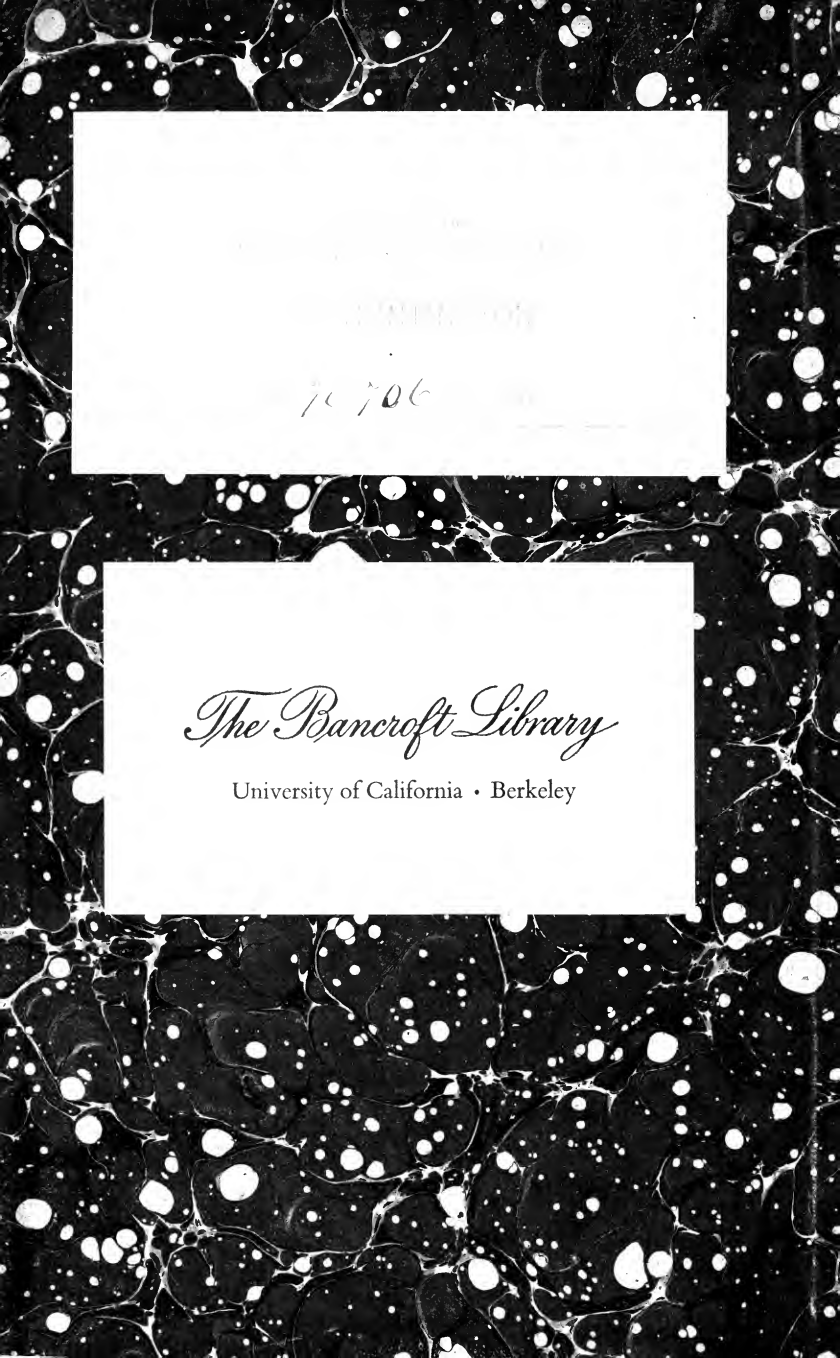

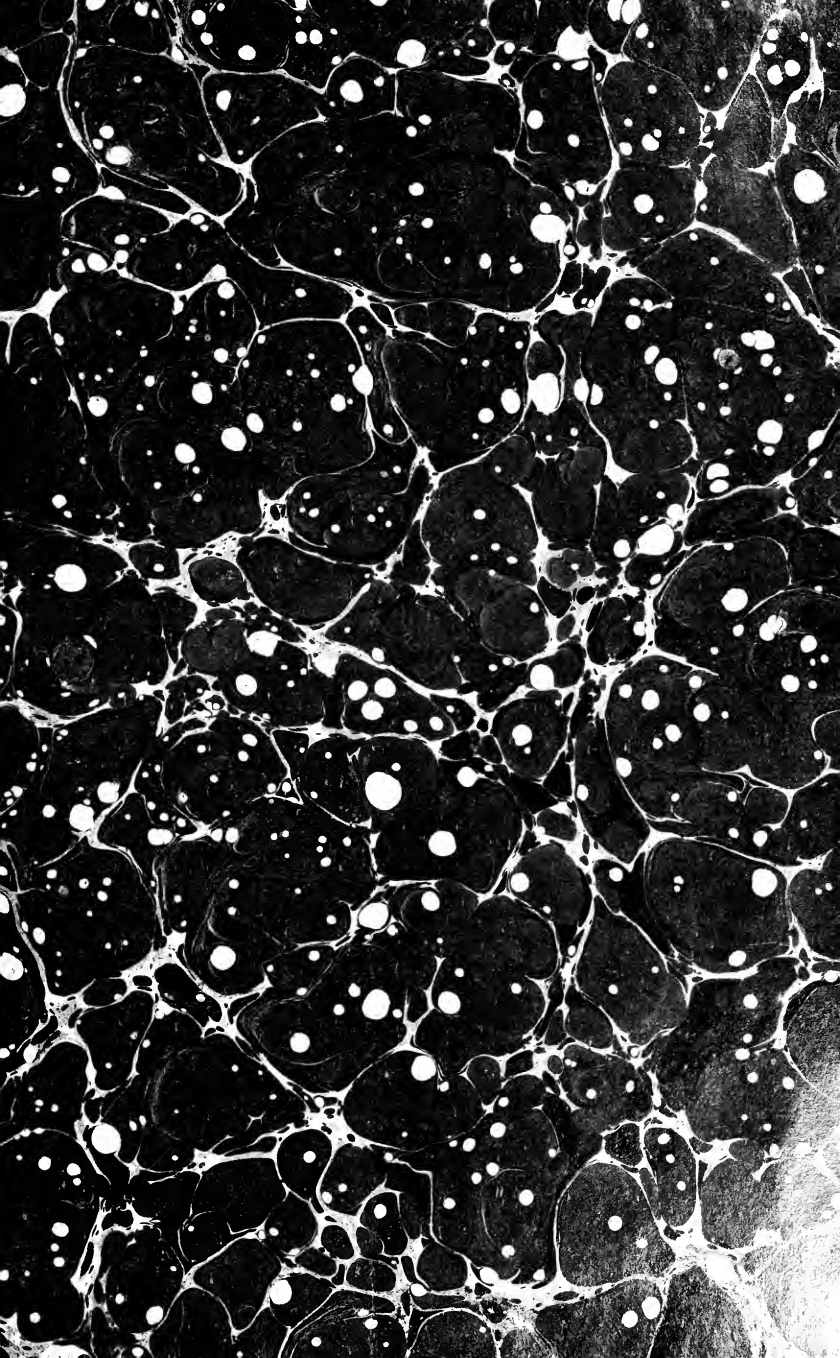

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GEOLOGICAL SECTION.

THE LAWS

OF

CLIMATIC EVOLUTION.

BY

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THE
LAWS OF CLIMATIC EVOLUTION.

The objects of this paper are, to formulate the laws of climatic evolution, and to show:

1. That in consequence of these laws a hot spheroid, holding water and air, or fluids of similar properties within the sphere of its control, and revolving about a source of solar energy, will be subjected to a series of uniform climates, gradually decreasing in temperature, and terminating in an Ice Age; that this age will be succeeded by a zonal distribution of climates, which, within certain limits, gradually increase in temperature and extent.

2. That the difficulties met in the attempts to interpret present, glacial and pre-glacial climates have been due, in part, to a failure to give due weight to certain of these laws, and to recognize the force of others.

