Table of rainfall at Panama and other stations.

	Panama, lat. 9° N., long. 80° W.					San José, lat. 10° N., long. 84° W.	Mazatlan, lat. 23° N., long. 107° W.	San Diego, lat. 33° N., long. 117° W.	S. Francisco, lat. 38° N., long. 122° W.	Portland, lat. 46° N., long. 123° W.
	1879.	1880.	1881.	1882.	Mean, 4 years.	Mean, 2 yrs.	Mean, 2 yrs.	Mean, 7 yrs.	Mean, 7 yrs.	Mean, 7 yrs.
	//	//	//	//	//	//	//	//	//	//
January .	0.04	1.89	0.16	0.00	0.52	0.22	1.74	1.72	6.61	4.98
February .	2.52	.12	.16	.12	.73	.00	.00	1.55	4.34	8.78
March . .	5 71	.16	.35	.00	1.56	1.00	.00	1.21	3.45	7.87
April . .	5.55	1.61	3.23	.98	2.84	4.20	.00	.95	2.38	2.91
May . . .	10.28	4.45	10.35	5.24	7.58	7.44	.00	.19	.64	2.90
June . . .	6.46	5.00	13.78	6.18	7.86	6.23	2.12	.06	.26	1.81
July . . .	7.91	9.88	7.20	5.35	7.58	10.30	10.16	.03	.01	.74
August . .	7.24	11 46	4.49	4.06	6.81	5.16	9.14	.08	.00	.91
September.	9.02	7.91	8.94	4.06	7.48	9.14	15.96	.07	.14	1.99
October .	9.80	11.81	9 69	6.69	9.50	10.02	3.26	.46	1.29	4.51
November .	19.21	6.46	9.72	10.91	11.58	2.87	.80	.90	3.08	8.83
December .	.98	5.51	2.48	2.01	2.74	.88	3.06	2.43	3.50	7.46
Year . .	84.72	66.26	70.55	45.60	66.78	57.46	46.24	9.65	25.70	53.69

accompanies the curve of maximum daily temperature due to the annual oscillatory movement of the thermal equator. The movement of this curve is closely connected with the annual movement of the sun across the geographical equator. The sun passes the zenith of the isthmus at mid-day twice in the year, on April 13 and Aug. 29. The sheet covers the isthmus from the beginning of May to the end of June, and from the end of July to the beginning of December. These two intervals occurring between the first of May and the first of December constitute the rainy seasons. The first is generally interrupted by the short 'summer of St. John.' During the remainder of the year is the dry season. At this time the sheet is entirely to the south of the isthmus, while during the 'summer of St. John' it is entirely to the north.

On the north side of this sheet the trade-winds of the northern hemisphere prevail, which, at the isthmus, have in general a direction from the north-east. On the south side the trades of the southern hemisphere prevail, which have a direction from the south. In the interior of the sheet, at the earth's surface, the wind is feeble and uncertain. This, then, for the isthmus, is the period of calms, the time of gentle breezes; now from the land, now from the sea, according to the hour of the day.

Percentage of precipitation in each month.

	Panama.	San José.	Mazatlan.	San Diego.	San Fran'co.	Portland.
January. .	1	0	4	18	26	9
February .	1	0	0	16	17	16
March . .	2	2	0	12	13	15
April. . .	4	7	0	10	9	6
May . . .	11	13	0	2	2	5
June . . .	13	11	5	1	1	3
July . . .	12	18	22	0	0	1
August . .	10	9	20	1	0	2
September.	11	16	34	1	1	4
October . .	14	17	7	5	5	8
November .	17	5	2	9	12	17
December .	4	2	6	25	14	14
Total . .	100	100	100	100	100	100

M. de Lesseps further remarks, that one can see, that, in the time during which the (overhanging) sheet of ascending air is over the isthmus, the season of rain prevails, because the trade-winds, blowing along the ocean's surface, accumulate in this sheet a mass of vapor, which rises up, comes to the higher regions of the atmosphere into lower and lower temperatures, and is condensed; producing, thus, a vault of perpetual cloud, which generally surrounds the earth in a dark ring, — called, by the French sailors, '*pol au noir;*' by the Americans and English, 'cloud ring,' — and continually precipitates during the rainy season the showers of the tropical regions.

