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THE MARRIAGE OF ST. CATHARINE.

By Parmigianino, 1504-1540. In the Pinacoteca at Parma.

Frontispiece to The Open Court.
THE EVOLUTION OF CLIMATE.

BY LAWRENCE H. DAINGERFIELD.
Local Forecaster, Weather Bureau, Pueblo, Colorado.

CAESAR said, "All Gaul is divided into three parts." With equal truth one may say that all of the earth is divided into three parts, namely, the geosphere, or solid portion, the hydrosphere, or liquid covering, and the atmosphere, or gaseous envelope. Climate may be defined as the resultant of the influences of these three spheres, plus the external influence of the sun. Each, to a certain degree, coordinates and cooperates with the others in establishing climate.

The object of this paper is to show something of the interrelation existing between the solid, liquid, and gaseous parts of the earth and the sun, in part through the media of plant and animal life, and attempt to trace some of the prominent features of this relation from the hypothetical, original, nebulous condition of the solar system, up through the various geological eras, to the threshold of the present time. In other words, we shall attempt to trace, as far as possible, the evolution of climate, especially that of North America.

Far beyond the four great geological eras of our earth, the Cenozoic, Mesozoic, Paleozoic, and the Archaean, there existed, according to the nebular hypothesis, a vast, nebulous mass, consisting of an extremely attenuated and highly heated gas. This gaseous body included, in their nascent state, all of the chemical elements now composing the solar system; at first it was "without form and void," but after the passage of untold ages it ultimately assumed a globular shape, due to the mutual attraction existing between every atom in the system and the final condensation around a nucleus or common center. The diameter of the great vapor sphere, to be
called ultimately the "solar system," was undoubtedly somewhat greater than the present diameter of Neptune's orbit—5,580,000,000 miles. The solar nebula was subordinate to the vast, universal nebula, and was correspondingly insignificant. Dense, secondary nuclei formed in time, and were attracted toward the center of gravity; only a slight deviation to the right of the common center of the vast system was necessary to initiate a slow, rotary motion of the whole solar nebula. The rotation necessarily caused a greater deviation toward the right on the part of the dense secondary masses in their passage centerward. A more rapid motion in rotation was thus stimulated, and the nebulous sphere became an oblate spheroid, with its polar diameter constantly shrinking and its circumference at the equator continually expanding. Swifter and swifter whirled the fiery vapor, until a titanic, equatorial ring with a maximum density at some point in its periphery, separated from the parent body, broke and clustered around the secondary center, and Neptune was born. The cooling of the surface of the primary, caused a slow but constant shrinkage and a corresponding acceleration in rotation.

Old Neptune moves leisurely along his orbit at the slow rate of about three miles per second, and his sidereal period of revolution is one hundred sixty-five earth years.

The shrinkage continued and Uranus, Saturn, Jupiter, the Asteroids (the fragments of a spoiled planet), the Earth, Venus, and Mercury, each, in turn, were born, with an ever increasing velocity of revolution along their respective orbits, the earth's velocity being 18 1/2 miles per second.

In the far-off age when the earth was born, it existed only as an atmosphere, without either geosphere or hydrosphere—an atmosphere composed of all of the elements and many of the compounds which can now be found above, on, or within the solid lithosphere.

Some idea of the temperature of the atmosphere may be conceived when one considers that all of the solids and liquids now composing the earth were maintained at a temperature sufficiently high to hold them in the vapor state during the genesis of the world.

Untold ages sufficed to reduce the temperature of the gaseous world sufficiently to precipitate some of the elements and compounds to form a molten, central nucleus, and other untold ages elapsed before the surface of the molten sphere froze and formed a solid crust of intensely heated, igneous rock. Thus the Archean Era was ushered in, and the earth's climatical and geological history began.

During all of the early history of the earth, axial rotation and
orbital revolution were progressing much the same as they do to-day: the moon had separated from the earth and had cooled much more rapidly than her progenitor, and was probably a fit habitation for animal life even during the earth's Archean Era. The sun shrunk slowly from his progeny thus favoring and augmenting the refrigerating and condensing process.

In the earliest period of the Archean Era, the earth's crust was blackened and charred; there was no water—no variation—nothing but the blistering, seething surface, under which the molten forces spent their fiery fury, and above which the vast, invisible ocean of poisonous vapor surged and played. The climate during that most primitive time was equitable from pole to pole; there was no change of season; the unspent, internal furnace radiated heat outward from the scorched surface equally in all directions; there was probably no circulation of air over the new-born earth, for the heat was uniform and a state of equilibrium existed. The dense and strongly acid atmosphere, filled with the water of future oceans, heavy with carbon dioxide, poisonous gases, and many of the most volatile elements and compounds, that exist as liquids or solids under less arduous temperature conditions, hung stagnant and lifeless above the fervid, alkaline earth. Thus it was in the beginning when extreme and uniform heat prevailed about a lifeless sphere; thus it will be in the end when intense and universal cold embraces an old dead world; the elements of each case are stagnation, equilibrium, chaos, death.

