ARTICLE VII.

# GEOLOGIC TIME RATIOS, AND ESTIMATES OF THE EARTH'S AGE AND OF MAN'S ANTIQUITY.

BY WARREN UPHAM, ASSISTANT ON THE GEOLOGICAL SURVEYS OF NEW HAMPSHIRE, MINNESOTA, AND THE UNITED STATES.

THE ancient Greek philosophers reasoned backward to primal cosmic conditions which they called Chaos; and the inspired author of the sublime first chapter of Genesis saw the earth, at the beginning of his earliest vision, "without form and void, and darkness was upon the face of the deep." In obedience to the Creator there came, in the first Mosaic vision, light, and the division of day and night; in the second vision, a world-wide ocean, and the gathering of a dense cloud-bank above a stratum of open air; in the third vision, areas of land, clothed with vegetation; in the fourth, the appearance of sun, moon, and stars, when rifts were first made in the previously continuous envelope of clouds; in the fifth, swimming and flying animals; and in the sixth and last vision, lowly and higher land animals, succeeded by God's crowning work, man and woman, endowed with the lofty capabilities of the human mind. So completely is this sequence in accord with the history revealed in the rocks to the geologist that Dana, the most eminent of Americans in this science, declares the record of Genesis "profoundly philosophical, . . . true and divine, . . . a declaration of authorship, both of Creation and the Bible."

Heathen sages, in all times, of whatever nation or religion, and modern scientists, whether Christian or agnostic,

have sought to penetrate the mysteries of the origin of man and of the earth, and to conjecture or measure their antiquity. Prominent among the contributions to these inquiries during the past year 1892 are Prof. G. F. Wright's series of Lowell Lectures on the "Antiquity and Origin of the Human Race," given in Boston during February and March; the treatment of the question of geologic time by Sir Archibald Geikie in his presidential address[1] before the British Association for the Advancement of Science; another consideration of the same question by Mr. W J McGee in a paper entitled "Comparative Chronology,"[2] read before the section of anthropology in the American Association; an article by Prof. James Geikie, "On the Glacial Succession in Europe;"[3] and Professor Wright's second and abridged work on the Ice age, bearing the title, "Man and the Glacial Period."

These writers and others, as Dana, Haughton, Wallace, and Alexander Winchell, weigh the geologic evidences of the earth's age. They are all approximately in agreement as to the ratios of the several great divisions of geologic time, but differ widely in their estimates of its aggregate duration. According to Sir A. Geikie, the known rates of deposition of sediments imply that for the formation of all the stratified rocks of the earth's crust a duration somewhere between 73 millions and 680 millions of years must be required. Most geologists would doubtless regard the lowest of these estimates as a minimum of the time needed for the processes of deposition and erosion revealed by their study of the rocks, and for the concurrent changes of the earth's floras and faunas from their beginning to the present time. But to some geologists

[1] Nature, Aug. 4, 1892, Vol. xlvi. pp. 317–323.

[2] Am. Anthropologist, Oct., 1892, Vol. v. pp. 327–344, with a plate showing relative durations of natural time units, historical eras, and geologic periods.

[3] Trans., Royal Society of Edinburgh, 1892, Vol. xxxvii. pp. 127–149, with map.

these figures seem far too small, among whom McGee, the most extravagant of all, reasoning from similar premises of geologic observations, would claim about seven thousand millions of years as the more probable measure of the part of the earth's duration since its earliest fossiliferous rocks were formed, and probably twice as long since the earth began its planetary existence.

On the other hand, the most eminent writers who have considered this subject from the standpoint of physical experiment and theory and their relationship with astronomy, including Thomson, Tait, Newcomb, Young, and Ball, tell us that geologists can be allowed probably no more than one hundred millions of years, and perhaps only about ten millions, since our earth was so cooled as to permit the beginning of life upon it.

It is comparatively easy to determine the ratios or relative lengths of the successive geologic eras, but confessedly very difficult to decide beyond doubt even the approximate length in years of any part of the records of the rock strata. The portions for which we have the best means of determining their lengths are the Glacial and Recent periods, the latter extending from the Champlain epoch or closing stage of the Ice age to the present time, while these two divisions, the Glacial or Pleistocene period and the Recent, make up the Quaternary era. If we can only ascertain somewhat nearly what has been the duration of this era, from the oncoming of the Ice age until now, it will serve as a known quantity to be used as the multiplier for giving us the approximate or probable measures in years for the recedingly earlier and far longer Tertiary, Mesozoic or Secondary, Palæozoic or Primary, and Archæan or Beginning eras, which last takes us back almost or quite to the time when the cooling molten earth became first enveloped with a solid crust. This series of eras, however, comprising all the story of geology, is only a part of the earth's age as a separate planet.