In attempting to trace the history of the earth back into the infinite past, the first step brings us in contact with the question: What was the cause of the Ice Age? Before going farther it might be well to glance at the theories which have been put forward to account for this age, and to briefly consider the present position of the scientific world as regards this first step in the problem. It is not necessary to review all the theories which have been urged.* The principal ones only will be mentioned in two classes. Class I embraces those

*See The Climatic Controversy, S. V. Wood, Jr., Geol. Mag., 1876 and 1883.

Report British Assn., 1892, p. 708.

The Great Ice Age, Ed. 1894, Chap. IV, Dr. Prof. Geikie.

which require an Ice Age, single in its occurrence and unique in the climatic history of the earth. The theories of this class proved unsatisfactory, and failed to fully explain the admitted facts of Geology. This failure, in a measure, warranted a resort to the ingenious theories of Class II; which theories require a recurrence of glacial epochs. The lack of evidence of such recurrence has prevented the theories of this class from being generally accepted.

Class I.—(1) A decrease in the original heat of the earth.

(2) Changes in the elevation of the land areas, and consequent variations in the distribution of land and water.

(3) A period of greater moisture in the atmosphere.

Class II.—(4) Changes in the obliquity of the axis of the earth.

(5) A coincidence of an Aphelion winter with a period of maximum eccentricity of the orbit of the earth.

(6) A combination of (2) and (5).

These have been frequently reviewed by various authorities. The general conclusions reached may be summed up in the following opinions:

Referring particularly to the first cause of the series, and probably the oldest, Prof. Jas. D. Whitney says:

"It is evident that the idea of connecting the phenomena of the internal heat of the globe with terrestrial climates, whether of the present or of past geological ages, must be entirely abandoned, as it has been by most writers on this subject. The hypothesis can not be allowed to stand as even one of the possible theories of climatic change. (The Climatic Changes of Later Geological Times, page 261. See also LeConte, Elements of

Geology, 3rd Ed., page 381. Shaler and Davis, Glaciers, page 70.)

After an exhaustive study and review of all the principal theories, Dr. James Geikie says:

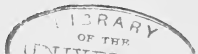
"The primary cause of these remarkable changes is an extremely perplexing question, and it must be confessed that a complete solution of the problem has not been found. Croll's Theory has undoubtedly thrown a flood of light upon our difficulties and it may be that some modifications of his views will eventually clear up the mystery. But for the present, we must be content to work and wait." (The Great Ice Age, 3rd Edition, 1894, page 816.)

After reviewing the principal theories as to the cause of the Ice Age, Dr. Jos. LeConte remarks of Dr. Wallace's modification of Croll's Theory (6) "This seems to be by far the most probable yet presented." (Elements of Geology, 2nd Edition, page 578.)

After a similar review, Dr. T. G. Bonney says:

"It follows from what has been said above that the low temperature which undoubtedly prevailed during the Glacial Epoch has not yet received any satisfactory explanation. Each one that has been proposed is either inadequate or is attended by grave difficulties. It is therefore probable that some factor which is essential for the complete solution of the problem is as yet undiscovered, or at any rate, the importance of one which is already known has not been duly recognized." (Ice Work, Present and Past, p. 260.)

It is generally admitted, therefore, that no satisfactory solution is offered for the problem before us, and that the most distinguished scientists who have investigated the subject have no considerable number of followers, that equally distinguished co-workers accept in part only,



or reject entirely the conclusions reached by their fellows.

The causes which have produced and are yet influencing the climatic evolution of our planet are so fundamental and far-reaching in their consequences that a failure to explain these causes and their mode of action constitutes a serious defect in those branches of science to which a study of these causes appertains. In the present stage of Physical Geography and Geology, the student is offered a mass of facts interpreted along various lines, each interpretation disputed by high authorities, and finally the results are summed up in the broad conclusion that "we must be content to work and wait."

SCOPE OF THE PROBLEM.

