ART. XXXVIII.—*On the thickness of the Ice-sheet at any Latitude;* by W. J. McGEE.*

1. ESTIMATES OF THICKNESS.

First preliminary estimate.—It was shown in Part I of this paper that the accumulation of glacier ice is dependent on precipitation; and in a general way it may be considered proportional therewith. It may also be assumed that the precipitation, and hence of course the accumulation of ice, is proportional to the vapor-tension. If then the thickness at any latitude is known, that at all other latitudes can be readily computed.

Professor Dana has shown † that the thickness of the Quaternary ice-sheet over the Canadian highlands (about N. lat. 48° to 50°) must have been at least 12,000 feet. As this accumulation took place under conditions less favorable than those considered in the present discussion, it may be assumed that a thickness of three miles might obtain at lat. 40°. The thickness at each latitude from 40° to the pole would accordingly be as represented in table XVII. The data forming the basis of the computation are derived from sources previously enumerated.

TABLE XVII.

Greatest thickness of Ice-field from lat. 40° to the Pole.

Latitude.	Temperature.	Vapor-tension.	Thickness of ice.
40°	+56·5° F.	0·457 in.	3·000 miles.
50	41·7	·264	1·733
60	30·2	·168	1·103
70	16·0	·090	·591
80	6·8	·059	·387
90	2·3	·048	·315

Second preliminary estimate.—It would doubtless be more satisfactory to base estimates upon the present accumulation of ice over polar regions, if the quantity were at all definitely known. The uncertainty regarding the exact amount is so great, however, especially in arctic regions, that any such estimate will serve only as a check on that already made.

It may be almost arbitrarily assumed that, if the land ice existing on the zone bounded by the eightieth parallel were uniformly distributed, it would form a sheet fifty feet in thickness. Now too little aqueous vapor is conveyed into arctic regions to permit the accumulation of sufficient ice to form an effective condenser. It is probable that, in consequence of this imperfection

* This article is from Mr. McGee's paper on "Maximum Synchronous Glaciation," making 65 pages of the Proceedings of the American Association for the Advancement of Science, vol. xxix, 1880.

† This Journal, March, 1873.

of the arctic condensing apparatus, enough moisture is not congealed, but allowed to fall as rain and thus to melt a portion of the ice, to reduce the accumulation which should take place by fully two-thirds. Were it not for this the accumulation might reach 150 feet on an average, and 300 feet near the margin. The corresponding maximum thickness when the ice extended ten degrees farther from the pole would be about 400 feet. These estimates enable us to institute a comparison with the antarctic ice-sheet.

Only about one-seventh of the seventieth parallel of north latitude is so free from land as to present no obstruction to the carrying in of vapor from more southerly regions. In the southern hemisphere, on the other hand, the whole parallel is practically open to the introduction of vapor from the adjacent temperate zone. The accumulation here ought accordingly to be seven times as great as in arctic regions, or 2,800 feet near the margin. It will probably not be objected that these estimates are too low, as they have purposely been made as large as seems at all consistent with the present condition of polar regions. It has already been shown that the present accumulation in these regions is probably about as great as ever can have existed.

Accepting the largest of these estimates as representing the greatest possible thickness of the ice-cap at lat. 70°, and computing the thickness at other latitudes as in table XVII, the respective values are found to be as follows:—

Lat. 40°	14217	feet,	= 2·693	miles.
" 50	8213	"	= 1·555	"
" 60	5226	"	= ·990	"
" 70	2800	"	= ·530	"
" 80	1835	"	= ·348	"
" 90	1493	"	= ·283	"

The approximate correspondence between the two estimates is apparent.

Final estimate.—It may be assumed that, in a hemisphere with parallel isotherms and isobars, all vapor is precipitated nearer the poles than where it is formed. Two factors (perhaps unequal), tending to produce opposite results in the final computation, will be disregarded. These factors are (1) the elevation of temperature outside the ice-field illustrated by table VI, and (2) the less frequent saturation of the atmosphere in frigid climates. As shown by the tables of Section II, when the ice-sheet reached any latitude the vapor which had previously been borne polar-ward would be precipitated near the margin of the sheet, mainly in the form of snow. The precipitation would hence be greater than the normal, at the border of the ice, in the ratio of $p : p + \frac{po}{n}$, where p denotes normal precipitation, o

area of zone bounded by margin of ice, and n area of hemisphere. Table XVIII has been computed in accordance with this ratio.

