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The Geological Story of Kansas

By L. C. Wooster

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TWENTIETH CENTURY CLASSICS AND SCHOOL READINGS

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THE GEOLOGICAL STORY OF KANSAS

BY

L. C. WOOSTER, Ph. D.,

Department of Botany, Zoology, Physiography and Geology, State Normal School, Emporia, Kansas.

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AUTHOR'S PREFACE.

THIS Geological Story of Kansas has been prepared for both the student and the general reader. The student will find the conclusions and the statements of general principles of service while doing research work in geology and while making a final review of the subject; and it is hoped that the general reader will find this story helpful to him in reaching a better understanding of the geological history of Kansas.

The myriad observations on which this story is based could not be given in the limits of this booklet, nor, indeed, of a hundred booklets. The proper place for the record of such observations is in the field note-book, and in the great reference books prepared by State surveys. Incorporated in a story, they would have little significance, except to their author. All others would find them dry and uninteresting.

To be appreciated, understood and enjoyed, the facts of observation must be gathered by each one, either from Nature's storehouses or from the reference books of libraries, just as fast as one needs them in formulating conclusions and no faster.

Original research work in the field takes much more time than research work in libraries, and it is therefore wise to combine the two methods of gathering information; but either should not be used to the exclusion of the other. The author earnestly advises both the student and the general reader to spend all the time they can spare doing research work in the field, and then spend the remainder of their time for research in the libraries.

The following books of reference have been consulted freely in preparing this story, and the author would commend them to all who desire to do library research work in connection with this Geological Story of Kansas:

First, must come the five reports of the University Geological Survey of Kansas. These contain such a wealth of material respecting the structure, resources and development of Kansas, that every high school, academy and college should possess copies.

Second, the student and general reader will find Le Conte's Elements of Geology, a book of exceptional value on the science and philosophy of geology.

Third, the author would name Dana's Manual of Geology. This compendium of geological information has been the most serviceable companion of all geologists doing field work in America and in foreign lands.

Fourth, and by no means least, is Scott's Introduction to Geology. This book contains the results, concisely stated, of the latest investigations of the geology of the United States.

Most text-books in geology give, first, a more or less choice collection of information on this subject, obtained from collectors; second, a statement of the conclusions of the most eminent scientists in each of the departments of geology; and third, full discussions of the theories of the scientist-philosophers who have sought and found the fundamental principles that have governed the evolution of the earth and its inhabitants. The author of this booklet has attempted to give a story of Kansas geology which shall contain only the more valuable conclusions and theories of men of science and philosophy. He has left the research work, the gathering of the myriads of facts of observation, on which these conclusions and theories are based, to the student and general reader.

L. C. W.

EMPORIA, KANSAS, Feb. 10, 1900.

THE GEOLOGICAL STORY OF KANSAS.

1. THE INTRODUCTION.

The white man has occupied the bottoms and prairies of Kansas nearly fifty years, the red man may have chased the bison across the plains lying between the Missouri river and the Rocky Mountains for fifty centuries, and the geologist tells us that for more than three hundred thousand centuries, before the advent of man on the face of the earth, wild beasts, huge reptiles and savage fish struggled for food and mastery within what are now the boundaries of our commonwealth.

During the three hundred thousand centuries of animal warfare, there must have been many wonderful changes in our Kansas Land, but they are unrecorded on the pages of any Kansas History, for they had no chronicler; during the fifty centuries in which the red man roamed, unrestrained by the white, over the broad plains in search of food and battle, no historian appeared to record the more stirring events for the generations of white boys who love to read of Indian warfare and strategy: only during the past fifty years have the great changes in Kansas surface and inhabitants been faithfully inscribed on the pages of history. To learn aught of what transpired in Kansas during the eons before the advent of the white man, would seem, at first thought, to be beyond the power of the human intellect to accomplish; but the geologist took the second thought, decided that he could and would learn something of that most ancient history, bent his energies to the problem, and has succeeded even beyond his hopes. Thanks to his efforts, it is now possible to write a fairly complete history of our Kansas Land for the myriads of centuries which preceded the coming of the red man and the white man.