The problem of explaining this succession of climatic variations is so attractive that there is perhaps none other to which deeper thought has been directed, nor upon which such diverse views are held. In its entirety it constitutes one of the most far-reaching and grandest problems of terrestrial physics. Nor is the scope of this problem bounded by its relations to the earth. The principles and laws involved in its solution must be general.

The development now reached by each one of the planets can not be the same, and we find each in that particular phase which its mass, environment, and exposure have permitted it to reach. When we trace the climatic history of the earth backward, the line of research must lead into conditions now apparently existing upon planets in a less advanced stage. If we can predicate the conditions towards which present climatic developments are tending, these must be the apparent conditions of a more advanced planet. Thus the stages

of climatic development reached by other planets should afford evidence as to the accuracy of our interpretations. In other words, the past and future stages of the earth's climatic development must be represented in a general way by the various stages now attained by one or the other of the planets of the Solar System.

THE LAWS OF CLIMATIC EVOLUTION.

The principal laws of climatic evolution are presented in the form of a series of postulates and corollaries.

(1) Heat rays can not pass through fogs and clouds, formed of the vapors of a fluid having the physical properties of water, except in very greatly diminished intensity.*

(2) A hot spheroid rotating in space and holding water and air (or fluids of similar properties) within the sphere of its control, gives off and receives heat subject to its passage through clouds. The spheroid must lose heat principally by the expansion of water into vapor and by radiation from the cool outer surface of its cloud envelope, which envelope is maintained by the evaporation of water by the heat of the spheroid, and conserved by heat reaching it from exterior sources; during its existence it acts as a conservator of the heat of the spheroid.

(3) That in the stages of cooling subsequent to the formation of oceans, land surfaces must, by reason of their low specific heat, cool faster than oceans; and that heat reaching the planetary surface by the circulation of meteoric or included water or by convection, or set

*Maury—Physical Geography of the Sea, 6th Ed., p. 212 *et seq.*
Croll—Climate and Time, p. 60.
Climate and Cosmology, p. 51.
Geikie, J.—The Great Ice Age, pp. 800–801.

free by denudations, faults and fractures, is principally taken up by water in its fluid and vaporous form, and conserved by water in the form of clouds.

(4) The surface temperatures of such a spheroid must be practically independent of exterior sources of heat until the greater portion of the water surrounding it be reduced to its point of maximum density or converted into ice, and that prior to this stage of its climatic evolution, its surface temperatures are practically controlled by interior (or planetary) heat, and are practically independent of latitude; and are therefore independent of the temperature to which the outer surface of the cloud sphere may be exposed. The effect of variations in exterior heat being mainly to increase or decrease the duration of the interior supply, and to expand or contract the sphere of cloud condensation. The principal function of exterior heat, prior to the chilling of the oceans, being conservative or to replace in part the heat lost by radiation from the cold outer surface of the cloud sphere.

(5) That until the exhaustion of the available internal heat supply, outside of a crust of low conductive power, the surface temperatures of the spheroid must be nearly uniform from pole to pole, varying only with elevation above sea level, or from local causes, such as the influence of lava outbursts upon the areas to the leeward of such outbursts. And that a series of uniform climates must prevail independent of latitude, and gradually decreasing in temperature as the spheroid loses heat.

(6) That the low specific heat of land areas permits them to cool more rapidly and to reach glacial temperatures before the oceans are reduced approximately to the point of maximum density, and consequently that snow

must accumulate upon these areas until the oceans cease to give off sufficient vapor to shield the earth from solar energy. That these accumulations of snow must reach their maxima along belts of maximum precipitation, and must be independent of latitude.

(7) That upon the chilling of the oceans, the supply of vapor maintaining the cloud envelope is cut off, and the atmosphere deprived of the greater portion of its heat intercepting power; and that heat rays from exterior sources then reach the planetary surface in sufficient quantity to dominate its climates. That a new distribution of temperatures is thereby inaugurated dependent principally upon latitude or exposure to exterior sources, and modified by elevation and local causes.