Beyond the beginning of geology, the physicist and astronomer see our solar system in the process of slow but very grand evolution, from a globular nebulous mass with as great circumference as the orbit of the outermost planet whose mass became first detached from the revolving nebula, followed successively by the inner planets to Mars, the Earth, Venus, and Mercury, till finally the chief residual part of the nebula became the splendidly luminous sun. In like manner, as the planets became condensed to their present forms, most of them suffered a like severance of comparatively small portions of their masses to form moons and for Saturn both moons and rings. From measurements of the rate of radiation of the sun's heat, from the rate of increase of the earth's heat observed in deep mines and borings, and from experiments in the laboratory, aided by elaborate mathematical calculations, the physicist determines, to his own satisfaction, how long the sun can have been the centre of light and life for his attendant planets, how long time has passed since the moon's mass was thrown off from our whirling world, then revolving more rapidly than to-day, and the duration of the ages since the earth became encrusted and so far cooled that its ocean ceased to boil and vegetation and animal life began.

Geology, studying the stratified rocks and their fossils and the earlier and later volcanic rocks, tells us of the encrusted earth's history; the sciences of physics, chemistry, and astronomy go farther and bring before our imagination preceding æons through which the nebula had become condensed to the sun, planets, and satellites; but before the nebula we must believe that time was and "in the beginning God." Vast as may seem to our finite comprehension the antiquity of our race and of our earth, they are perhaps, nay, apparently must be, only a small and infinitesimal portion of the past eternity, just as the magnitude of our earth and solar system seems little in contrast with the infinitude

of universal space, containing its myriads of stars, each a blazing sun, and probably frequently or commonly attended with a retinue of worlds. In our inquiries concerning the earth's duration we may profitably first consider briefly what the physicist thinks of it in the light of his observations of nature, experiments in the laboratory, and mathematical computations, and afterwards what the geologist has learned from his reading the "sermons in stones."

Sir William Thomson (now Lord Kelvin) long ago estimated, from his study of the earth's internal heat, its increase from the surface downward, and the rate of its loss by radiation into space, that the time since the consolidation of the surface of the globe has been somewhere between 20 millions and 400 millions of years, and that most probably this time and all the geologic record must be limited within 100,000,000 years. Prof. George H. Darwin computes, from the influence of tidal friction in retarding the earth's rotation, that probably only 57,000,000 years have elapsed since the moon's mass was shed from the revolving molten earth, long before the formation of its crust. From the same arguments and the rate at which the sun is losing its store of heat, Prof. Guthrie Tait affirms that apparently 10,000,000 years are as much as physical science can allow to the geologist. Professor Newcomb, summing up the results of these physical and astronomic researches, writes: "If the sun had, in the beginning, filled all space, the amount of heat generated by his contraction to his present volume would have been sufficient to last 18,000,000 years at his present rate of radiation. . . . 10,000,000 years . . . is, therefore, near the extreme limit of time that we can suppose water to have existed on the earth in the fluid state." Not only the earth but even the whole solar system, according to Newcomb, "must have had a beginning within a certain number of years which we cannot yet calculate with

certainty, but which cannot much exceed 20,000,000, and it must end."

The geologist demurs against these latter far too meagre allotments of time for the wonderful, diversified, and surely vastly long history which he has patiently made out in his perusal of the volume of science disclosed by the rocks. He can apparently do very well with Lord Kelvin's original estimate, but must respectfully dissent from the less liberal opinions noted. Somewhere in the assumed premises which yield to mathematicians these narrow limits of time, there must be conditions which do not accord with the actual constitution of the sun and earth. It must be gratefully acknowledged, however, in the camp of the geologists, that we owe to these researches a beneficial check against the notion once prevalent that geologic time extends back practically without limit; and it is most becoming for us carefully to inquire how closely the apparently conflicting testimonies of geology and of physics may be brought into harmony by revision of each.