The ocean of stagnant air and suspended water vapor remained practically inert above the earth as long as the major portion of the heat came from within the charred surface, but when the crust had thickened, and the heat received from the sun exceeded that expended by the earth, then a vast change occurred. The poles became appreciably colder than the equator. The seasons went and came. The vast atmosphere was set in motion, due to differences in temperature over the dead world, and stable gave way to unstable equilibrium. Then the boundless vapor-ocean became visible as cloud, and eclipsed the arduous sun, and darkness covered the face of the parched and desert earth. The condensation continued and the first rain of heaven descended upon a thirsty, igneous earth, but long before this deluge could moisten the primordial hills and valleys, the surface heat burst the liquid bands asunder, and forced the vapor back to the clouds from which it came.

By degrees, the clouds hovered nearer and ever nearer, with the constant diminution of geothermic power, and then another
deluge came, amid the terrific flash and crash of heaven's artillery, and water covered the face of the earth in that far-off, twilight epoch. Thus, for the first time, the earth was complete in a threefold sense. The geo- or lithospheric struggle beneath a boiling hydrosphere, and above the latter surged the torrid atmosphere, many times exceeding in volume, density, and number of constituents the thin, residual gas in which we live and have our being.

In that early Archaean ocean, no living creature could exist, and the boiling point was probably maintained in the ocean's bottom through a vast age as time is reckoned. Climate, in its fullest sense, is hardly applicable to the conditions existing during that ancient era, since life had not then broken the bonds of its chrysalis, and was not subject to climatic vicissitudes.

By degrees the world-wide ocean cooled, and the crust settled about the shrinking sphere, causing flexures in thin and weakened places, and the first mountains raised their igneous summits far above the Eozoic sea, and became the nuclei of future continents. Then the sea began its erosive struggle of leveling the eructant structure and depositing the sediment upon the sunken floor. (When sedimentary rock was formed, a new formation came into existence—the metamorphic. Fire, pressure, and highly heated water are the principal agencies by which igneous and sedimentary rocks are metamorphosed).

The Archaean continent of North America (Fig. 1) formed the outline of the present continent. The desert, Laurentian stone extended like a great arch around the future Hudson's Bay, with smaller land areas constituting the nuclei of the Appalachian system on the east and the Cordilleran on the west of our future Republic. The upheaval and subsequent growth of the land areas of North America profoundly influenced the climate.

Prior to the upheaval of the primary rock above the level of the sea, oceanic climate had reigned supreme. The climatic zones had existed as parallel, latitudinal belts from the equator to the poles. There had been, of course, a constantly growing difference between the climatic conditions of the Torrid, Temperate and Frigid Zones, but the divergence was not so marked, even during that primeval era, over a water-covered sphere, as it would have been had the primal rocks never been emersed. But from the day that the first rock ridge divided the Archaean Sea, dates the decadence of a purely oceanic climate. The embryo of the complex, continental climate came into existence contemporaneously with the Archaean land-surfaces. That embryonic climate grew into childhood during the
Paleozoic era, reached adolescence during the reptilian, Mesozoic era, gained manhood with the advent of the Glacial age of our era, the Cenozoic, and will reach senility when a frozen, lifeless earth revolves about the embers of a dying sun.

Mountains are the "benchmarks" of future continents. And as the Blue Ridge range in the East, and portions of the Rocky Mountain range in the West, divided the waters of the Archaean Ocean, they surveyed the general trend of the future North American Continent. The Canadian uplift, being somewhat general, might be considered an epeirogenic movement of the earth's crust. The first foldings of the eastern and western boundary lines were orogenic, or mountain-making movements.

Fig. 1. THE Eozoic OR ARCHAEO CONTINENT OF NORTH AMERICA.

That portion of the American continent which was above the level of the sea at the close of the Eozoic era, before the dawn of life. (After a drawing by Alexander Winchell.)

During the Archaean era the earth's surface retained much of its initial heat. The temperature of the earth at the time heating by convection ceased, is estimated by Professor King to have been 3600 degrees (F) above zero. When the temperature fell below 3600 degrees, the transfer of heat was accomplished principally by conduction to the surface and by radiation from the surface of the earth. When the diffusion of heat by convection ceased, and the transmission of heat by conduction to the earth's surface began, we
may consider that the Archaean era was ushered in, which event, according to Professor King, was about 24,000,000 years ago.

Refrigeration continued uninterruptedly and comparatively rapidly during the Archaean era, and the warm, nascent sea, which was at first strongly alkaline or basic, greedily combined with the acids of the air, and salts were formed, giving to the oceans their saline principles.* During the millions of years that elapsed between the morning and evening of the Archaean era, the primitive rock surface, cooled from the fusing point until the ocean bathed the fervid earth; the water grew in saltiness and lost its alkaline principle with passing years; the backbone of the North American continent grew and was denuded by æolian and aqueous processes, and the detritus was spread out in ever thickening layers over the ocean shallows; refrigeration at last reduced the water of the sea to a temperature suitable to an humble form of life, and the dead Archaean world passed into geological history with the advent of the Palæozoic era.