(8) That solar rays by contact with the planetary surface are partly converted into dark or obscure rays and are trapped,* or are selectively absorbed.† That a gradual accession of heat must be thereby inaugurated, resulting in the removal of glacial conditions, and that such removal of glacial conditions must be on lines determined by the degree of exposure to solar energy, and by the susceptibility of the different portions of the globe to be influenced by such exposure. That these new conditions must inaugurate a new distribution of temperatures ranged in zones and subject to solar control.

The necessary corollaries of these postulates are:

(a) That a planet having water and air within the sphere of its control, and which has not yet exhausted its internal heat, must be densely shrouded in clouds whose outer surface presents a high albedo.

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*Tyndall—Proc. Royal Soc., Vol. XIII, p. 160 Phil. Trans., Vol. 152, p. 95. Archives des Sciences, tom. V., p. 293.

†Langley—Investigations on the Action of the Atmosphere on Solar Radiation. Mem. Nat. Academy of Sciences, 1885-7.

Buff—Archives des Sciences, tom. LVII, p. 293.

(b) That a planet whose internal heat has been practically exhausted, and which holds water and an atmosphere within the sphere of its control must reflect solar energy deficient in those rays which are most readily trapped, or selectively absorbed by its atmosphere, and it must have a low albedo, and that the color of its reflected rays must be controlled by those least readily utilized and trapped.

(c) That glacial conditions may exist locally during any period of a planet's climatic evolution provided there be regions sufficiently elevated; but that an Ice Age occurs as its oceans are finally exhausted of their available remnant of planetary heat, that this age marks the period during which surface temperatures pass from interior to exterior control, or is the transition period of its climatic evolution, and is unique.

(d) There are two great eras in the climatic evolution of a planet: 1st, the era during which its internal heat controls its surface temperatures, and solar heat acts principally as a conservator of interior heat; 2nd, the era of solar control of climates. The former being an era of gradually decreasing temperatures, of uniform distribution at sea level; and the latter an era of gradually rising temperatures of a zonal distribution. The two eras, so far as land areas are concerned, must be separated by an Ice Age. The difference in the specific heat of land, and that of water, permits the land areas to cool first. The precipitation of snow upon them must therefore have been cumulative, until the oceans were reduced to about the point of maximum density.

It is reasonably certain that glacial conditions were first removed from equatorial regions, and that maximum glaciation of land areas in temperate latitudes may have occurred subsequent to the inauguration of solar

control over equatorial latitudes, and that polar glaciations may have reached their maximum at a period subsequent to the commencement of the disappearance of glaciations in temperate latitudes.

(e) The accession of solar heat by the trapping process being the result of a positive difference between the rate of receipt and the rate of loss, and not being a function of the orbital distance, a rise in temperature may as certainly follow in one position as another.

(f) That glacial conditions although imposed upon lines independent of solar exposure, must have reached their maximum upon areas subject to maximum precipitation, and as the movement of the atmosphere in temperate latitudes is towards the east, the west coasts of continents are more exposed to moist winds and hence were more deeply glaciated than the east coasts. The narrow North American continent was thus more exposed to glaciation from the wide Pacific, than was the broad Euroasian continent from the narrow Atlantic.

(g) That the northern hemisphere of low specific heat has progressed further in climatic development than has the southern hemisphere of high specific heat. Similarly, the Atlantic has been warmed to a greater extent than the Pacific.*

*It will probably be noted that no mention is made of light rays; these can be filtered out by clouds and pass through in greatly diminished intensity. It is not considered necessary to discuss their influence at this point, as their effect is slight at temperature approximating the freezing point. The gradual development of visual organs and the development of all other senses prior to that of sight are lines of investigation which the author has not been permitted to make for want of time and means.

BRIEF REVIEW OF PAST CLIMATIC CONDITIONS.

THE EVIDENCE OF RISING TEMPERATURES SINCE THE ICE AGE.

The elementary laws of climatic evolution having been briefly deduced and formulated, it may be necessary to revert to the geological record of past climatic conditions, and to note whether they agree with these laws.