Among all the means afforded by geology for direct estimates of the earth's duration, doubtless the most reliable is through comparing the present measured rate of denudation of continental areas with the aggregate of the greatest determined thickness of the strata referable to the successive time divisions. Now the rates at which rivers are lowering the altitudes of their basins by the transportation of sediments to the sea vary from an average of one foot taken from the land surface of its hydrographic basin by the River Po in 730 years to one foot by the Danube in 6,800 years. As a mean for all the rivers of the world, Alfred Russel Wallace assumes that the erosion from all the land surface is one foot in 3,000 years. The sediments are laid down in the sea on an average within 30 miles from the coast, and all the coast lines of the earth have a total measured length, according to Dr. James Croll and Mr. Wallace, of about 100,-

000 miles, so that the deposition is almost wholly confined to an area of about 3,000,000 square miles. This area is one nineteenth as large as the earth's total land area; hence it will receive sediment nineteen times as fast as the land is denuded, or at the rate of about nineteen feet of stratified beds in 3,000 years, which would give one foot in 158 years. With this Wallace compares the total maxima of all the sedimentary rocks of the series of geologic epochs, measured in whatever part of the earth they are found to have their greatest development. Prof. Samuel Haughton estimates their aggregate to be 177,200 feet, which multiplied by 158 gives approximately 28,000,000 years as the time required for the deposition of the rock strata in the various districts where they are thickest and have most fully escaped erosion and redeposition.

Most readers, following this argument, would infer that it must give too large rather than too scanty an estimate of geologic duration; but to many students of the earth's stratigraphy it seems more probably deficient than excessive. All must confess that the argument rests upon many indeterminate premises, since the total extent of the land areas and the depths of the oceans have probably been increasing through the geologic eras, and the effects of tides have probably diminished. The imperfection of the geologic record, so impressively shown by Charles Darwin in respect to the sequence of plants and animals found fossil in the rocks, will also be appealed to as opposing the assumption that the 177,200 feet, or 33½ miles, of strata represent the whole, or indeed any more than a small fraction, of the earth's history. To myself, however, this last objection seems unfounded, since in many extensive and clearly conformable sections observed on a grand scale in crossing broad areas, there is seen to have been evidently continuous deposition during several or many successive geologic epochs, and by combining such sections from different regions a record of sedimentation is

made wellnigh complete from the earliest Palæozoic morning of life to its present high noon. But perhaps we may do better to change somewhat the premises of our computation, in view of the extensive regions where the rock strata remain yet to be thoroughly explored, and because of certain large land tracts having little rain and therefore no drainage into the sea. Let us assume that the total maxima of strata amount to 50 miles, and that the mean rate of the land denudation is only one foot in 6,000 years; and we then obtain a result three times greater than before, or about 84,000,000 years for the deposition of the stratified rocks.

As a confirmation of the validity of his estimate of 28,000,000 years, Wallace cites the estimates differently obtained through the geologic time ratios of Lyell and Dana, in combination with Dr. Croll's astronomic theory of the causes of the Ice age, which attributes the accumulation of the ice-sheets to stages of high eccentricity of the earth's orbit. The Quaternary Glacial period is assigned by this theory an extent of about 160,000 years, from 240,000 to 80,000 years ago. The next preceding epoch of great eccentricity was about 850,000 years ago, and to that time are referred large ice-borne blocks in Miocene or Middle Tertiary strata of northern Italy. The union of this assumption with the time ratios for the Tertiary and earlier eras is explained as follows by Wallace in "Island Life," chapter x.:—

"Sir Charles Lyell, taking the amount of change in the mollusca as a guide, estimated the time elapsed since the commencement of the Miocene as one third that of the whole Tertiary epoch, and the latter at one fourth that of geological time since the Cambrian period. Professor Dana, on the other hand, estimates the Tertiary as only one fifteenth of the Mesozoic and Palæozoic combined. On the estimate above given [that the time since a Miocene glacial epoch has been 850,000 years], founded on the dates of phases of high eccentricity, we shall arrive at about four million years

for the Tertiary epoch, and sixteen million years for the time elapsed since the Cambrian, according to Lyell, or sixty millions according to Dana. The estimate arrived at from the rate of denudation and deposition (twenty-eight million years) is nearly midway between these, and it is, at all events, satisfactory that the various measures result in figures of the same order of magnitude, which is all one can expect on so difficult and exceedingly speculative a subject. . . . The time thus arrived at is immensely less than the usual estimates of geologists, and is so far within the limits of the duration of the earth as calculated by Sir William Thomson as to allow for the development of the lower organisms an amount of time anterior to the Cambrian period several times greater than has elapsed between that period and the present day."