TABLE XVIII.

Maximum thickness of Ice-cap.

Latitude.	Temperature. —Dove.	Vapor-tension.	Value of $p+\frac{p\,o}{n}$.	Thickness of Ice-cap. Feet.	Miles.
10°	+79·9° F.	1·020 in.	1·863	55,871	10·582
20	77·4	·940	1·559	46,753	8·855
30	69·8	·728	1·092	32,749	6·203
40	56·5	·457	·620	18,594	3·422
50	41·7	·264	·326	9,777	1·852
60	30·2	·168	·191	5,728	1·085
70	16·0	·090	·095	2,800	·530
80	6·8	·059	·060	1,799	·341
90	2·3	·048	·048	1,440	·273

It is almost needless to reiterate the proposition already demonstrated, that vapor could not be borne far enough within the margin of the ice to affect materially the above results, without seriously deranging the sequence of phenomena to which the ice owes its origin and conservation.

The suggestion that the property of flowing might enable the ice to assume a uniform depth may be anticipated by mentioning that the polar slope above given is less than one-tenth of that requisite, according to Hopkins's experiments, to produce the slightest motion.

2. COMPARISON WITH THE ICE-CAP THEORY.

Concomitants of the theory.—The ice-cap theory seems to have been framed chiefly to account for the equatorial motion of the Quaternary glaciers. Now, to be consistent with itself, the theory requires that the assumed thickness of the cap shall be sufficient to form a slope down which ice will flow by gravitation alone. Hopkins found that ice barely moves on a slope of one degree; and there is no evidence that existing glaciers move on a less slope. To form such a slope from lat. 40° to the pole, the polar thickness of the ice would have to be 60 miles—the "twenty leagues" of Adhemar. If, with the same mean thickness, it extended only to lat. 45°, the content of the cap would be 575,000,000 cubic miles, equal (the density of ice to water being as ·92 to 1) to 529,000,000 cubic miles of water. But taking the water-area of the globe at 145,000,000 square miles, and the mean depth at 12,144 feet, or 2·3 miles,* we find that

* Sir Wyville Thompson says: "It seems now to be thoroughly established by lines of trustworthy soundings which have been run in all directions, that the average depth of the ocean is a little over 2,000 fathoms." This Journal, vol. xvi, (1878), p. 351. Dr. Krümmel estimates the mean depth at 1877 fathoms. See note in Popular Science Monthly, vol. xvi, Dec. 1879, p. 287.

all the water of the globe amounts to only 335,500,000 cubic miles or but little more than three-fifths of that required to form the assumed ice-cap.

If the above estimate seems too large, let it be reduced by seven-eighths, which will bring it well within the bounds prescribed by more moderate advocates of the theory; but even then it is too large to be admissible; for it would require one-fifth of the water of the globe to form even the smaller ice-cap. But diminishing the water of the globe one-fifth would diminish the water-covered area by a considerably larger fraction; for the sea bottom does not descend uniformly to the deeper abysses. The slope is, usually, gentle for a considerable distance from the shore, and then steep and precipitous to the abyssal depths. Reducing the water one-fifth would therefore reduce the area covered by it one-third. Suppose now the ice-cap be around the south pole: The diminution caused by the removal of so much water, and the further diminution resulting from the displacement of the earth's center of gravity, would drain nearly all the water from the northern hemisphere. But the consequent stoppage of marine circulation and of the formation of aqueous vapor would, as shown in Section I, so increase the diurnal and annual thermometrical range as to render the hemisphere uninhabitable for existing organisms.

Relative mass of the two ice-caps.—Assuming the ice-field tabulated above to be of uniform thickness for five degrees on each side of the parallels given, and to extend to lat. 45°, its mean depth would be 1·356 miles. Its mass would therefore be only $\frac{1}{15}$ of the larger or little over $\frac{1}{2}$ of the smaller of the ice-caps considered in the preceding paragraphs. It should be borne in mind, too, that this is the *maximum synchronous accumulation* under more favorable conditions than would be likely to obtain in nature. The consequent displacement of the earth's center of gravity has accordingly not been computed.

Conclusion.—It seems quite safe to affirm that in any extensive polar ice-field the thickness will decrease from near the margin toward the pole, where the attenuation will be greatest. It may accordingly be concluded that a sufficient accumulation of polar ice to displace seriously the earth's center of gravity or influence the motion of middle-latitude glaciers, can never have taken place in this hemisphere.