundred feet west it was very dry.
16. Sample from 12th level west and beyond fault; water hole; very slow drip Cl 0.051
Ca 0.075
17. From end of 14th level, a water hole in damp, much broken ground. Cl 0.102
Ca 0.013 to .028
Hardness 0.035
The 15th and 16th levels were dry.
18. Under a seam with flatter dip than bedding, slow drops about 50 feet from east end of level. Cl 0.110
Ca 0.172
19. From a slow drip not at the clay seam but farther on in a cross-cut north. Cl 0.128
Ca 21.45 or 50
20. From 19th level cross-cut just under heavy trap, at 460+78. Cl 2.920 or 2.140
Ca 0.830
Hardness .810
21. On a seam at 1260 which dips with the formation Cl 3.550
Ca 3.00
22. At 510 north of the lode Cl 0.660
Ca 0.060
23. At a stub drift Cl .500
Ca .100
25. In the 22nd west Cl 10.640
Sp. Gr. 1.012
Ca .960
26. In the 22nd east Cl 7.400
Ca 1.440

In its freshness down to the 12th level to which point was a lively circulation, in the dry zone then succeeding (the 15th and

16th levels, for instance) from which the salt water may have drained off, and in the distinctly salt water at the 19th to 22nd levels this mine is typical. The lode is not an amygdaloid but a shattered zone in the foot of a trap. On the whole the copper is supposed to be best from the 11th to 14th levels, thence making west. To the east there is a cross-fault, the east side thrown 50 feet south.

TESTS OF THE BALTIC LODGE.

This is the lowest of the lodes worked. It lies between a conglomerate (the Baltic conglomerate) as it is generally called (No. 3) and a heavy ophite, known as the Mabb ophite, whose mottles are up to 7 mm. across. The distance above the conglomerate varies, but is about (150) feet more or less, and it is (170 to 200) feet below the ophite. It is no one well-defined amygdaloid top to a flow but rather an impregnated shear zone or stockwerk, copper being found over a belt more than 40 feet wide.

The Baltic lode is the lowest horizon much worked.

In tests at the Isle Royale section 12 shaft I found only fresh water. Only a few nuggets of copper were found, looking almost like boulders,—residues of solution and redeposition perhaps. The rocks were full of reddened clay slips and wet. See Fig. 45 and description in Chapter V.

The set of samples of waters gave the following (by field tests) results, which by checks on Yale No. 2 and T. 3 are somewhat low.

No.	Location	Cl	Ca
1.	About 117 feet in, in west cross-cut drip..	.007	.012
2.	About 300 feet in, in slow drip.....	.005	.001
3.	About 360 feet in, in fast drip.....	.005	.000
4.	About 450 feet in, in fast drip, 15 feet from end .....	.005	.000
5.	30 feet from end of east cross-cut, very slow drip .....	.298	.019 to .041
6.	Conglomerate in the east cross-cut.....	{ .030	tr.
7.	20 feet above it.....	{ .025	.003-.6
8.	Diamond drill hole, free flow.....	.035	.001-2
9.	Diamond drill hole 3, free flow.....	.142	.012-25
10.	Diamond drill hole 1, free flow.....	.028	.001-6
		.277	.022-47

These are all characteristic soft upper waters, none as strong as at the Superior. The calcium is only so much as might consist with sodium silicate.

At the Superior shafts next south No. 1 shaft was reported notably salty at the 2nd level and has shown better copper ground, of the same class as at the Champion Copper mine. This, as shown in the map (Pl. X) is about 1200 feet south of the north line of Section 15. Samples gave

Mark	Cl	Ca	Ca:Cl	Location
1s	.674	.014	.048	5th level 500 feet south of No. 1
2s	{ 3.510	.855		5th level 660 feet north of No. 1
	{ 3.297			
3s	2.482	.462	.13	6th level 230 feet south of No 1
5s	5.318	1.430		7th level 110 feet north of No. 1
6s	{ 1.129	1.753		
	{ 1.114			

This is plainly saltier to the north, and to the south in No. 2 and the Atlantic the workings are both very fresh and poor.¹

No. 2 is about 2540 feet southwest of No. 1 and showed no good ground, until the 600-foot level, and then in the north drift. It is nearer the disturbed zone of Atlantic section 16.