Commencing at sea level near the polar circles, at an elevation of a few thousand feet above this level in temperate latitudes, and at a still greater elevation in tropical latitudes glacial ice is found to rest upon the land. Adjacent to this ice are found evidences of previous extension. It matters not whether the glacier be the dwarfed remnant left on the summit of the mountains of tropical Africa* or South Ameria† or the great glaciers of Alaska or Greenland,‡ once greater extension is a characteristic and general fact noted by all observers.

The evidences of this retreat near the base of the glacier is not disputed. But as the distance from the living glacier increases the evidence of ice action becomes fainter; the traces of this action are more modified by decomposition and denudation and more deeply covered with vegetable mould, as we recede either in altitude or latitude from the living glacier. Nowhere is this better marked than at uniform levels above the

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* Mt. Kenia Quart. Jour. Geol. Soc., Vol. LI, No. 204, pp. 675–6. G. F. Scott Elliott.

† Travels among the Great Andes of the Equator, p. 62. Note. Wymper.

‡ The Glaciers of North America, Prof. I. C. Russell. See also authorities quoted by Prof. R.

Report on an Exploration in the Yukon District of the N. W. Territory. Part B, Annual Rep. 1887, pp. 51–58, Geol. and Nat. History of Canada.

Am. Geologist, Vol. XIX, No. 4, p. 263.

Am. Geologist, Vol. XX, pp. 329–330.

sea on the west coast of North America. Here in latitude 40 to 45 degrees, the geologist finds types of topography built up or shaped by ice action, yet so modified and buried beneath successive growths of conifers that only the trained eye of the close observer can follow the forms and features. In the next few degrees northward, the work of the glacier is less modified and hence more distinct. Great forests tower over and grow upon successive generations of fallen trees, which rest upon glacial débris. Still further north, and at the same general elevations above the sea, these forests grow upon a thinner layer of dead and rotting trunks and the humus is less thick. Still more northward yet, these forest trees are found in the prime and vigor of full growth—no aged and fallen trunks encumber the ground, the roots of the living trees are buried in the gravelly, rocky soil of moraines and a thin layer of decomposing vegetable matter covers the ground. Where there is no morainic material, the thin soil gives scant roothold, and an upturned root sometimes uncovers fresh glacial scratches. From commanding positions, the glittering glacier can be seen, and as he nears its front, the observer is forced to note that the forests are of young and half grown trees, then saplings and finally the very seedlings sprout from the freshly uncovered gravel of the matchless glaciers of British Columbia and Alaska.

Now and then these young forests are uprooted and plowed under by a temporary advance of the glacier, and its gradual retreat will sometimes reveal the crushed roots and trunks of a previous advance. But the integral of successive retreats is greater than the integral of successive advances, and the forest has for thousands of years kept an accurate record of the fact, although successive generations of dead trunks, whose decay has

been retarded by the moist climate of the locality, have been necessary to keep the records. In making the observations one has to traverse twenty degrees of latitude, but the observations are only typical of what can be observed in a few thousand feet of elevation upon the slopes of Mt. Kenia, the Equadorian Andes, or other glacier-crowned peak of any latitude. Above the timber line, the physical evidences of glacial retreat present the same gradations of distinctness as we recede from the active glacier.

The fact that the evidence of glacial retreat grows progressively fainter as we recede from the living glacier, either in latitude or elevation, marks a progressive retreat from the equator polewards and from sea level upwards; since it is progressive it must be accounted for by progressive laws now active, and suppositions of upheaval and depression and other hypotheses are not necessary. The areas over which the ice invasions once extended may and probably will be wrangled over for generations to come, but no Geologist nor Physicist, who will take the trouble to observe a single glacier and to read what others have recorded, can dispute nor deny the fact that glacial extension has within a comparatively recent period been vastly more extensive at all latitudes than it is at present, and that successive retreat has been a marked characteristic of glacial conditions during the present era of geological time. The fact that glacial conditions are giving place to milder temperatures is recorded in all latitudes, and wherever glacial ice yet rests this record, although a slightly fluctuating one, is being legibly inscribed. The bare citation of the facts establishes the interpretation that solar energy is rewarming our planet after the chill of the Ice Age—that the mean tempera-

tures of the climatic zones now belting the earth have risen since that Age, and that this rise is yet in progress.