To understand this history one must become to a degree a geologist, for to all except the geologist the tale is too wonderful to seem entirely true. Therefore our first efforts must be directed towards the mastery of the more elementary principles of the science of geology.

Geology may be defined as the history of the evolution of the earth and its inhabitants, as revealed in its structure, and as interpreted by causes now in operation.

That division of the subject in which we study causes now in operation is termed dynamical geology, and includes much of what is studied in physical geography. The study of the structure of the earth is termed structural geology; and of the evolution of the earth and its inhabitants, historical geology.

2. DYNAMICAL GEOLOGY.

1. CHEMICAL AND MECHANICAL AGENCIES.

The chief agencies now operating at the surface of the earth to modify it are oxygen, carbon dioxide, water at rest, frost, wind, water in motion, and glaciers.

1. Oxygen.

Perhaps oxygen should not have been given in this list, for it long since united with most of the elementary substances in the earth's outer crust and modified the composition of many of its minerals; but it is still active in producing decomposition of vegetable tissues and certain minerals, in unlocking energy for plants and animals, and in the rusting of metals, especially of iron.

2. Carbon Dioxide.

Carbon dioxide prevents in large measure the escape of radiant heat from the earth, and thus renders it habitable by man over a large portion of its surface. It is the chief agent in causing the solution of limestones, in producing their rapid weathering, and in excavating underground waterways and caverns. Limestone is but slightly soluble in pure water, but is readily dissolved in water containing carbon dioxide.

Carbon dioxide, besides serving as a blanket to retain at the surface of the earth the heat derived from its interior and from the sun, and besides being the chief agent in causing the solution of the calcite of limestone and of other minerals in various rocks, is an indispensable food to vegetable life, constituting with water the material out of which more than half of the substance of all green plants is manufactured.

3. Water at Rest.

Most water at rest in the earth and on its surface contains an excess of carbon dioxide derived from decomposing organic matter and possibly from the earth's interior, especially in volcanic regions. As has been already stated, water holding an excess of carbon dioxide is an active solvent of calcite, and is therefore able to disintegrate rapidly all limestones and other rocks containing calcite.

As all know, rainwater is soft while falling, but quickly becomes hard when it has penetrated any rock containing calcite. Granite consists of quartz, feldspar and mica with no calcite, and hence, in all regions where the subjacent rock is granite, standing and running waters are soft. But in all regions where calcite is found in the soil, subsoil, or underlying rock, whether sandstone or limestone, the standing and running waters are always hard.

When hard water, holding calcium bicarbonate in solution, is heated or slowly evaporates, the extra carbon dioxide deserts the calcite, and the latter collects as a solid on the bottoms of teakettles, on the pipes of steam-engine boilers, on sticks, stones and moss of springs, in fissures in the rocks, and as the stalactites and stalagmites of caves.

In regions where the subjacent rock is a calcareous sandstone, the rainwater holding carbon dioxide dissolves the calcite, the sandstone crumbles, and a sandy soil results; where the subjacent rock is an impure limestone, the removal of the calcite leaves a heavy, clay soil.

Should the limestone be several hundred feet in thickness, the rainwater with carbon dioxide readily penetrates the interior of the stratum through joints and fissures, dissolves the calcite from the sides of the passageways, and caves of enormous extent result. The Mammoth Cave of Kentucky, the Wyandotte Cave of Indiana, and most other caverns were formed in this way. When the passageways become too broad for the walls to support the roof, great blocks of limestone fall to the floor, where they remain obstructing the passageway, or till they are dissolved and the calcite passes with the water to the outside world or underground to the sea.

Sometimes the water which penetrates limestone strata is so heavily charged with calcite that it deposits this mineral in the cavities, large and small, in the rock, making it very compact. The so-called Iola marble was formed this way. This deposition of calcite likewise occurs in mineral veins, where water saturated with calcite is compelled, for some reason, to drop a portion of its burden and deposits it in the vein walls and in the cavities of the ores.