Professor Haughton has estimated time ratios from two series of data. His results deduced from the maximum thickness of the strata, for the three grand divisions of Archæan, Palæozoic, and subsequent time, expressed in percentages, are 34.3:42.5:23.2; and for his computations as to the secular cooling of the earth, 33.0:41.0:26.0. From his consideration of the present rates of denudation and the maximum thickness of the strata, he obtains "for the whole duration of geological time a minimum of two hundred millions of years." In my opinion this is a large rather than a small total estimate; but the length of Archæan or pre-Cambrian time seems to me proportionately much greater than is here allowed.

The ratios reached by Profs. J. D. Dana and Alexander Winchell from the thicknesses of the rock strata, are closely harmonious, the durations of Palæozoic, Mesozoic, and Cenozoic time being to each other as 12:3:1. The Tertiary and Quaternary ages, the latter extending to the present day, which are here united as the Cenozoic era, Dana would rank approximately in the ratio of 3:1, giving to the Quaternary

a sixty-fourth part of all time since the beginning of the Cambrian period, to which our earliest well preserved fossil faunas belong. For reasons to be stated later, I think that this estimate of the relative length of Quaternary time is greatly exaggerated; but this would not sensibly affect the general ratios. Professor Dana has further ventured a supposition that these three vast eras, from the Cambrian down until now, may comprise some 48,000,000 years, which would give for the Palæozoic era, 36,000,000 years; the Mesozoic, 9,000,000; the Tertiary, 2,250,000; and the Quaternary, 750,000 years. He disclaims, however, any assumption that these figures are "even an approximate estimate of the real length of the interval, but only of relative lengths, and especially to make apparent the fact that these intervals were *very long*."

Prof. W. M. Davis, of Harvard University, without speaking definitely of the lapse of time by years, endeavors[1] to give some conception of what these and like estimates of geologic ratios really mean, through a translation of them into terms of a linear scale. Starting with the representation of the Postglacial or Recent period, since the North American ice-sheet was melted away, as two inches, he estimates that the beginning of the Tertiary erosion of the Hudson River gorge through the Highlands would be expressed by a distance of ten feet; that the Triassic reptilian tracks in the sandstone of the Connecticut Valley would be probably 50 feet distant; that the formation of the coal beds of Pennsylvania would be 80 or 100 feet back from the present time; and that the Middle Cambrian trilobites of Braintree, Mass., would be 200, 300, or 400 feet from us.

Having such somewhat definite and agreeing ratios, derived from various data by different investigators, can we secure the factor by which they should be multiplied to yield the approximate duration of geologic epochs, periods, and

[1] Atlantic Monthly for July, 1891, p. 77.

eras, in years? If on the scale used by Professor Davis we could substitute a certain time for the period since the departure of the ice-sheet, we should thereby at once determine, albeit with some vagueness and acknowledged latitude for probable error, how much time has passed since the Triassic tracks were made, the coal deposited, and the trilobites entombed in the Cambrian slates. Now just this latest and present division of the geologic record, following the Ice age, is the only one for which geologists find sufficient data to permit direct measurements or estimates of its duration. "The glacial invasion from which New England and other northern countries have lately escaped," remarks Davis, "was prehistoric, and yet it should not be regarded as ancient."

In various localities we are able to measure the present rate of erosion of gorges below waterfalls, and the length of the postglacial gorge divided by the rate of recession of the falls gives approximately the time since the Ice age. Such measurements of the gorge and Falls of St. Anthony by Prof. N. H. Winchell show the length of the Postglacial or Recent period to have been about 8,000 years; and from the surveys of Niagara Falls, Mr. G. K. Gilbert believes it to have been 7,000 years, more or less. From the rates of wave-cutting along the sides of Lake Michigan and the consequent accumulation of sand around the south end of the lake, Dr. E. Andrews estimates that the land there became uncovered from its ice-sheet not more than 7,500 years ago. Prof. G. Frederick Wright obtains a similar result from the rate of filling of kettle-holes among the gravel knolls and ridges called kames and eskers, and likewise from the erosion of valleys by streams tributary to Lake Erie; and Prof. Ben. K. Emerson, from the rate of deposition of modified drift in the Connecticut Valley at Northampton, Mass., thinks that the time since the Glacial period cannot exceed 10,000 years. An equally small estimate is also indicated by the studies of Gilbert and Russell for the time since the last great rise

of the Quaternary lakes Bonneville and Lahontan, lying in Utah and Nevada, within the arid Great Basin of interior drainage, which are believed to have been contemporaneous with the great extension of ice-sheets upon the northern part of our continent.