The dawn of life occurred in the Cambrian period of the Palæozoic era. As might be expected, life was both tropical and aquatic. Imagine if you will the diet of the Cambrian arthropode and mollusks; their menu was surely far from elaborate. There was a twofold reason for placing the earliest form of animal life in the water of that ancient sea: (1) No air-breathing animal could exist in the Cambrian climate. The air that circulated above the tepid ocean was full of carbon dioxide and numerous other noxious gases which prohibited the separation of the life-giving oxygen from the death-dealing constituents. No man can ever know just what many of the ancient gaseous constituents may have been for many of the less volatile have long since entered into chemical unions, while hydrogen, that very light gas, has either joined its affinities—other elements—or fled outward into that great ocean of waste matter—etheral space—to possibly accumulate around larger heavenly bodies, the centrifugal force of the earth’s rotation having overcome gravitation. (2) The earliest forms of life were very simple, and it is extremely doubtful if those backboneless creatures could have

*Some of the alkaline compounds, the hydroxides, found on the surface of the earth or in the sea were NaOH, KOH, Ca(OH)₂, (quicklime), Mg (OH)₂, and others, no doubt united with the acids then in the air in great quantities, such as HCl, H₂SO₄, and H₂S (thrown out in large quantities by volcanoes together with HCl), etc., to form salts, for instance NaOH+HCl=NaCl+H₂O; KOH+HCl=KCl+H₂O; (NaOH)+H₂SO₄=Na₂SO₄+2H₂O; CaOH₁+H₂SO₄=CaSO₄+2H₂O; Mg(OH)₂+2HCl=MgCl₂+2H₂O; Mg(OH)₂+H₂SO₄=MgSO₄+2H₂O.
long survived a rugged existence on the desert, storm-beaten rocks of the Cambrian land surface.

Among the humble forms of life found in the Cambrian Sea were the foraminifera, sponges, grap'tolites, corals, brachiopoda, tri'lobites, ostracods', phyllocar'ida, worms, pelecypoda, and gastropoda, most of which were shell-bearing, and all invertebrates and without red blood. The world was not then a fit abode for the higher forms, and Deity placed the lowly invertebrates in the sea while preparing the land for higher and better types of his creation.

During the succeeding period, the Lower Silurian, the first armored fishes appeared, some of which found a cemetery near Cañon City, Colorado. The early armored fishes show a gradual transition from the earlier shelled animals to the later vertebrates, being entirely without endo-skeletons, i.e., the armors served as skeletons.

The succeeding period, the Upper Silurian, produced armored fishes in vast numbers, which were contemporaneous with the ammonoidæ, shelled animals, similar to the nautilus; the ammonidae were prolific during the Devonian period, when fishes much like those of
to-day, and great toothed sharks became the monarchs of the world, showing a gradual upward trend in animal creation.

The land area had grown during the Cambrian and Silurian periods. (Fig. II), the belt around Hudson's Bay having widened materially; the Appalachian system had grown, but much of the Archaean land area in the western part of the continent had subsided leaving only island-like formations above the sea. Volcanic action was prolific, and added steam, sulphurous gases, sulphurated hydrogen, hydrochloric acid, methane, carbon dioxide, and much heat to the dense, poisonous atmosphere, forcing animals to linger longer in the sea. The time for the air-breathing animals had not arrived.

Tropical climate is indicated for regions in the present Frigid zones by the presence of fossils of Silurian and Devonian coral reefs.

Plant life had existed contemporaneously with the animal forms, or even before in the Archaean era (both on land and in water), but not to such an extent as during the great Carboniferous period, which followed the age of fishes.

Much of the interior of the future United States was under water up to the beginning of the Carboniferous period; then the continent rose slowly and lifted parts of the Appalachian region, and the future states of Ohio, Indiana, Michigan, Kentucky, Illinois, Iowa, Missouri, and Kansas slightly above the surface of the ocean, and vast swamps, filled with the sediment of erosive action of unnumbered years, became suitable hotbeds for a luxuriant, flowerless, tropical flora. Great ferns, lycopods, calamites and cycads flourished in the carboniferous swamps and lowlands, and drew from the air much of the super-abundant carbon dioxide (CO₂). That the climate of North America was not only tropical but remarkably uniform is evidenced by the structure of the Carboniferous tree trunks—little change of season being shown. The rank and marsh-loving plants of the era indicate abundant rainfall.

Many elevations and subsidences of the Carboniferous lowlands occurred, each exhibiting a vast accumulation of plant life which formed the coal measures.

Amphibians animals appeared in large numbers, and hopped or crawled under the shadows of the sigillarians and lepidodendroids in the silent solitude of the first inhabited forests, thus indicating that the air had become sufficiently purified to support a low form of air-breathing animal.

The amphibians of the Carboniferous and Permian periods were of the order Steg'ocepha'lia, which shows a gradual transition from the dominant fish-life of the late Paleozoic era, and the higher rep-
tilian orders soon to appear (Fig. III). The young stegocephalians had true gills, and the full grown were covered with an armor of overlapping, bony scales. They were carnivorous or flesh-eating animals, as is shown by their pointed, cone-shaped teeth, and were the first four-footed vertebrates and were equally at home on the land or in the water. Their very form and nature demonstrate that conditions above the surface of the sea were not quite favorable for a permanent abode on terra firma, and that the air was not quite adapted to the use of air-breathing animals, living exclusively above the surface of the water. A gradual improvement in conditions on the land is shown by the fact that a sub-order of Stegocephalia shows marked increase in size and adaptation to an exclusively terrestrial life during the Permian period, which followed the Carboniferous, individuals of the sub-order having attained a length of ten feet—the largest of the American amphibians—and a much greater length was attained by the adults of an European sub-order.

In the jungles of that far-off, Carboniferous period lie buried the carbon remnants of an atmosphere once heavily laden with carbon dioxide. Never again was rainfall to be so universally torrential; never again was plant life to be so luxuriant and prodigal. The dense, tropical flora of to-day is only a faint reminder of the

Fig. III. MASTODONOSAURUS AND HYPERODAPEDON.
Extinct European descendants of Stegocephalia. (From Animals Before Man in North America, by Frederic A. Lucas.)
verdure of that distant period, doomed to fall in tangled masses, and sink beneath the erosive deposits of the relentless sea, and become the vast storehouses of heat and locomotion for the inhabitants of a chilled and far more rigorous world.

Differentiation in climate is shown near the close of the Carboniferous period by the fact that conifers—cone-bearing trees—the greatest of the four living groups of the gymnosperms, appeared in the far frigid zones. The conifers are adapted to a colder climate, and are far hardier trees than was the Carboniferous verdure represented by the lycopods and kindred plant life. The slow encroachment upon the tropics of the conebearers plainly indicates the gradual but almost imperceptible refrigeration of our globe.

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**Fig. IV. THE PALEOZOIC CONTINENT OF NORTH AMERICA.**

Those parts of the North American continent which were above the Permian or Triassic Sea at the close of the Paleozoic or dawn of the Mesozoic era. (After a drawing by Alexander Winchell.)

The clarifying of the air by the Carboniferous flora, and the separation of the earth into better defined climatic zones, the gradual growth of land area around Hudson's Bay and the St. Lawrence valley and the Appalachian and Cordilleran mountain systems. (Fig. IV) marked the close of the coal-making period and the advent of the Permian. The consumption of a vast amount of carbon dioxide ($\text{CO}_2$) by the luxuriant plant life of the Carboniferous period, and the loss of much moisture from the air, favored an accelerated
radiation of terrestrial heat into interplanetary space. Consequently
traces of glacial action are found which were made during the
Permian period, in remote portions of the southern hemisphere, and
even in the extreme northern portion of our hemisphere. Volcanic
eruptions probably resupplied the air with sufficient carbon dioxide
to check the too rapid refrigeration of the earth through radiation,
and prolonged the life of the tropical flora and fauna in the temperate
and frigid zones. That most ancient invertebrate, the Trilobite,
passed away with many of his contemporary, backboneless fellow-
creatures, and many others of his kind and time dwindled away and
became subordinate to the ponderous sea, amphibious, and land rep-
tiles, which became the monarchs of the earth during the strangest
era of ancient times—the Mesozoic; even the fishes assumed a
secondary place while the monster reptiles paddled through the sea,
stalked upon the land, or stretched their membraneous wings and
soared above the marshes and jungles of the ancient past.

The warm, moist Permian climate of North America was ideal
for the amphibians and they became the languorous monarchs of
their age. But the upward trend of life could not be long impeded,
and the reptiles appeared, showing many amphibian characteristics,
but also added higher types. The reptilian innovation intimates
further improvement in climatic and vegetal environments. Many
of the reptiles were herbivorous, probably the first herbivorous ani-
imals to inhabit the world. Many retained the carnivorous habits
of their fish and stegocephalian ancestors. All types of animal life
before the advent of birds and mammals were cold-blooded, i. e.,
the temperature of the invertebrates and fishes of the sea, the am-
phibians of sea and land, and the reptiles of the sea, land, and air,
was little if any above that of the water or air in which they lived.
The lungs of the reptiles were large, but lacked the innumerable,
microscopic air-cells which are present in the lungs of birds and
mammals. Being cold-blooded indicates that the aerating surface
of the reptilian lungs for oxygenation of the blood was both defi-
cient and unnecessary. What their lungs lacked in delicate and
complicated structure was more than compensated for in toughness
of texture and admirable adaptation to breathing the noxious air
of the Permian and succeeding periods of the Mesozoic era.

The Triassic or morning period of the Mesozoic era marks the
rise of the reptiles and the decline of an inferior class of creatures—
the amphibians. Terrible and grotesque must have been many of
the orders and suborders of the reptilian class. Mythical dragons
and griffons could not have assumed forms more hideous than did
the monarchs of the Mesozoic era. The terrified amphibians and small reptiles must have fled before their large antagonists with ravenous, carnivorous appetites, to hide themselves in the slime under the somber shade and flowerless plumes of the marsh-loving, horsetail rushes. The great eycads, with their radiating, fernlike leaves, afforded friendly shelter alike to friend and foe—the one from an unnatural and sudden death; the other from the blistering tropical sunshine or torrential rain. Possibly some of the small and hardier types fled northward and wandered in the silent shadows of
the cone-bearing forests of a more temperate climate, free from the presence of their ponderous enemies.

The dominating types of both plant and animal life of that strange era were ponderous and somber. The giant, Mesozoic Cyc'ada'ceae and Equise'tum have since then shrunk to the lowly ferns and rushes; the terrible reptiles have shriveled to the insignificant snakes and lizards, or more pretentious alligators and crocodiles of the tropics. Physically the era was great—but life was either brainless or flowerless—Reptilia or Gymnosperm.

The largest of the dinosaurs, the herbivorous brontosaurs (thunder lizards), roamed the primitive marshes and lowlands of the present state of Wyoming, on the western border of the great Jurassic Sea, extending from the Arctic Ocean to the Gulf of Mexico. These great brutes walked on all fours (Fig. V), and their footprints covered a full square yard of ground. The adults attained a length of sixty feet, and their probable average weight was about twenty tons. The skeleton of the great brontosaur in the American Museum of Natural History, New York City, measures sixty-seven feet in length, and the live animal, according to some authorities, would have “tipped the scales” at about ninety tons. Its brain would have weighed about as much as that of a ninety-pound child.

Through the tepid waters of the inland sea the ichthyosaurs and plesiosaurs paddled their massive bodies, while over forest and plain, mountain and sea, the pterodactyls soared with expanded membraneous wings reaching twenty feet from tip to tip—true “dragons of the air” (Fig. VI).

The mountains, foot-hills and vast plains were slowly rising above the sea of western North America during the Mesozoic era, but much of the eastern portion of the continent, extending as far west as Iowa and eastern Kansas, and south to the northern portions of Arkansas, Mississippi, Alabama, and Georgia, were above the water at the close of the Paleozoic, and much of the Appalachian system was growing old before the close of the Paleozoic, and was crumbling before the æolian and aqueous attacks extending through the Mesozoic era.

As the warm, moisture-laden air moved from west to east across the western archipelago, the great inland sea, the central valley low-lands, the Appalachian Mountains, and off the eastern seacoast, it yielded copious rain on the western land-masses, and was generously replenished with moisture taken from the ocean’s arm that divided the continent, to again fall in torrents over the
eastern land area. The interior of the earth still rendered substantial aid in maintaining a tropical temperature over much of the temperate zone, while the sun was lavishly expending his radiant energy in prolonging the life of tropical fauna and flora far north of the present confines.

During the Cretaceous period, the evening of the Mesozoic era, triceratops, the last and noblest of the dinosaursian race, appeared. Already the reptile orders of sea, land, and air were experiencing a waning glory, and were yielding before races better adapted to the
changing vicissitudes of climate and resultant vegetation. Already Archaeopteryx (Fig. VII), the reptile-like bird, was usurping the domain of the pterodactyl and pteranodon. Already the first diminutive mammals were roaming through the first flowering pastures and blossoming woods, for the gymnosperms or flowerless plants were yielding to the angiosperms or flower-bearing vegetation. Refrigeration had brought the world forward to a more modern stage, but tricer'atops still roamed the marshes, hills, and plains, a stranger among strangers, a grand but forlorn representative of a decadent race; he walked as do the quadrupeds, and the crowning glory of his twenty-five-foot body was his six-foot armored head, with three great horns or knobs ranging upward in a single row from near the point of his massive nose to the crown of his brainless head. But
tricera'tops died and joined his fellow dinosaurs. A diagnosis of the cause of his death would have been over-specialization, changing climate and vegetation, and to make room for a superior race.

Contemporaneous with Archæopteryx, the primitive bird with reptile-like caudal appendage, was Ctenac'odon, the earliest known mammal, found in the upper Jurassic stone of Wyoming; that diminutive creature was but little if any larger than a mouse, and an humble successor to the mighty herd of reptiles then in the fading twilight of their ponderous, physical ascendency, and nearing their last, long degradation to the dust from which they sprang, or the consignment of their massive bones to the rocky matrix of nature's grand sarcophagus to become fossil history, read and pondered over by a far superior race of beings in a distant epoch.

Fig. VIII. THE MESOZOIC CONTINENT OF NORTH AMERICA.

Those parts of the North American continent which were then above the Cretaceous or Tertiary Sea at the close of the Mesozoic or dawn of the Cenozoic (modern) era.

The North American continent at the close of the Mesozoic era showed further growth above the Cretaceous sea along the southwestern border of the principal land mass (Fig. VIII), and the foothills and plains expanded out from the Cordilleras, and encroached upon the shallows of the ocean's bed. The great inland sea was gradually becoming a shallow strait, but still extended from the Arctic Ocean to the Gulf of Mexico over the present state of Texas, and embraced much of what is now Oklahoma, Kansas, Neb-
raska, the Dakotas, Colorado, Wyoming, Saskatchewan, Alberta, and Mackenzie. The rainfall no doubt was becoming less torrential, excepting possibly over the steep, western incline of the Cordilleras. Conduction, convection, and radiation had reduced the temperature of the land, water, and air, causing a further shrinkage of the tropical faunal and floral area. At the present rate of cooling, it is estimated that the interior of the earth loses eighty-one degrees (F) of interior heat in 100,000,000 years by conduction through the rocks to the surface, and radiation from the surface. But, no doubt, the early refrigeration of the earth was much more rapid than the present rate.

At the close of the Mesozoic era, the atmosphere probably possessed nearly the same elements and compounds as at present, but it was far more extensive. It was during this interval of the world's geological history that the cumbersome and brainless, ancient reptiles passed to their last long rest, leaving nothing but fossilized bones to prove their very existence. The mammals appeared in time to view the passing of the reptiles, and, in turn, became the kings of earth; they sprang from a lowly and insignificant ancestry, but culminated, as Deity ordained, in the birth of Man, which event probably occurred at the close of the Pleistocene Period of the Cenozoic era.

The passing of the great reptiles, and the advent of the mammals near the dawn of the Cenozoic era indicates changing environments. Changing climate and resultant vegetation were prominent factors in the transition in animal life and the vegetable kingdom. Decrease in temperature and precipitation caused the decline of the vast, tropical, swamp-loving flora, which was the food of many reptiles, while increasing frigidity drove the reptile horde equatorward or destroyed them utterly from the face of the earth, leaving behind them a small remnant of their hardy, diminutive representatives in the temperate zone, and a somewhat larger, fiercer progeny in the tropics.

Each of the four great geological eras represents well-defined transitions in plant and animal life, effected largely through changes in the metereological elements, viz., the temperature, pressure, and humidity of the air; precipitation, or the amount of water excluded from the air; evaporation, or the amount of water excluded from the land and water surfaces, or by transpiration from plant life, and acquired by the air; the electrical condition of the air. The Mesozoic was the great transition era between the embryonic life of the Paleozoic and the more highly organized life of the Cenozoic era. The transition did not occur within a few short years, but millions
of years were required to exclude from the air many superfluous and poisonous gases, fatal to higher forms of life, and reduce them to the harmless liquid or solid state.

As the North American continent grew upward, and expanded its borders, the climate gradually grew colder and drier; the sky became clearer, humidity decreased, and evaporation was greater, even though the temperature was less. Consequently the jungles, bogs, and swamp lands shrank slowly or passed away as they do to-day, and the moisture-loving vegetation yielded to the sylvan or prairie flora. The ferns and cycads, and many of the monocotyledonous angiosperms retreated slowly toward the equator, while the deciduous forests of the temperate zone encroached upon the tropics, and the conifers, lichens, and mosses spread southward and intruded upon the temperate zone. As the climatic zones became more distinct, more local areas, forests, grasslands, and deserts, appeared, dependent largely on three atmospheric factors, namely, wind, moisture and temperature. Each local area was the habitat of its peculiar form of vegetation (and resultant life). Of the three climatic factors, rainfall was and is of prime importance, and where the air had less moisture, the trees of the forests became fewer, and park-like savannas, or plant societies showing transitional conditions between forests and grasslands, appeared; these losing their trees, gradually became the prairies of North America, which correspond to the pampas of South America, and the steppes of Europe and Asia. It is doubtful if deserts, as we know them, existed as far back as the beginning of the Cenozoic era, but if grasslands had been subjected to still further exclusions of moisture, through dry winds, such as blow over the Great Sahara, or through being far remote from the sea, as the interior of Siberia, or through being closed in by mountain ranges, as portions of Arizona, Nevada, Utah, and New Mexico, the third great society of plant life—the desert flora—would have inevitably appeared. Monotony rather than poverty characterizes the desert flora of to-day. The few species representing desert vegetation are well supplied with root-anchorage to draw moisture upward through the thirsty earth, while their leaf surfaces are small or entirely wanting, thus reducing transpiration to the minimum, and reservoiring the precious liquid within the plants’ bodies.

About three million years ago, more or less, the Tertiary period of our Cenozoic era dawned, with the birds and mammals, the first warm-blooded animals, and the flowering plants (angiosperms) in the ascendancy. The birds were adapted to migratory habits then becoming necessary through increasingly distinct climatic zones and
change of seasons. The herbivorous mammals with their swifter means of locomotion and superior teeth were better suited to subsist upon the primitive grasses and cereals than were their ponderous, reptilian predecessors, while the hardy, cunning carnivorous mammals were equally well fitted to their sylvan homes. The clearing atmosphere permitted the sun's rays to fall in rich profusion over the flowering hills and valleys, and open wide the petals of the Angiosperms, inviting admiration from an unadmiring world, and enticing the passing insects to alight and taste the hidden nectars.

Eocene, Oligocene, Miocene, and Pliocene times of the Tertiary period were prolific in the development of thousands of mammalian species, many of which have long since become extinct through changing climate and resultant vegetation. Over 10,000 species of the sub-class, Eutheria, of the mammalian class, have evolved from the Tertiary animals, and live on the earth to-day. Physically, the genus Homo, or man, belongs to the order of Primates, of the sub-class Eutheria of the class Mammalia, and of all the mammals that have come forth from the Tertiary period to live during the Quarternary period, or age of man, the Ungulates, or hoofed beasts, are the most useful.

The epidermis of all mammals produces a covering of hair, or modified hair in the form of bristles or even scales, while the Aves, or birds, are equally well protected with feathers, of epidermal origin. These modified, epidermal growths are well adapted to protect the dominant animal life from the vicissitudes of climate. The seasons were well marked before the close of the Tertiary period. By the end of the Pliocene time, the North American continent was practically clear of the Tertiary sea, and was yielding to the grasp of the frigid zone. Temperate zone fauna and flora were forced southward to the tropics or died at the touch of the chilling, arctic breath. Precipitation in the form of snow covered the earth where the luxuriant vegetation of a tropical climate had flourished. The ice congealed around the lily and the iris, and the frost of winter robbed the trees of their foliage. And then the Quarternary period broke, with all its fury, upon a world hitherto languishing in a spring, summer, autumn, or tempered winter sun, and this was the advent of the Glacial or Ice age. The massive sheet of snow and ice grew and spread until it enveloped Canada, New England, the St. Lawrence valley, the Great Lakes, New York, New Jersey, Pennsylvania, and the vast region extending from the Ohio to the Missouri River. Down the slopes of the Rocky and Sierra Nevada mountains the glaciers descended into the valleys, and over the
plateaux, while over Alaska and British Columbia there extended a
universal ice sheet. Five times was the glaciation of North America
accomplished, and six times was all of northeastern Europe cov-
ered with the sheet of ice, during the Pleistocene period.

A very plausible explanation* of the refrigeration and glacia-
tion of the Northern Hemisphere follows: The eccentricity of the
earth's orbit is subject to secular variations. At times the orbit is
more elliptical than on other occasions. When the orbital eccen-
ctricity reaches its maximum, the earth is 14,000,000 miles nearer the
sun during perihelion than in aphelion, causing a difference of 20%
in the amount of direct heat received from the sun between these
two positions. At the present time midwinter occurs in the North-
ern Hemisphere when the earth is in perihelion, or the closest point
to the sun, but through what is called the "precession of the equi-
oxes" the midwinter of the Northern Hemisphere will occur in
aphelion, or the farthest point from the sun, in about 10,500 years.‡
If during the Ice age the earth's orbit had assumed its maximum
eccentricity of 14,000,000 miles, and the northern midwinter had
occurred in aphelion, or the farthest point from the sun, then the
winter's length would have been increased by twenty-two days, and
the summer's shortened by an equal amount. The Northern Hemi-
sphere would have received one-fifth less direct heat from the sun,
daily, during the long, cold winter, but one-fifth more daily during
the short, hot summer. The difference between the length of the
two seasons would cause refrigeration, and the hot summer would
be too short to melt the constantly accumulating ice and snow of
the aphelion winters of the Pleistocene age and glaciers would have
been the inevitable result. If the earth's orbit had retained its maxi-
mum eccentricity during the Pleistocene period, the precession of
the equinoxes would have carried the earth to aphelion during the
northern midwinter every 21,000 years, and caused periodic glacia-
tion of our hemisphere, thus satisfying the evidences of repeated
glacial periods.§

The great ice sheet profoundly changed many of the lesser de-

*See Croll's Climate and Time in their Geological Relations, and Physical
Cause of the Change of Climate During the Glacial Period.

‡ The northern midwinter would occur in aphelion in 13,000 years except
for the fact that the major axis of the earth's orbit makes a complete revo-
lution in about 108,000 years in the opposite direction to the equinoctial mo-
tion, thus shortening the precession period by about 2500 years for a semi-
revolution, or 5000 years for the complete revolution of the equinoxes.

§ The before-mentioned glacial action in high latitudes, following the Car-oniferous period, was probably due to causes similar to those just men-
tioned.
tails of our continent. As the glacial mass moved southward from the Laurentian highlands of Canada, across the St. Lawrence River, it dammed that outlet of the Great Lakes, thus raising their water-level about 500 feet, and turning the water from Lake Ontario southward through the valleys of the Mohawk and Hudson Rivers. A closing of the outlet of Lake Michigan turned the water of that lake southwestward through the Illinois River, and thence through the Mississippi to the Gulf of Mexico. An enormous, temporary lake was formed during the Glacial period which extended from Minnesota and North Dakota far northward into Canada and exceeded in area the combined surfaces of the Great Lakes. Even the preglacial lakes were expanded, rivers were deepened and widened, and many of the small lakes of New York, Wisconsin, and Minnesota were created through the erosive action of the glaciers.