The Atlantic mine on Section 16 was in a much faulted and disintegrated zone, full of clay slips in which the surface water seemed to have penetrated far.

The Baltic comes next up the slope.

The Baltic water appears to be fresher than the Trimountain. The drift covering was much thinner, the bed rock surface higher and the lode on the whole richer.

At the 4th level was a "red" water, probably swamp colored. The 6th level cross-cut (now Atlantic at the north end) was very fresh. There is a fissure dipping south from Shaft 4 at the 4th level to Shaft 3 at the 14th level and when the fissures were struck surface wells of the town went dry. The character of the ground and the amount of copper according to Capt. M. Tretheway, changes in crossing the fissures. On the whole a greenish tone of rock rather than a brown amygdaloid is thought better, quite different from the feeling at the Mohawk, but I think it is a chlorite green rather than an epidote green.

¹But see analysis in appendix.

Baltic mine. 15th level. Dr. Fernekes reports:

Cl	27.264
Ca	13.682
Na	1.929
Br	0.3112
Sum	43.187
Difference	.813 (CO ₂ or SO ₄)
Total solids	44.000
Na : Cl	.073

The ore contains considerable sulphur and arsenic.

We may compute:

CaCl ₂ 38.	Cl=	24.3
NaCl ₂ 3.79,	Cl=	2.946
NaBr .402,	Br=	.312
Na ₂ CO ₃ .23		
<hr/>		
44.492		

Trimountain. On a visit to the Trimountain mine of the Copper Range Company, Sept. 4, 1906, I took a sample of salt water from 200 feet N. of shaft No. 3 S. 9th level in a lean streak of rock that comes under a cross-seam which dips about 45° to the south. Salt water is reported even as high as the 6th level North of No. 3 from a drill hole in the hanging wall.

The Sp. Gr. as estimated in the mine was 1.078 at the mine temperature, probably about 51° F.

Dr. Fernekes found, Sept. 8, 1906.

Sp. Gr.	1.053 (=65.8 CaCl ₂)
Total solids	74.44 parts per thousand
Cl	46.02
Na	3.36
Ca	24.58
SO ₃	.484
Fe, Mg, CO ₂	tr.
<hr/>	
Sum	74.444

We may compute:

NaCl	8.54
CaCl ₂	63.90
CaSO ₄	.823
Excess of Ca combined with CO ₂ in part	1.28
<hr/>	
74.543	

Na : Cl	.076
Ca : Cl	.535

These values are so abnormal that one is tempted to suspect an analytical error.

A larger less strong sample taken for and tested by Dr. Fernekes was perhaps of the water of the drift as a whole as follows:

Trimountain 9th level.	
Cl	19.874 per thousand
Ca	9.000
(to satisfy acids) Na	2.653
Br	.243
<hr/>	
31.770	
Diff.	.230
Total	32.000
<hr/>	
Na : Cl	= 0.133
Ca : Cl	= 0.453

On the whole the Trimountain has been much poorer in copper than its neighbors north and south. The south end of the Trimountain, a compact light gray quartz epidote rock, was poor and the north end of the Champion, Shaft B, is not so good as the south end where E shows excellent ground.

In the upper levels of the Champion, at least as I visited it in 1901 and 1909, the copper was in lumps, sometimes richly, but not associated with prehnite, and while the rock was amygdaloid it was not markedly so, being more an amygdaloid trap at the foot of a marked amygdaloid. Some fine specimens of iceland spar came from the 6th level east, and selenite crystals three inches wide and ten inches long occurred in the 13th level east, being the last formed, the order of growth being chlorite, epidote, calcite in half inch dog-tooth spar crystals, then gypsum.

Whitneyite (Cu₉As₂) occurs on the 3rd level. Chalcocite (Cu₂S) occurs in seams parallel to, not across, the strike, but both sulphides are supposed to be superficial. On a visit in 1909 (Aug. 4) I collected samples from the 13th level. It was reported that the water at the 7th level E shaft was quite drinkable.

A sample representing the water pumped and collected between the 6th to 12th levels gave A. A. Koch: