the nicols, since the intermediate colors are elliptically polarized. Colors are white for thick plates and one may note in addition that $\mu_e - \mu_o$ and d are reciprocally related.

Interference. Diffraction.—For the case of two slits, real or virtual, at a distance c apart and r from the screen, if d is the distance of a lateral dark band from the central fringe for light of wave length λ, we may write

$$n = (2c/r) \cdot d/\lambda,$$

where odd numbers for n determine the position of the successive minima. Hence if the phase difference in which the rays meet $\phi = \pi n$ be introduced,

$$\phi = (2\pi c/r) \cdot d/\lambda$$

and the chart is applicable at once, with the understanding, however, that the dark horizontal bars now denote maxima, the dotted bars minima. This, however, is not necessary, for the bars may be moved up by inserting in one of the rays a thickness of lamina t of the refracted index μ (compensator) by the amount $2\pi(\mu - 1)t/\lambda$, until a minimum replaces the central maximum. The compensator thus has the same effect as the rotation of the nicols in the first paragraph. The chart shows the lateral extent of spectra of different orders very clearly, the first having a breadth of $d = 0$ the other breadths being proportional to the intercepts of the successive bars between the oblique lines blue and red. The overlapping of these spectra is also well shown. The spectra must be less spread out as the slopes $2\pi c/r\lambda$ are steeper. If the slit of the spectroscope be placed at a given distance, as at $d = a$, for instance, the vertical section indicates the channeled spectra which will be observed and the dark lines may be sharp enough to suffice the standardizing the spectrum.

With certain well-known changes the same remarks apply for most cases of the diffraction of white light.

Colors of Thin Films. Ordinary Light.—If d denote the thickness of the film or a given section of the wedge of refractive index μ, λ the wave length of light in air, r the angle of refraction corresponding to the angle of incidence i we may write

$$\phi = 2\pi\mu \cos r \cdot d/\lambda$$

where minima correspond to even numbers of π. Hence the positive field of the chart applies at once. The equation as written is primarily useful for the wedge. What the diagram points out very well is the resolution of doublets in the spectra of very high order. If the incidence is normal and the wedge be of air as in the interferometer $\phi = 2\pi d/\lambda$. If the thickness is constant and the angle of incidence varies the oblique lines are still applicable if instead of d the quantity cos r be laid off as the abscissa. They are real between $r = 0$ and the angle of total reflection.

In practice the oblique lines may be drawn to the scale on a sheet of paper, the black bars on a sheet of celluloid capable of sliding up and down over the former and the vertical lines may be represented by threads movable to right and left over the celluloid. The whole is to be serviceably framed on a sheet of tin plate.

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The Causes of the Glacial Epoch[1]

Of the various hypotheses advanced to account for the occurrence of a protracted glaciation of a large portion of the earth's surface in post-tertiary times, none has thus far met with universal acceptance; partly because of the insufficiency of data regarding critical geographical areas, but mainly because of the feeling that although the causes discussed by Croll, Chamberlin and others are or may be true ones, they are inadequate to account, quantitatively, for all the facts observed. The paleontological evidence of the prevalence of temperate and even semi-tropic floras and faunas in the late Tertiaries within what are now arctic regions, gives such forcible evidence of the comparative uniformity of tem-

[1] Read at tenth session of the International Geological Congress, Mexico, September 6–14, 1906.

perature prevailing even in late preglacial times all over the globe, that we instinctively seek for some more cogent cause of the widespread glacial phenomena that followed so closely upon the periods of greatest mountain-making recorded in geological history.

It is not the purpose of this paper to discuss the glacial theories alluded to above in detail, that having been done by many able writers; but rather to call pointed attention to another hypothesis now before the scientific world for a number of years, and which seems to me to offer a complete solution of the problem, provided it can pass the criticism of physicists; for from the geological point of view it seems to suffer no valid[2] objections.

[2] While it is evident that extended glaciation existed in the Permian era, the claim that it was as extensive and continuous as the Pleistocene glaciation does not seem to me to be well established. The Permian having been, as is strongly emphasized in Chamberlin and Salisbury's 'Handbook of Geology,' a time of extended deformation of the earth's crust, to which the deflection of ocean currents, causing glacial conditions, is ascribed by them, it seems quite reasonable to suppose that such deformations extended to the upraising of large areas, together with orogenic uplifts, of which no evidence now remains except the seaward borders of the glaciated areas, with their till and roches moutonnées, such as we now see at the foot of glaciers. It is pertinent to inquire, in this connection, by what imaginable changes in land areas and ocean currents the north and south polar regions could *at this time* remain deglaciated and made to grow magnolias, figs and the like. The Arctic Ocean is now substantially closed to equatorial currents; the Antarctic is wide open; yet both are glaciated. What intermediate arrangement could give either or both a temperate climate, with or without more, or less, carbon dioxid?

The claim that aridity is shown by the prevalence of evaporation-deposits of rock-salt and gypsum, is hardly tenable alongside of that made for glaciation. The low temperature and abundant moisture required for glaciation do not seem compatible with arid heat. Evaporation due to currents of undersaturated air, such as always characterizes descending air currents, is very effective; and the arid conditions would hardly be expected to extend as far north as Stassfurt.

This hypothesis or theory (for it seems rather to deserve the latter name from its comprehensiveness) first brought forward by Dr. Marsden Manson in 1891, has until lately suffered the initial fate of many others now generally accepted, viz., that of being 'todtgeschwiegen' at first, as being too much opposed to some generally accepted, but by no means proved dicta regarding earth-heat, and especially the time-limit of its influence upon terrestrial surface-temperatures. Physicists at one time claimed that the globe as a whole is more rigid than steel, since it must otherwise suffer sensible tidal deformation; but were met by the ocular proof, known to every geologist, that so far from being even moderately rigid, the crust as known to us is a mere congeries of fragments in unstable equilibrium and in more or less constant movement for readjustment.[3] We are now told that the transmission of earth-heat to the surface must have ceased in early geological time, because of the low conductivity of the rocks known to us. But the enormous effusions of molten rock even in late Tertiary times, followed by manifestations of vulcanism which, though now apparently in course of extinction, proves the continued existence of high temperatures not far below the surface crust, again invalidates the physicists' objection, because based on the arbitrary assumption that conduction was the main or only manner in which the interior heat could reach the surface.

It is evident that whatever may have been the original source of that heat, whether from cosmic contraction or planetesimal collision, it has existed and exists now, even though practically insensible at the earth's surface. Even if, as some believe, to-day's vulcanism were only 'skin-deep,' the evidence of former much greater heat is too strong to be set aside. That this heat must have been brought up from the depths of the earth-mass by water, aqueous vapor and other gases, as is now the case in volcanic eruptions, and is also being done by

[3] See, for the latest discussion of this subject, the paper on 'The Geodetic Evidence of Isostasy,' etc., read before the Washington Academy of Sciences by John F. Hayford, May 18, 1906.

geysers, can not be questioned. Whatever part chemical action, the friction or collisions connected with faults, or that accompanying flexures of strata may have in generating heat, that heat-generation must have been much more active in times of higher original temperatures and active mountain-making. It seems as though, despite all contrary suggestions thus far made, a higher temperature at the earth's surface than exists at present, within the geological ages covered by the warm-temperate flora and fauna found also in the arctic regions, may fairly be presumed on physico-geological grounds alone. This reasonable assumption forms the basis of Manson's theory of the ice age.

It can not be doubtful that during any highly heated condition of the globe, of whatever origin, the bulk of the water now gathered in seas, lakes and rivers existed in the form of vapor, which as it ascended was condensed into a mass of clouds forming a thick spheroidal envelope all around. On the outside, upper surface of this cloud-sphere the sun exerted substantially the same zonal effects as it now does upon the earth's surface, modified mainly by the uniformity of the physical nature of the cloud-surface, as against the alternation of sea and land as they now exist, and which by their differences in the absorption and radiation of heat, in heat capacity, and in topographic features, modify profoundly the typical, regular zonal order of climates. The tropical belt with its strong ascending currents, low barometer, and high temperatures; the two adjoining arid belts with descending currents and high barometer, and the temperate zones to poleward of the same, with variable but generally low barometer, would be defined on the cloud-spheroid as they are now on the earth's surface, but with greater regularity, though perhaps less sharply. It is also clear that, though not directly influencing the temperature of the earth's surface, the solar radiation would act powerfully as a conservator of earth-heat, compensating to some extent the radiation into space from the cloud-surface, of the heat carried up by convection currents.