Water at rest, when warm and holding in solution some alkali, readily dissolves the quartz of granite, sandstones and volcanic rocks, and helps in segregating the silica of limestone mud. When the water cools or the alkali is neutralized by some acid, the silica (quartz) is deposited where the water chances to be, in cavities, in fissures, in veins, in soft rock, or in wood. In the last case the wood is said to be petrified. The decaying wood may have given an acid to the water, thus neutralizing the alkali and causing a particle of silica to replace each particle of wood as it decays. Petrified or silicified wood in which the exact structure of the original is preserved, is found in all parts of Kansas.

When the silica is deposited among the grains of sand of sandstone, a very hard rock results, known as quartzite. This is a petrified or silicified sandstone, and is not uncommon in Cambrian strata.

The method by which the particles of silica were segregated in limestone mud, assuming finally the form of flint nodules, is not well understood; but it is deserving of study, for the lead and the zinc ores of southeastern Kansas are found with these nodules. Similar nodules of flint are found in the limestones of the Flint Hills of Chautauqua, Elk, Greenwood, Chase and Lyon counties, Kansas, together with a small amount of lead and zinc ores.

4. Frost.

The work of frost is most marked in northern latitudes, where the frost penetrates from five to twenty-five feet and more into the crust of the earth, rending all porous rocks, widening fissures and loosening the heavy soils. The disintegration of the rocks is thus hastened, and soils are made more permeable and productive.

In Kansas the frost, penetrating the crust but two or three feet, is not nearly so potent an agent in splintering the rocks and in loosening the soil, as in the north temperate regions; but the work of this agent in our State is far from being unimportant, as one will observe if he compares the fall contours of our bluffs with their spring contours.

The loosening power of frost is a somewhat serious matter to farmers, for the frost-loosened soil of the cultivated fields is readily dissolved by the spring rains, and thus the way is prepared for rapid work by the next agents to be considered,—wind, and water in motion.

5. Wind.

The effect of wind on the surface of the earth is most marked where the soil contains a large proportion of sand, and on the leeward side of lakes and rivers and the ocean. The Red Beds of southwestern Kansas, the Dakota sandstone of central Kansas and the marlites of western Kansas yield an abundance of loose sand in disintegration, and hence sandhills or dunes are most abundant in those portions of the State where these formations outcrop. The Arkansas valley cuts through the same formations, and hence beds of sand are not uncommon in its vicinity, where the wind has driven the sand from the river-margin.

The sand-dunes on the eastern shore of Lake Michigan, on Cape Cod, along the coasts of the Carolinas, of England, and of many other parts of the world, formed by the agency of the wind, have buried with sand many square miles of productive land, and the inhabitants of these countries use all known devices to bind the sand in its place so the wind cannot get at it to drive it inland.

The sand, besides burying much valuable soil, is a very active agent in western Kansas in etching the cliffs which border the river valleys. Driven by the wind, the sharp grains beat against the rock, cut out the softer portions, and leave it sculptured in all sorts of fantastic shapes. Even the harder portions are rounded and otherwise carved so that their outlines harmonize with those of the softer layers. In these ways are formed from cliffs, isolated by running water, the castles and monuments in all portions of the West.

6. Water in Motion.

Under this head may be considered the work of rivers, waves, and tides. Each one of these agencies erodes the surface of the earth and transports the débris to some point at a distance from its source, and there deposits it in a way peculiar to water and in a series of layers known in general as Sediments.

1. Rivers as Erosive Agents.

To erode means to gnaw or to cut into. The most obvious thing in observing the topography of any portion of

Kansas is the fact that the rivers, creeks and streamlets have deeply eroded the surface of our State. Each stream and streamlet has a valley of its own, evidently fashioned by its waters. Many beautiful fields are cut up in a way most distasteful to the one who desires to till them, by the floods which accompany heavy rains, and former valleys are deepened and broadened. Stand on any eminence, and one will have spread out before him a topography which shows on every hand the effects of the gnawing power of water. Not even the bottom lands of Kansas, the lands that have been most recently made, have escaped the erosion of water in motion.

Physicists tell us that the power of water to erode varies as the square of the velocity. This agrees with what all have observed, for all know that water with a doubled velocity has greatly increased erosive power.

The power to erode is likewise increased by the presence of sediment in currents of water. Wind alone would have little power to etch the face of cliffs, but furnished with grains of sand it rapidly gnaws into the surface even of the hardest rock. So water carrying silt and sand cuts into the soil and indurated rock far more rapidly than clear water. This action is termed corrasion. Water in rivers frequently corrades the banks so deeply that large sections fall into the current and are washed away. This is termed sapping.