During the interglacial epochs, the fauna and flora would follow the ice sheet northward, to be again driven backward to the tropics and the southern temperate zone when the great, ice Juggernaut again migrated southward. Five times the glaciers and the organic life fought back and forth across the continent, and then the ice sheet retreated to the mountain tops, or far northward to Greenland and the Arctics, to become the present remnants of their past glory, and temperate and frigid zone fauna and flora either ascended the mountain sides or migrated to their natural habitat in northern latitudes.

The faunal and floral reclamation of North America was probably coincident with a lessening of the earth’s orbital eccentricity, and the approach of a northern perihelion winter, i. e., midwinter when nearest the sun.

The increase in terrestrial temperature at the close of the Ice age may have been augmented by another cause, according to the theory of Professor Frech.* He argues “That there is a parallelism between the maxima of terrestrial temperatures and the maxima of volcanic activity, and that there is a simultaneity between the glacial epochs, and the minima of eruptive activity.” In other words, the volcanoes are responsible for the major portion of the carbon dioxide present in the atmosphere. Carbon dioxide in the air prevents the rapid radiation of the heat energy from the earth, acquired through the radiant energy of the sun. Plant life constantly consumes carbon dioxide, thus robbing the air of its initial charge of this important gas. The luxuriant vegetation of the Carboniferous and succeeding periods would have necessarily reduced the charge of carbon.

* See Monthly Weather Review, p. 31, January, 1903.
dioxide, and caused more rapid refrigeration, and the work of re-
charging the air would have devolved upon the volcanoes. If the
supply from this source fell below the demand of vegetation, re-
frig-
eration and glaciation would have resulted as demonstrated in mild
form during the close of the Paleozoic era and in the severe type
of the dawn of the present or Quarternary. "The diminution of
eruptions in the last portion of the Tertiary period runs parallel
with the diminution of heat: the glacial epoch (precisely as in the
case of the Paleozoic cold period) is to be recognized by an almost
perfect cessation of eruptive activity, but the present epoch by a
renewed activity."* From the above statements it is reasonable to
conclude that the diminution in volcanic activity and the resultant
decrease in atmospheric carbon dioxide assisted in the refrigeration
of the earth during the Glacial period.

Some idea of the enormous work done by volcanoes may be
conceived when one considers that, besides raising the temperature
in their immediate vicinity, they throw out vast quantities of lava,
steam, sulphurous gases, sulphurated hydrogen, hydrochloric acid,
methane and carbon dioxide. Krakatoa in 1883 is said to have
ejected 4.3 cubic miles of solid and liquid matter, besides an enor-
mous quantity of highly heated and noxious gases. Pelée, during
certain days in May and August, 1902, ejected material in bulk,
greater than the sediment discharged by the Mississippi River in a
full year—7,500,000,000 cubic feet. The recent activity of Mt.
Vesuvius is a painful reminder of their capabilities.

When the great ice caps had disappeared, and the plant and
animal kingdoms regained their ancient homes, many of the older
types had passed to their long, last rest, and harder, brainier genera
and species appeared, among them the genus Homo, the climax
of creation. Man has come down through the Rough, the Smooth
Stone, and the Bronze ages, to the Iron age, advancing by slow
degrees through the stages of savagery, barbarism, and civiliza-
tion, to the present stage of enlightenment. But throughout the tradi-
tional and written history of the human race, climate has shown
but little change. The view just stated is held by Prof. Willis L.
Moore, Chief U. S. Weather Bureau, from whom I quote as fol-
lows:*:

"Notwithstanding the popular notion to the contrary, there is
reason to believe that there has been no appreciable change in the
climate of any large area within the period covered by authentic
history. Changes in the surface of the earth may be noted within

the lifetime of an individual, that are thought to prove that a change in climate has taken place, when the alterations may be due to the persistent action of freezing, thawing, rainfall, and flood. Great changes have occurred during geologic periods, but it is the opinion of the writer that they take place so slowly that thousands of years must elapse before their effect is measurable."

The past life of man is as yesterday compared to the unnum-
bered years stretching far back to the earliest era of creation, when "the earth was without form and void," and who can tell but that the evolution of climate is surely and slowly progressing toward a definite end. Stop to think that the mass of our present atmosphere is only five quadrillion tons or $\frac{1}{1200000}$ of the earth's mass; that after the solid portion of the earth was formed, the air contained all of the water vapor, now constituting the oceans, lakes, and seas, amounting to 1,300 quadrillion tons, or $\frac{1}{4540}$ part of the entire earth. At that time the water vapor alone was 260 times the present mass of the entire atmosphere. Consider how the air has shrunk through all the years until it has become a thin residual of the vast, primitive atmosphere.

Through the millions of years to come, science tells us that the earth will rotate more slowly, through tidal friction, until the same face will ultimately be turned constantly toward the dying sun. The attenuated atmosphere will become yet more tenuous, and finally, in the far-off end, all gases will turn to liquids, and the liquid shell will freeze upon or within the surface of a cold and lifeless sphere,

"When the sun grows cold,
And the stars grow old,
And the leaves of the Judgment Book unfold."