The waters of the gulf-stream which come from the equator are charged with a great quantity of vapor; and this is condensed and precipitated by the Cordilleras. This accounts for the abundant rains of the Atlantic watershed. This cause does not exist on the Pacific watershed. The general current along the coast of the isthmus is just the reverse of that in the sea of the Antilles. On the contrary, the tide comes from the north; and in consequence these waters are cooler, and furnish less vapor to the air flowing along the surface. This explains why it rains more at Colon than at Panama, and why, in proportion as one removes from the Atlantic coast, the rain diminishes. So upon the island of Naos, situated in the Bay of Panama; and, where the canal company has established a meteorological station, the rain gathered is less than at Panama.

The existence of winter and summer rains in belts approximately parallel to the equator has been long recognized. A glance at the table above will show that the rains all along the Pacific coast are markedly periodic, and occur later in the year as we go north; and the heavier rainfall occurs at the time the sun is the farthest south of the equator.

H. A. HAZEN.

THE COPPER-BEARING SERIES OF LAKE SUPERIOR.

IT may not be unprofitable, at this presumably the closing stage of the present discussion of the Keweenawan series, to state summarily the main grounds on which its pre-Potsdam age is maintained. It is obvious that such a statement can but imperfectly indicate the nature of the evidence relied upon; for the significant data are derived from numerous localities, and from diverse phenomena which cannot be adequately, and at the same time briefly, described. The formation involves an area of upwards of forty thousand square miles; and only a wide survey of it, a critical elaboration of trustworthy observations, and a judicial treatment of the evidence, can command complete deference, and that is a thing of the future. No

one has seen the formation in its entirety; and only one investigator has approached to a general familiarity with it by personal study, and his more comprehensive results are not yet before the public. I have even hesitated on this account to offer this summary, having myself visited only seven of the significant districts outside of Wisconsin, with the investigations within which I have, of course, been intimately familiar, as also with the results of Professor Irving's more extended studies, which are herein somewhat drawn upon.

Brevity requires the omission of citations and authorities in the main.

The general stratigraphical facts which are not open to reasonable question are these: 1. Around the edges of the great depression occupied by Lake Superior lies an immense series of interleaved igneous and detrital beds, dipping inward toward a synclinal axis, lying mainly beneath the lake, but stretching landward across north-western Wisconsin; 2. Both within and without this basin are horizontal series of sandstones, each of which is traceable into contact with the dipping series at a few points, and into approximate junction at several others. The horizontal sandstone on the outside contains primordial fossils, and has long been known as Potsdam. The horizontal sandstones within the trough, unfortunately, have not yet yielded fossils of any positive character. Some of these are so situated that they might be supposed to be portions of the synclinal fold, but the greater part are not so placed as to admit of this interpretation.

Now, those who advocate the distinctness of the Keweenaw series maintain that the great tilted group of interbedded igneous and detrital rocks which constitute the copper-bearing formation belongs to an entirely different age from the horizontal sandstones without, and from most, but not all, those within. They offer, among other considerations, the following classes of evidence in support of their view: —

1. First and weakest, *the general stratigraphical relations above indicated.* — These afford at least a presumption of distinctness. This admits of easy verbal objection, and to those personally unfamiliar with the *tout ensemble* of the problem and its data, and with the methods Nature habitually pursues in distinction from those she might be imagined to pursue, can have but little force; but experienced stratigraphists will appreciate the fact, that great differences in the attitudes of closely associated strata, especially if otherwise differentiated, are usually indicative of differences in age, and that definite evidence of unity is required to justify the somewhat violent dynamics necessary to otherwise explain these diverse attitudes. This is especially true when the surrounding region is altogether devoid of evidence of disturbance during the supposed period of disruption. Not only in the immediate vicinity, but throughout the interior, there is an absence of evidence of more than the gentlest oscillations in the recognized primordial strata; while the Keweenaw series suffered a depression of more miles than it would seem judicious to estimate here, and embraces one of the most stupendous series of eruptions known to early geological history. Upon this argument, being a general one, we do not much insist. It gains force, however, in connection with the following points, and gives especial significance to the next.