The general disposition of the rain-belts would also be substantially as it is now, but the amounts of rainfall would, in so thick a cloud-cover, undoubtedly be greater than at present. The isothermal spheroids or shells corresponding to our present temperatures would at first be at heights more considerable than at present; but as the heat carried up from the earth's surface was more and more lost by radiation into space from the exterior cloud-surface, the isothermal shells would gradually descend, and the temperature of the falling rains would become lower, so as under favorable conditions to fall as snow. It is clear that snowfall might occur at any period of the earth's evolution on high mountain ranges or plateaus, and there the accumulation of snow might at any period have formed nevees and glaciers with their well-known effects. The earlier glaciations observed, especially in the Permian, are, therefore, quite compatible with Manson's theory. Elevation as a cause of glaciation must, however, be accompanied by its necessary correlative factor, an abundant rainfall; a point frequently left out of consideration in this connection. Labrador is a conspicuous example of non-glaciation from low precipitation.

Owing to the higher radiating power of the earth-surface as compared with the ocean, as well as to its much lower specific heat, the earth must have cooled more rapidly than the oceans by radiation alone. In addition to this, the water flowing from it into the seas would carry off a large amount of heat. Even while the ocean still received heat from its bed, the land areas would be a cooling agency especially for the ocean depths, while the warm oceanic surface waters would be supplying abundant vapor for precipitation on the relatively colder land areas. The latter would finally fall to so low a temperature as to receive their precipitation in the form of snow, thus inaugurating the glacial period, during which the isothermal shell of say the freezing-point of water, and below, descended near to the earth's surface. As the ocean gradually also cooled and evaporation diminished, the protecting cloud-envelope became thinner, first in the tropics and the flanking belts of lesser

rainfall (which later became the arid belts); and thus gradually the zonal solar régime was established.

Such are main features of Manson's theory, the details of which have been elaborated in his published treatise on the evolution of climates and other papers, and the substance of which will be presented to this body by the author himself. In my view it is not a conception to be lightly set aside, for whatever evidences of former glaciations may have been observed, there has not appeared in former geologic history anything resembling in magnitude the pleistocene glaciation, the scattered remnants of which are even now in gradual retreat under our eyes. The observed evidences of glaciation in former geologic ages do not appear to be of such extent, or to be accompanied by detrital deposits indicating a continental extent of glaciation; they are apparently such as might be produced at any time by either the upthrusting of mountain chains, or by wider, epeirogenic elevations of the surface. Thus far, it seems as though there had been but one distinctively glacial epoch of world-wide importance and extent; and that nearly contemporaneous with the appearance of man upon earth.

It has been asked how the early floras and faunas could have existed and developed under the perpetual cloud assumed by Manson's theory to have covered the earth prior to the establishment of the solar climate, toward the end of the glacial period. In answer to this it may be suggested, apart from the fact that even at the present time the average cloudiness of the sky is estimated at 60 per cent., that the earlier floras consisted almost exclusively of plants whose analogues or evolutional successors, such as ferns and horse-tail rushes, vegetate preferably in dense shade, even in cloudy climates; and the extreme succulence of the carboniferous flora is sometimes approached when in certain climates, under unusally rainy seasons, such plants grow to maturity almost without a ray of sunshine. The plants growing under the canopy of primæval forests, in perpetual twilight, show how easily vegetation adapts itself to such conditions. In later periods, as the cloud-envelope brightened, the higher orders of plants, now preferably basking in sunshine, had opportunity to develop to their present prominence. But it is notable that the present forms of peculiarly arid-region plants, which are specially adapted to hot sunshine and dry air, are absent from any of the fossil forms thus far reported. They clearly had no *raison d'être* until the cloud-veil was dissipated by the sun.[4]

There seems to be as little difficulty in assuming the animal creation to have been tolerant of, or adapted to, a sunless existence. Not to speak of our present nocturnal and deep-sea faunas, the adaptability of the pupil of the eye now existing provides all needful conditions so far as vision is concerned; and the great wide-open orbs of the ichthyosaurs suggest ready adaptation to dark days. Here