The muddy Missouri river is such a powerful corrading and sapping agent that it is unsafe to build homes near its banks, and its channel in times of flood makes such wide changes in its course that valuable bridges become useless, and great cities are threatened with destruction.

So seriously does the Missouri river menace property of great value that it is proposed by engineers that extensive reservoirs be constructed along the upper courses of the Missouri and its tributaries,—not alone to prevent great floods and to provide water for irrigation and summer navigation, but also to free the water from its silt, that it may not corrade and sap the banks as it does now at all stages of water.

2. Rivers as Transporting Agents.

The erosive power of rivers would be very slight if the water did not remove the material eroded so that a fresh surface is exposed to the action of running water. The transporting power of streams is in part due to the fact that there are side currents, whirling currents, and even revolving currents in the stream as it moves along in its tortuous and uneven channel. As a pebble or grain of sand is heavier than the water it displaces, when it has gained the velocity of the stream it is sure to descend to the bottom in a more or less inclined path, unless it meets an ascending current. When it has reached the bottom, however, it loses its velocity, and the water lifts it forward on another journey, to be terminated by another stop and period of rest.

This power of streams to transport solids varies, according to physicists, as the sixth power of the velocity. According to this law, if the velocity of a stream is doubled it can transport a stone sixty-four times as heavy. This is made evident when we remember that the striking power of water when the velocity is doubled is four times as great as before, and that a stone weighing sixty-four times as much presents sixteen times the surface of the smaller stone to the action of the current of water. Thus a force four times as great as another, acting on sixteen times as large a surface, would exert sixty-four times the power. Experiments have shown that this reasoning is correct:

Currents moving 3 in. per second carry fine clay.
Currents moving 6 in. per second carry fine sand.
Currents moving 8 in. per second carry coarse sand.
Currents moving 12 in. per second carry gravel.
Currents moving 24 in. per second carry pebbles.
Currents moving 36 in. per second carry 3-oz. pebbles.

As all rivers rising in mountains or highlands descend to lower levels more rapidly in the upper part of their course than in the lower part, the water has a much higher velocity, as it leaves the mountains and highlands, than when it approaches the sea. Hence, in all such rivers, boulders alone are left behind, and thus characterize their upper courses, medium-sized material their middle, and silt their lower courses. The high transporting power of the stream has caused the removal of the finer material from its bed in the mountains and highlands, and its diminishing transporting power as it approaches the sea causes it to drop first, the coarser portions of its load, in the middle of its course, and then the finer as it approaches the salt water.

As all rivers, in highlands and mountains, possess high erosive and transporting power, these streams cut deeply into the mountains, and carry great quantities of débris to the lowlands bordering the ocean. This action continues till these streams have reached a theoretic condition termed their base-level. The rivers of any basin are said to be at their base-level when they neither erode nor deposit material in any part of their course before they reach the ocean. It is not known that any river system has ever attained this condition, but all river systems tend to do so. The base-level of a river system is not the same as sea-level, for in that case the streams would cease to flow, and would no longer be rivers. The base-level of a river-basin is such a level that the streams draining it simply flow to the sea without erosion or deposition of material. Such a river-basin is termed a peneplain.

A river system is young when it is made to cut a new base-level for its basin by reason of a great and extensive elevation of the continent. The rivers of such a system are characterized by waterfalls and rapids near their mouths and broad valleys towards their sources. In middle age, such a system of rivers is characterized by narrow valleys and cañons in the middle and upper portions of their courses. But in old age the valleys again become wide and waterfalls and rapids have disappeared.

Nearly all the rivers of Kansas are past middle age.

The St. Lawrence river system is in its prime, for rapids are found in the St. Lawrence river near Montreal, and the greatest waterfall of the continent exists in the Niagara river between Lakes Ontario and Erie.

The rivers of the South Atlantic and Gulf States possess rapids about midway between the mountains and the sea, and hence would seem to have nearly reached middle age; but this condition was brought about by the removal of the coast-line eastward and southward by a geologically recent elevation of the South Atlantic States.