Prof. James Geikie maintains that the use of palæolithic implements had ceased, and that early man in Europe made neolithic (polished) implements, before the recession of the ice-sheet from Scotland, Denmark, and the Scandinavian peninsula; and Prestwich suggests that the dawn of civilization in Egypt, China, and India, may have been coeval with the glaciation of northwestern Europe. In Wales and Yorkshire the amount of denudation of limestone rocks on which boulders lie has been regarded by Mr. D. Mackintosh as proof that a period of not more than 6,000 years has elapsed since the boulders were left in their positions. The vertical extent of this denudation, averaging about six inches, is nearly the same with that observed in the southwest part of the Province of Quebec by Sir William Logan and Dr. Robert Bell, where veins of quartz marked with glacial striæ stand out to various heights not exceeding one foot above the weathered surface of the enclosing limestone.

Another indication that the final melting of the ice-sheet upon British America was separated by only a very short interval, geologically speaking, from the present time, is seen in the wonderfully perfect preservation of the glacial striation and polishing on the surfaces of the more enduring rocks. Of their character in one noteworthy district, Dr. Bell writes as follows:—"On Portland promontory on the east coast of Hudson's Bay, in latitude 58 deg., and southward the high rocky hills are completely glaciated and bare. The striæ are as fresh-looking as if the ice had left them only yesterday. When the sun bursts upon these hills after they have been wet by the rain, they glitter and shine like the tinned roofs of the city of Montreal."

From this wide range of concurrent but independent testimonies, we may accept it as practically demonstrated that the ice-sheets disappeared from North America and Europe some 6,000 to 10,000 years ago. But having thus found the value of one term in our ratios of geologic time divisions, we may know them all approximately by its substitution. The two inches assumed to represent the postglacial portion of the Quaternary era may be called 8,000 years; then, according to the proportional estimates by Davis, the Triassic period was probably 2,400,000 years ago; the time since the Carboniferous period, in the closing part of the Palæozoic era, has been about four or five millions of years; and since the middle of the Cambrian period, twice or perhaps four times as long. Continuing this series still further back, the earliest Cambrian fossils may be 20 or 25 millions of years old, and the beginning of life on our earth was not improbably twice as long ago.

Seeking to substitute our measure of postglacial time in Dana's ratios, we are met by the difficulty of ascertaining first its proportion to the preceding Glacial period, and then the ratio which these two together bear to the Tertiary era. It would fill a very large volume to rehearse all the diverse opinions current among glacialists concerning the history of the Ice age, its wonderful climatic vicissitudes, and the upward and downward movements of the lands which are covered with the glacial drift. Many eminent glacialists, as James Geikie, Wahnschaffe, Penck, De Geer, Chamberlin, Salisbury, Shaler, McGee, and others, believe that the Ice age was complex, having two, three, or more epochs of glaciation, divided by long interglacial epochs of mild and temperate climate when the ice-sheets were entirely or mainly melted away. Professor Geikie, in the very able paper noted near the beginning of this article, claims five distinct glacial epochs, as indicated by fossiliferous beds lying between deposits of till or unstratified glacial drift, and by other evi-

dences of great climatic changes. In this country Mr. McGee recognizes at least three glacial epochs. The astronomic theory of Croll attributes the accumulation of ice-sheets to recurrent cycles which bring the earth alternately into aphelion and perihelion each 21,000 years during the periods of maximum eccentricity of the earth's orbit. Its last period of this kind, as before stated, was from about 240,000 to 80,000 years ago, allowing room for seven or eight such cycles and alternations of glacial and interglacial conditions. The supposed evidence of interglacial epochs therefore gave to this theory a wide credence; but the recent determinations of the geologic brevity of the time since the ice-sheets disappeared from North America and Europe make it clear, in the opinions of some of the geologists who believe in a duality or plurality of Quaternary glacial epochs, that not astronomic but geographic causes produced the Ice age.