[4] Chamberlin (SCIENCE, October 26, 1906) claims that the existence of palisade cells in plants of paleozoic age proves the existence of arid-region plants at that time. But palisade cells as such depend much less upon climatic factors than upon leaf-texture and botanical relationship. It is only the presence of *several* tiers of such cells beneath the epidermis of the upper leaf-surface that constitutes such presumptive proof; witness the existence of abundant palisade cells in firm-leaved ferns that are at home in the deepest shade, right alongside of others which show no such tissue; as well as the abundant palisade tissue in the leaves of the shade-loving Pyrolaceæ and other ericaceous plants, of *Vinca minor*, *Myosotis palustris* and thousands of other shade plants. Moreover, *saline* soils cause xerophytic structure and growth; which, therefore, should not surprise us if found in coal plants. The very generally clayey (fire-clay) nature of the substrata of coal beds plainly suggest that the coal-forming flora was one of *swamp* plants, and not xerophytic or even upland, as suggested by Chamberlin. So far as I am aware, no plants showing the well-known extreme provisions against drying-out, such as we find in the cactus and others, have been found among the fossils of even the late Tertiary. On the other hand, the fauna of the Permian, belonging chiefly to the Brachiopod and Cephalopod orders, indicates a warm temperate or tropical, not a frigid temperature of the seas, such as is shown by the marine fauna of the Pleistocene glacial epoch.

as in the case of plants, the organisms specially adapted to continual sunshine—the desert fauna—seem to be absent from prepleistocene deposits. Horned toads, Gila monsters and animals of similar habits were not then in evidence, so far as the writer is aware.

In any case, the postulates for a sunless existence of prepleistocene beings are not greater, if as great, as those involved in Chamberlin's hypothesis of a materially greater, or less, content of carbonic dioxid in the atmosphere.

It does seem to the writer that unless it can be shown that the temperature prevailing at the beginning of the glacial epoch could not have been high enough to maintain a cloud envelope, Manson's theory as outlined above must be considered the most probable among those that have heretofore been suggested, as fulfilling both qualitatively and quantitatively the postulates of the great ice age; not excluding, of course, the probable influence of the agencies claimed by Arrhenius and Chamberlin as the chief ones, but which appear to the writer to be inadequate to account for the phenomena in actual evidence.

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January, 1907

CURRENT NOTES ON METEOROLOGY

WINDS ON THE PEAK OF TENERIFFE

The controversy regarding the direction of the upper winds in the vicinity of the Cape Verde and Canary Islands has prompted Hann to bring together (*Met. Zeitschr.*, Dec., 1906) the published observations of wind direction on the summit of the Peak of Teneriffe (Lat. 28° 49′ N.; Long. 16° W., altitude 12,172 feet). The conclusion is as follows: the S. W. and W. wind which is very often observed above 3,000 meters, even in summer, is certainly not a local wind, but belongs to the upper members of the general atmospheric circulation. The N. E. trade occasionally blows on the top of the peak, at least in summer. The mean direction of cirrus clouds in winter is W. by S. The N. W. winds observed by Hergesell in summer in the vicinity of the Canary Islands were probably connected with the then location of the subtropical high-pressure area of the North Atlantic Ocean. The map of isobars at 4,000 meters (Teisserenc de Bort) shows, in July, the center of the maximum somewhat N. W. of the Canaries, so that northerly winds at 4 km. above sea-level would not be contradictory to the pressure distribution. According to the interesting observations of temperature and humidity made by Hergesell in the free air above the anticyclone, the latter may extend to greater altitudes than has thus far been assumed. More constant equatorial currents are to be expected over the West Indies and Central America in the same latitudes.

CLIMATOLOGY OF THE UNITED STATES

'The Climatology of the United States,' by Professor A. J. Henry (Bull. Q, U. S. Weather Bureau, 4to, 1906, pp. 1012, Pls. 34, Figs. 7), is one of the most important publications of our Weather Bureau. The need of a compact summary of the essential climatological data for the United States has long been felt. Hitherto these tabulations have been scattered through various annual reports of the chief of the Weather Bureau. Since Loren Blodget's famous classic, 'The Climatology of the United States' (1857) there has been no attempt to collect into one volume, and to discuss, the mass of climatological material collected by our official and voluntary observers. The data in this volume cover, generally speaking, the period 1870–1893. There is a discussion, satisfactory on the whole, of the climates of the United States in general (84 pages), illustrated by a considerable number of maps. This is the portion of the book which will be most generally used, and it will serve its purpose well. A long series of tables follows, in such form that they can easily be referred to by those who wish detailed information. At the end, occupying the larger part of the volume, come condensed summaries for the different states. The advertised price of the book is $10, which is much too high if the volume is to find its way