Richmond, Raleigh, Columbia, Augusta, Macon and Columbus are near the ancient coast-line and not far from the rapids of the streams on which they are situated. Thus the rapids have not receded far from the ancient mouths of these streams, and the rivers were therefore rejuvenated by the elevation of this part of the continent. On the other hand, should a basin at or near base-level sink to a lower level, it is said to be wholly or partially drowned.

In some cases, one or more rivers of a system have much harder rocks to erode than the others, and are consequently much behind them in the work of erosion, possessing rapids and falls long after the other streams have cleaned out and broadened their valleys. The rivers which rise in the Flint Hills of east-central Kansas are in this belated condition.

Those rivers of a system which receive a heavier rainfall or have softer rocks to erode, deepen their valleys very rapidly and push their divides into the territory of neighboring streams. In such cases they may capture some of the tributaries of their neighbors, when they are termed pirates.

There is some evidence to the effect that the Smoky Hill river once emptied into the Arkansas river by way of the Little Arkansas. This may have been brought about by the advance of a great glacier from the north, thus obstructing the Kaw valley at Topeka and Lawrence, or it may have been a case of capture of the Smoky Hill river by the Republican river, aided by the Solomon and Big Blue. The problem is an interesting one, and requires more study for its solution.

Observations on waterfalls prove that they move up-stream. There is always at a waterfall a soft stratum of rock beneath a harder stratum. The soft stratum is dug back more rapidly than the hard stratum, and thus the hard stratum projects down-stream farther than the soft one, and is removed mostly by sapping. The rate at which waterfalls recede has been approximately ascertained in a few cases, and the age of the fall has been used as a measuring-rod in estimating the age of the American continent. The rates of recession of the Falls of St. Anthony and Niagara Falls have been thus used to determine the time that has elapsed since the disappearance of the ice of the Glacial Epoch, and this time has served as the measuring-rod in estimating all time.

As will be explained more fully in Historical Geology, the Quaternary Age is subdivided into the Glacial, Champlain and Recent Epochs. The Glacial Epoch was many times longer than both the others combined; and was characterized by great elevation of North America and Europe, and by cold sufficiently great to cause the formation of great glaciers in Canada and the Cordilleras of British Columbia, and a southward movement of the ice into the United States. A similar movement occurred in Europe.

The Champlain Epoch covers the period of subsidence of northern lands, of sluggish rivers, great lakes, warm climate, and slow melting of the ice of the glaciers.

The Recent Epoch has witnessed a partial return to the conditions of the Glacial Epoch.

Niagara Falls were once at Queenstown Heights, near Lake Ontario. They have receded about seven miles to their present position. Some good authorities estimate the rate of recession at one foot per year, others think that it is three feet. Taking two feet per year as an average rate, the Falls have been twenty thousand years receding to their present position. This time, twenty thousand years, is taken to be the time that has elapsed since the partial melting of the Laurentide Glacier and the removal of the ice from the basin of Lake Ontario.

The Falls of St. Anthony, at Minneapolis, Minnesota, have receded northward from the escarpment of a high plateau bordering the Minnesota river a distance of eight miles. The time of recession is estimated, on good authority, at eight or ten thousand years. As the direction of recession is northward, the excavation of the gorge below the falls could not have begun till after the close of the Champlain Epoch, for southward-flowing streams could do little or no work of erosion till the northern lands became re-elevated during the Recent Epoch. The two estimates, therefore, are readily harmonized.

But the time that has elapsed since the recession of the Laurentide Glacier is but a very small fraction of the time that has elapsed since the appearance of life on the earth. Without attempting at this place to give the data upon which are based the estimates of the length of time that has elapsed since the beginning of the third eon of creation, as given in Genesis, it may be stated that conservative estimates make this time to have been thirty million to forty-five million years in length.

The length of time required by river systems to lower their basins one foot has been estimated by measuring the volume of water discharged by the system each year into the ocean, and weighing the average amount of solids held in solution and in suspension by each cubic foot of water. Dividing the total weight of solids emptied into the sea by the number of square feet in area of the basin gives the weight removed per square foot. This is found to be sufficient in the case of the Mississippi basin to lower the surface one foot in five thousand years.