Glacialists who reject Croll's ingenious and brilliant theory mostly appeal to great preglacial altitude of the land as the chief cause of the ice accumulation, citing as proof of such altitude the fjords and submarine valleys which on the shores of Scandinavia, and the Atlantic, Arctic, and Pacific coasts of North America, descend from 1,000 to 3,000 and even 4,000 feet below the sea level, testifying of former uplifts of these continental areas so much above their present heights. But beneath the enormous weight of their ice-sheets these lands sank, so that when the ice attained its maximum area and thickness and during its departure the areas on which it lay were depressed somewhat lower than now and have since been re-elevated. This view to account for the observed records of the Glacial period is held by Dana, Le Conte, Wright, Jamieson, and others, including the present writer. It is believed to be consistent either with the doctrine of two or more glacial epochs during the Quaternary era, or with the reference of all the glacial drift to a single glacial epoch, which is thought by Wright, Prest-

wich, Lamplugh, Falsan, Holst, and others, to be more probable. To myself, though formerly accepting two glacial epochs with a long warm interval between them, the essential continuity of the Ice age seems now the better provisional hypothesis, to be held with candor for weighing evidence on either side. The arguments supporting this opinion are well stated by Professor Wright in his works on the "Ice Age in North America," and "Man and the Glacial Period," and especially in an article on the "Unity of the Glacial Epoch."[1] The duration of the Ice age, if there was only one epoch of glaciation, with moderate temporary retreats and re-advances of the ice-border sufficient to allow stratified beds with the remains of animals and plants to be intercalated between accumulations of till, may only have comprised a few tens of thousands of years. On this point Professor Prestwich has well written as follows:—

"For the reasons before given I think it possible that the Glacial epoch—that is to say, the epoch of extreme cold—may not have lasted longer than from 15,000 to 25,000 years, and I would for the same reasons limit the time of . . . the melting away of the ice-sheet to from 8,000 to 10,000 years or less."

From these and foregoing estimates which seem to me acceptable, we have the probable length of Glacial and Postglacial time together 30,000 or 40,000 years, more or less; but an equal or considerably longer preceding time, while the areas that became covered by ice were being uplifted to high altitudes, may perhaps with good reason be also included in the Quaternary era, which then would comprise some 100,000 years. Comparing the Tertiary era with the Quaternary, however, I cannot agree with Professor Dana's estimate that the latter was a third as long as the former, and am quite at a loss to discern evidences justifying that

[1] Am. Journal of Science, November, 1892.

view. The best means for learning their ratio I think to be found in the changes of faunas and floras since the beginning of the Tertiary era, using especially the marine molluscan faunas as most valuable for this comparison. Scarcely any species of marine mollusks have become extinct or undergone important changes during the Glacial and Recent periods, but since the Eocene dawn of the Tertiary nearly all of these species have come into existence. Judged upon this basis, the Tertiary era seems probably fifty or a hundred times longer than the Ice age and subsequent time; in other words, it may well have lasted two millions or even four millions of years. Taking the mean of these numbers, or three million years, for Cenozoic time, or the Quaternary and Tertiary ages together, we have precisely the value of Professor Dana's ratios which he himself assumes for conjectural illustration, namely, 48,000,000 years since the Cambrian period began. But the diversified types of animal life in the earliest Cambrian faunas surely imply a long antecedent time for their development, on the assumption that the Creator worked before then as during the subsequent ages in the evolution of all living creatures. According to these ratios, therefore, the time needed for the deposition of the earth's stratified rocks and the unfolding of its plant and animal life must be about a hundred millions of years.

Reviewing the several results of our different geologic estimates and ratios supplied by Lyell, Dana, Wallace, and Davis, we are much impressed and convinced of their approximate truth by their somewhat good agreement among themselves, which seems as close as the nature of the problem would lead us to expect, and by their all coming within the limit of 100,000,000 years which Sir William Thomson estimated on physical grounds. This limit of probable geologic duration seems therefore fully worthy to take the place of the once almost unlimited assumptions of geologists and writers on the evolution of life, that the time at their dis-

posal has been practically infinite. No other more important conclusion in the natural sciences, directly and indirectly modifying our conceptions in a thousand ways, has been reached during this century.