THE WIDESPREAD TEMPERATE CONDITION OF THE TERTIARY.

Throughout the whole of the northern hemisphere which has been reached by geologists, fossil fauna and flora have been found which establish the fact that during the tertiary warm temperate conditions prevailed. During the middle tertiary, palms flourished well within the Arctic Zone.* Buried in bogs and mingled with gravel and boulders the bones of gigantic mammals are found in tropical Brazil.† These gigantic mammals and other types of life correspond with those found in Alaska, or in Patagonia; tertiary life in Siberia records the same temperatures as that on the shores of the Mediterranean, so that from nearly one polar circle to the other, we are called upon to note, not only a once greater glacial extension, but also a preceding temperate age. The evidence of the existence of the one is no less conclusive than that of the existence of the other. Evidence of the temperate age everywhere precedes the evidence of the Ice Age. In some regions the Ice Age yet exists, but beneath the ice is found evidence which establishes the prior existence of milder climates.‡

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*Heer. Miocene Flora of North Greenland. Brit. Ass'n. Rept., 1886. Brit. Ass'n. Rept. 1870, p. 88.

†Branner. The Journal of Geology, Vol. 1, No. 8, p. 767. The peculiar distribution of boulders and gravel is ascribed by Dr. Branner to wave action, and to a reversion of the order of upheavals and depressions appealed to by others to account for the Ice Age. The distribution of drift, as described by Dr. B., is that which Sir H. H. Howarth considers necessary to prove the glaciation of the Amazon Valley. The Glacial Nightmare and The Flood, Vol. II, p. 495. London, 1893.

‡Am. Geologist, Vol. XX, pp. 343-4.

THE TROPICAL CONDITIONS OF THE MESOZOIC AND PALAEOZOIC AGES.

During the Jurasic ammonites flourished well up to the polar circles, and how much further geological research has not yet been able to determine. It would be useless to recite to the youngest students in geology the facts which could be massed to prove the universal distribution of the tropical flora and fauna of the Mesozoic and Palaeozoic Ages.* The manuals and textbooks of geology are overburdened with illustrations. That an age of tropical climates existed prior to the temperate age may be considered a geological fact, as it is universally taught in the textbooks of geology.

Underneath the strata of these ages lie those of the previous Cambrian and Laurentian Ages, whose structure and fossils likewise mark a widespread torrid climate. Beneath these in turn are the enormously thick rocks of pre-Cambrian and Azoic Ages, beyond which lie the ages preceding those of geology and reaching into the domain of cosmology. We are taught alike in the textbooks of the common schools† and in the profound treatises of Geologists and Phycists‡ that during these ages the Earth "was a melted fiery ball surrounded by a thick atmosphere of gases and vapors." Of this stage of the Earth's climatic development, Sir A. Geikie says: "At an early period of the Earth's history, the water now forming the ocean, together with the rivers, lakes and snowfields of the land, existed as vapor, in which were mingled many other gases and vapors, the whole

*Manual of Geology, Dana, 4th Ed., p. 711 and p. 574.

†Textbook of Geology, Sir A. Geikie, London, 1882.

‡Warren's New Physical Geography, p. 11, edited by Dr. Wm. H. Brewer of Yale. See also Essays, p. 40, Prof. S. T. Hunt.

forming a vast atmosphere surrounding the still intensely hot globe."*

STAGES OF CLIMATIC EVOLUTION.

Various stages of climatic evolution are apparently represented in the conditions of the planets Jupiter, the Earth, and Mars. The former is of great size, and is apparently shrouded in dense clouds, and appears to be in the first era of climatic evolution. The cloud sphere presents a surface of high albedo, and the heat from it is of about that intensity which we should receive by the reflection of solar energy.†

The Earth, a much smaller mass, has passed through the first era of climatic evolution, and has reached the earlier epoch of the second era; during this epoch glacial conditions are being removed and surface temperatures are slowly rising. Since the rays of the violet end of the spectrum are most easily trapped, the Earth must reflect light in which red rays predominate, and it has a low albedo.