At this rate, if eastern Kansas has been exposed to erosive action for eight million years, a layer one thousand six hundred feet thick has been removed from that part of the State and deposited elsewhere.

But not all the solids removed by the rivers of the Mississippi system reach the Gulf of Mexico. Much sediment is deposited on the bottoms along the lower courses of the rivers, especially in times of flood, and thus the above estimates are below rather than above the truth.

3. Deposits Made by Rivers.

Wherever the current of a river slackens, there it must leave the coarsest material it is carrying; if the current stops, the finest silt settles slowly to the bottom.

According to Prof. Brewer of Yale, fine silt requires fifteen to twenty days to settle to the bottom of quiet ponds and lakes. In salt water, such silt reaches the bottom in only two or three days. In consequence of these different rates of deposition, the bottoms of fresh-water ponds and lakes are silted up evenly, while salt seas and the ocean receive the silt only along their margins. The effect of this law of deposition will be discussed when that topic is reached in Structural Geology.

In rivers it will be remembered that water slackens its speed whenever the channel broadens, in places where the river overflows its banks, and where the river encounters tide-water, either in its course or on entering the sea. No one with experience would ford a river where it is broad and the water sluggish, for he would there expect deep mud. Those who have run levels across flood plains know that they are usually highest near the stream, where the current of water, in times of flood, is most quickly checked. The coarser silt is dropped here and constitutes the natural levee. The third place where the current of a river is checked, that where the tide is encountered, is marked by a bar, and this is situated at the mouth and sometimes at the limit of high tide. The Hudson river has a bar, which is a serious hindrance to navigation, near Albany, and another, less serious, at its mouth.

Wherever sediment is deposited on the bottom of a slowly retarded stream of water, it is spread out in a broad and nearly horizontal sheet. As the velocity of a river varies from day to day and from season to season, the coarseness of the material deposited on any one portion of the bed will vary also. This causes an alternation of layers of different degrees of coarseness. Such sediments are said to be stratified. The amount of sediment deposited on any one portion of the bed each year is found to be very small,—not more than enough, usually, than would be sufficient to make a compact layer of rock one-tenth to one-fourth of an inch in thickness per annum. The first number is also believed to be very nearly the average annual thickness of river sediments spread over the bottoms of lakes and along ocean margins. Such sediments are likewise spread out in layers and in a horizontal position.

So universal is the application of the statements made in the above paragraph that they are termed fundamental principles of geology. They are so important that I re-state them:

1st. All sediments are stratified.

2d. All undisturbed sediments are horizontal.

3d. All sediments are slowly deposited.

Corollary: Since most stratified rocks are believed to be consolidated sediments, they were slowly deposited in a horizontal position.

This is true of all the rocks at the surface in Kansas, and throughout most of the United States. All folding and tilting of the strata have been produced by crustal movements subsequent to their deposition.

4. Erosion, Transportation and Deposition by Waves.

Storm-driven waves dash pebbles and boulders against sea-cliffs and corrade them deeply. On gently sloping beaches the waves have less effect in gnawing into the coast-line, but all shingle on such beaches is eventually pulverized and carried by the undertow into deep water and deposited in horizontal layers.

In sheltered coves receiving sandstone débris, the gentle wave-motion arranges sand in nearly parallel ridges, forming in the bottom ripple-marks like those at the surface of the water. More rarely ripple-marks are formed in limestone mud. Such cases are exceptional, for its particles do not yield themselves so readily to the influence of gentle wave-action as do the particles of sand. Nearly all sandstones are ripple-marked in some of their layers, but the only ripple-marked limestone known to the writer is found in the Flint Hills of Greenwood, Chase and Lyon counties, Kansas.

Where the wave-action is violent, fine and coarse water-worn materials are intermingled and disposed in beds dipping in diverse directions and at all angles.

5. Erosion, Transportation and Deposition by Tides.

Tides, like ocean currents, have little influence in modifying coast-lines. They increase the vertical range of the work of wind-waves and scour out the mouths of rivers, carrying the débris out to sea, where it may be scattered still more widely by the ocean currents. As has been already stated, tidal currents flowing into rivers stop the flow of river water and cause bars to form at the highest point reached by the tidal influence. Such bars can be removed only by persistent dredging, as at Albany on the Hudson, for the conditions which cause their formation are perennial.