2. *Differences in thickness.* — The recognized Potsdam strata in the adjacent region have been penetrated at numerous points by artesian wells, and are only rarely found to reach a thousand feet in depth. On the other hand, the thickness of the Keweenaw series is so enormous as to have led to a studied watchfulness for possible sources of error of estimate. Unless faults be assumed where there is no proof of them, the maximum thickness must be upwards of forty thousand feet, of which about fifteen thousand feet are detrital. Without insisting in a controverted matter, that this estimate may not be too high, owing to undiscovered faults, it remains that an enormous difference is absolutely demonstrable. Now, this great difference means something in the mere matter of accumulation, but great stress is not laid upon this. Plausible, but really inapplicable, answers readily suggest themselves. If, however, it is insisted that the igneous eruptions furnished exceptional conditions for rapid accumulation, it will be freely granted, and even urged: but the great mass of the detrital beds were formed after the eruptions had ceased; and, besides, the fossiliferous Potsdam strata lie against the same rocks in the St. Croix region, and, if contemporaneous, should have been likewise favored in accumulation.

But whatever this incongruity of thickness signifies in the question of deposition, it is at least important in the interpretation of the discordant attitudes of the strata, and the adjudication of approximately observed, but not actually visible, unconformities. We hold that to be a violent structural hypothesis which assumes that portions of the same unmetamorphosed series are tilted at high angles, while, within a distance much less than the thickness of the formation, other portions lie undisturbed. That this extraordinary phenomenon should be several times repeated, in a region not otherwise characterized by more than broad open folds, seems to us incredible.

3. *Differences in constitution.* — The sandstones of the Keweenaw series are largely composed of grains of various *silicates* derived from igneous rocks; while the Potsdam, within as well as without the basin, is mainly *quartzose*, as shown by the investigations of Irving and Sweet. The former are manifestly derived, as maintained by these writers in common with others on both sides of the question, immediately from the igneous series, with relatively little wear or assortment. The latter are thought to have had wider sources, and to have been subjected to more erosion and winnowing; for even where in the vicinity of the igneous series they are still notably quartzose.

4. *Unconformity.* — While every unconformity has a significance, only those are urged in this relationship which seem to us to testify directly to the fact of a tilting of the great copper-bearing beds before the Potsdam sands were laid down upon and against their upturned edges. The cases of unconformity may be grouped in three classes: *a*, those actually observed; *b*, those in which the contact, though observed, is complicated with disruption; and, *c*, those in which the immediate junction is concealed, and the evidence is only approximate.

a. Of the first class are those of the St. Croix district, substantiated by the independent observations of Sweet in 1875, Strong in 1876 and 1877, Winchell at one or more dates unknown to me, and myself in 1876, 1879, and 1880. There are also here several cases of approximately visible junctions beside those actually seen. To us, the facts — which manifestly cannot be properly described here, but which are in a measure set forth in the Wisconsin publications — teach explicitly that the copper-bearing beds were not only formed, but uplifted and extensively worn into hills and valleys, before the Potsdam sands were laid down against and upon them. The full force of the evidence presented by this region can only be felt when a just appreciation of the facts is acquired,

and judicially considered in connection with the great mass of stratigraphical evidence with which it links itself, and of which it furnishes at once the key and clearest exponent.

From this decisive locality, there stretches away north-easterly, to Keweenaw Point, a belt of outcrops constantly maintaining the typical character, *bedding*, and *dip* of the Keweenaw series. Mr. Strong mapped no less than fifty-five exposed areas within the county in which occur the unconformities on the St. Croix (*Geol. of Wisc.*, iii.; *Atlas*, sheet xix.); and no concealed interval of so much as four miles occurs along the belt within thirty miles of the decisive locality. Throughout the whole broad belt to Keweenaw Point, occupying several thousand square miles, all the outcrops, numbered by hundreds, are of the Keweenawan class, and there are *none of any other kind*. This we conceive to be decisive evidence, notwithstanding some concealment from drift.

b. To the second class belong the unconformities of Douglas County, in the extreme north-western corner of Wisconsin, and those of the Keweenaw range of Michigan. In the former region, in a distance of twenty-five miles, there are four excellent sections across the junction-line. These have been described in detail, and illustrated by Sweet. On the one side, the Keweenawan beds dip from 35° to 50° southward, terminating northward in upturned, worn edges. Approaching these from the opposite direction are horizontal beds, which, at a distance from the contact, are simple sandstones, but, near the junction, become conglomeritic from material manifestly derived from the copper-bearing series. The beds are locally broken and bent upwards near the junction; but this, in our judgment, does not vitiate the evidence of unconformity at the time of deposition. We maintain that these sections afford strong evidence that the Keweenaw rocks were upturned before the flat-lying beds abutting against them were formed.