The error by which Mr. McGee, in the estimate stated in the early part of this article, wanders so far astray, consists in his relying largely on Dr. Croll's theory for the cause of the Glacial period, whereby he concludes that this period was of great length and that the ice-sheets were due to astronomic conditions while the land throughout the Ice age had somewhat approximately its present height, with only moderate uplifts and depressions. Drawing his ratios of Postglacial and Glacial time, and of the preceding early Quaternary or late Tertiary epoch to which the Lafayette formation belongs, from the amounts of stream erosion, he has supposed the conditions then similar to those of the present time, so that the relative durations of these epochs may be estimated from their excavation of valleys by water courses. But it seems preferable, as before noted, to refer the Ice age to great elevation of the land, whereby the erosion of streams would be caused to proceed very much more rapidly than if the country were as low as now. With an altitude of our Atlantic coastal plain and whole continental area westward 3,000 feet higher than now, the valley-cutting may have gone forward twenty or a hundred times faster than to-day, or even near to the coast a thousand times faster than now. The factor with which Mr. McGee starts on the multiplication of the earlier ratios to change them to years is evidently far too large, and it gives therefore for all the geologic eras and for the earth's total age too vast figures probably by twentyfold to a hundredfold.

Anthropologists, not less than geologists, have a lively interest in the estimates and measurements of the length of the Glacial and Recent periods, for the earliest reliable testimony of man's existence comes to us from the Ice age both

in North America and Europe. Confining our attention to the observations which prove that men were living on our continent as contemporaries of its northern ice-sheet, we have many independent and widely separated localities where traces of man's presence during the Glacial period have been found. Under the beach ridge of gravel and sand on the south side of Lake Iroquois, the Glacial representative of Lake Ontario, charred sticks, with ashes and stones laid to form a rude hearth, were discovered about 18 feet below the surface in digging a well in Gaines township, Orleans county, N. Y. Lake Iroquois was dammed on the northeast by the receding continental ice-sheet and outflowed by way of the Mohawk and Hudson. The hearth and fire were made, according to Mr. G. K. Gilbert, "not long after the establishment of the Mohawk outlet and during its continuance." To a much earlier stage of the glacial retreat we must refer the extensive gravel deposits of the Delaware River in the vicinity of Trenton, N. J., in which Dr. C. C. Abbott, Prof. F. W. Putnam, and others have found many palæolithic implements and chipped fragments of argillite. Somewhat farther south, in Delaware, Mr. Hilborne T. Cresson has found similar palæoliths in glacial gravel belonging to a still earlier part of the Ice age, probably deposited during the maximum extension of the ice-sheet. Other localities where palæoliths have been discovered in glacial gravel and sand beds, formed during the departure of the ice, are Newcomerstown, on the Tuscarawas River, in eastern Ohio; on the Little Miami River at Loveland and Madisonville, in southwestern Ohio; on the East Fork of the White River at Medora, in southern Indiana; and on the upper Mississippi at Little Falls, in central Minnesota. Again, in one of the beach ridges of the Glacial Lake Agassiz, held in the basin of the Red River of the North and of Lake Winnipeg by the barrier of the waning ice-sheet, Mr. J. B. Tyrrell has found chipped fragments of quartzite, evidently of human work-

manship, contemporaneous with the rounded gravel and wave-worn sand of the beach. West of the Rocky Mountains, also, an obsidian spear-head was discovered by McGee in the sediment of the Quaternary Lake Lahontan; and stone mortars, pestles, and even human bones, including the famous Calaveras skull, have been obtained by Whitney, King, Becker, Wright and others, from the gold-bearing gravels under the lava of Table Mountain, California. Though these last are south of the continental drift sheet, they seem referable, on sufficient geologic evidences, to the Pleistocène or Glacial period.

At one time the Californian discoveries were believed by some to prove man's presence there during the Pliocene or closing period of the Tertiary era, far longer ago than the Ice age; but no indisputable proof, nor even apparently reliable evidence, for so great antiquity of man has been brought to light in any part of the world. *Homo sapiens*, as Professor Le Conte stated in discussions of this subject at the meeting of the American Association last August in Rochester, N. Y., must be regarded, in the present stage of our knowledge, as restricted to the Quaternary era, although his anthropoid ancestors may have begun as far back as in Pliocene or Miocene time their ascent toward man's present intellectual and spiritual eminence.