Mars, smaller and more distant from the sun than the Earth, has apparently reached a still further stage of climatic evolution. Polar snow caps form in winter and melt off in summer,‡ thus indicating milder polar conditions than prevail within our polar circles. The albedo of Mars is low, and solar energy reflected from its surface is deficient in violet rays, thus showing that the atmosphere of Mars, like that of the Earth, most readily traps the rays of the violet end of the spectrum. Thus Mars is apparently in a condition towards which the

*Textbook of Geology, p. 33 (London, 1882).

†Young's General Astronomy.

‡Dr. E. E. Barnard, Popular Astronomy, No. 20, 1895.
See also Young's General Astronomy, p. 337.

climatic evolution, now in progress upon the Earth, is tending.

CONCLUSIONS.

The author therefore holds: (1) that the present zonal distribution of climates is gradually increasing in temperature and extent; (2) that this rise in temperature is due to the trapping of solar heat by the lower layers of the atmosphere; (3) that this rise in temperature was inaugurated at the culmination of the Ice Age in tropical latitudes, and that it must be gradually checked by a denser cloud formation as the surface temperatures of the oceans are raised;* (4) that the Ice Age was unique in the climatic history of the earth, and the result of the laws previously cited; (5) that preceding climates were independent of latitude and were controlled by the internal or planetary heat of the earth, that they were the result of the cooling of a hot spheroid subjected to the gradual loss of heat by the evaporation of water to vapor, by the radiation of heat from the cool outer surface of the resultant cloud sphere, which loss by radiation was retarded by the conservative action of solar energy; (6) that local glaciations could have occurred during any period and in any latitude, provided there were land areas sufficiently elevated.

*The equatorial cloud ring is possibly the nucleus of a more extended ring which will protect a greater area from noon and afternoon exposure to direct solar energy. As evaporation was reduced to a minimum at the culmination of the Ice Age, cloud formation and precipation, being direct functions, were likewise at a minimum and this ring was then probably of less extent.

DIFFICULTIES IN PREVIOUS EXPLANATIONS.

The postulates and corollaries just given appear to the author to satisfactorily account for the great variations in climate geologically recorded in the history of our planet. The difficulties met with in previous attempts to explain present, glacial and pre-glacial climates have been due in part to a failure to give due weight to certain of the laws which are above cited, and to fully recognize the force of others. For instance:

(1) The influence and functions of water in its various forms upon the mode and rate of loss of planetary heat have not been given due weight.

(2) The effect of the difference in the specific heat of land and water has been omitted in most of the discussions.

(3) The conservative function of solar energy prior to the exhaustion of planetary heat has not been fully recognized.

(4) The ultimate influence of the trapping of solar energy in the lower layers of the atmosphere, and the cumulative effect of this action upon surface temperatures has been left out of consideration.

(5) That the acceptance of ice action alone as proof of a glacial epoch is not warranted.

The failure to fully weigh and adjust the effects of the laws of climatic evolution has almost necessitated a resort to assumptions and hypotheses, some of which have been of a vague and indefinite nature, and others rest upon an inadequate foundation. Of these may be cited: Variations in the amount of solar energy, in the heat absorbing power of the solar atmosphere, in the temperature of space, in the direction and temperature of the Gulf Stream, in the elevations and depressions

of land areas, and in changes in position of the polar axis, and in the orbital eccentricity of the earth. Some of these are beyond the range of analysis and investigation, and others are of local and minor influence, and may be left out of consideration in a discussion of the fundamental principles.

If the eras of climatic evolution which our planet has undergone have herein been referred to their proper laws and sequence, the questions involved may not be the fearful "glacial nightmare" that some would make them; but rather the means whereby we recognize the Ice Age as one of these eras, during which the land areas were made smoother and more stable, and the soils more uniform in composition and fertility.

If new light has been thrown on the grand problems of terrestrial physics, much remains to be done. The worshipers who bow at the altars of science will have a stronger faith to cheer them on; and if some of their early structures have been rudely struck, it is hoped that in their stead grander and more stately temples will be reared whose foundations rest upon everlasting truth.