Upon the discussion of the controverted contact-line along the base of the great escarpment of Keweenaw Point, I will not here enter, partly because it might be useless without elaborate discussion, and partly because I could scarcely fail to trench upon data that belong to another. The whole region in controversy has recently been re-examined, and sketches carefully prepared, intended to show the exact facts exposed to observation, stripped of the bias of interpretation. Pending their appearance, I need only call attention to the fault-line long since claimed by Foster and Whitney to exist here, — a view in which several subsequent students of the region acquiesce, among them Irving and myself, with qualifications. Now, while the existence of this fault may be maintained consistently with the view that the flat-lying sandstones on the east are the equivalents of the uppermost beds of the tilted series on the west, and also with the view that the eastern sandstones were deposited unconformably against the cliff formed by the upturned beds, the faulting in this case being held to have previously taken place, it is altogether inconsistent with the view that the eastern sandstones pass continuously under the cliff.

c. Besides the above regions, which present more than a dozen separate localities of actual or approximate contact, several other districts afford strong evidence of unconformity, though they do not rise to actual, at least to ocular, demonstration. The more important are found on the upper St. Croix River, on the Snake and Kettle Rivers in Minnesota, and in the vicinity of Lake Agogebic, Michigan. These localities present horizontal quartzose sandstones, regarded as Potsdam, lying near upturned igneous and detrital silicate rocks, referred, on the basis of irrefragable evidence, to the Keweenawan series. The relations of these are so close, that all recent investigators who have examined them regard them as instances of unconformity between diverse formations, and find no other explanation consonant with the general geology of the region. It was my purpose to present the more significant facts relating to these little-known districts, upon two of which I have made unpublished observations; but space forbids. Let it be observed, however, that in all cases the upturned beds are distinctly Keweenawan in type, and are referred to that series on stratigraphical evidence, that, apart from controversy, would be accepted as conclusive, while all the horizontal beds, which are exhibited at eight separate localities, are quartzose, and definitely of the type referred to the Potsdam. We hold these to be facts of much significance as parts of the chain of evidence. The wide range of territory represented by these several cases of unconformity adds to their force as evidence of the distinctness of the formations.

5. *The inherent consistency of the view.* — The harmony of the foregoing evidences, drawn from diverse sources and from widely separated localities, and the mutual confirmation they lend each other, as well as their accordance with the entire phenomena of the region, are inherent arguments for the correctness of the whole.

6. *The dynamic simplicity of the view.* — No important orographic movements, beyond those that must be independently assumed to explain the attitude of the Huronian strata of the region, and such faults as there is independent evidence of, are invoked. On the other hand, an extraordinary amount of local faulting and disturbance seems necessary to the alternative hypotheses, and this notwithstanding the unmetamorphosed condition of the beds.

7. *The discovery by the United States geologists of a like series in the Grand Cañon of the Colorado.* — This, while not a direct argument, has an important collateral bearing on the question. By reference to p. 183 of No. 6 of this journal, it will be seen that a series remarkably similar to the Keweenawan in its essential characters occupies the same general position and attitude, lying in inclined, unmetamorphosed beds, unconformably below the upper Cambrian, and also resting unconformably upon the crystalline archaean series. The observations of Bell show a somewhat similar group bordering Hudson's Bay; but too little is yet known of it to indicate its true horizon. The ultimate acceptance of the Keweenawan group as the representative of an important period in geological history, will, of course, largely depend on the discovery of similar formations elsewhere, or the persistent failure to otherwise fill the gap between the Cambrian and Huronian.

T. C. CHAMBERLIN.

Washington, D.C., May 5, 1883.

LIQUEFACTION, VAPORIZATION, AND THE KINETIC THEORY OF SOLIDS AND LIQUIDS.[1]

THIS paper discusses at length the two kinds of vibratory motion which the molecule of a solid body may have, rotary and translatory. It is demonstrated that the mean kinetic energy of such an oscillatory

[1] Abstract of a paper presented by H. T. EDDY, Ph.D., University of Cincinnati, to the Section of physics and chemistry of the Ohio mech. inst., April 26.