7. Glaciers.

About one-tenth of the surface of Kansas was in ancient times covered by a glacier which reached Kansas from the north across Nebraska and the Dakotas. This glacial lobe was a part of a continental ice-sheet which covered the northeastern United States during the Glacial Epoch.

The ice-sheet, most like the one which covered northeastern Kansas and the States north and east, is the great ice-mantle which covers Greenland at the present time. A brief summary of what has been learned by careful observations of the glaciers of Greenland, Alaska and Switzerland will enable the student to better comprehend the mode of formation and movement of these huge masses of ice and rock débris.

Wherever the climate is sufficiently damp and cool to cause more snow to fall during the year than melts or evaporates, the snow accumulates and finally descends to lower levels either as an avalanche or as a glacier. Where the slope is very abrupt, it may descend suddenly as an avalanche, but where it is more gentle it flows from the higher elevation to a lower one as a glacier or ice river. The laws of glacier formation and movement may be briefly stated as follows:

Wherever snow accumulates to a great depth, and lies for a number of years, repeated thawings and freezings cause it to become coarsely granular; such granular snow is termed névé. With a greater increase in the depth of the snow, the lower portions are compressed by the great weight into, first, a vesicular ice, and next into alternating bands of vesicular and blue ice; this, at length, escapes from the superincumbent mass of névé, and moves through some valley, broad or narrow, to lower levels, moving in most respects like a river of water. This is the glacier, and it continues to move onward till it either enters the sea or reaches a level where the heat is sufficient to melt the ice as fast as it moves forward. In the first case, the waves of the ocean and the buoyancy of the water break off the snout of the glacier, and the great mass of ice floats away as an iceberg. The berg melts slowly as it moves out into the ocean, and drops the rocks and earth which were held in the glacial ice, far out at sea. In the second case, the melting ice serves as the fountain-head for a stream of milky water, which flows out from beneath the ice, and onward to the ocean. The coarser rock-débris is left in great heaps at the foot of the glacier.

As the glacier moves through its narrow valley or over the uneven surface of a plain, its great weight enables it to remove all obstructing inequalities at its sides and bottom. Hills and ridges are leveled and the fragments pushed into neighboring valleys. Grains of sand and boulders held in the bottom and sides of the glacier serve to polish and striate the solid rock over which the glacier moves.

The boulders and crushed rock fragments beneath the ice are termed its ground moraine; those on top of the glacier are either its lateral or medial moraines; and the great heaps of rounded and angular material left by the melting ice at the termination of the glacier form its terminal moraine.

People who have never seen ice except in ponds and rivers find it difficult to conceive of ice as flowing, in most respects, like water in rivers; but Forbes, Tyndall and Agassiz have proved by their observations of glaciers in the Alps that the middle of the glacier moves more rapidly than the sides; that the top moves more rapidly than the bottom; and that the line of swiftest motion is more sinuous than the channel. In rate of flow alone do glaciers differ much from rivers.

It has been ascertained also that glaciers move more rapidly in the daytime than at night, and in summer than in winter; and that the thicker and broader the glacier, the more rapid is its flow.

Men of science have differed somewhat widely in their explanations of the cause and manner of glacier movement. All admit that gravity is the chief cause of motion, and that slope of the upper surface of a glacier and not of its lower surface is essential to its motion. Glaciers move over a level plain and even up an opposing hill or mountain, provided the upper surface of the ice continues to slope towards the obstacle.

The chief theories advanced to explain the flow of glaciers are those of Forbes, Tyndall, and Thomson. Forbes thought that ice moved like a viscous body such as tar or asphaltum. Even a stick of sealing-wax may be bent into the form of a horseshoe without fracture if time enough be given to the operation. Tyndall thought that the ice broke, the parts slipped by each other, and froze together again, thus permitting differential motion. Thomson proved that great pressure will cause ice to melt; he maintained that flowing ice melted at points of stress, and solidified when the stress was relieved. Each of these three theories explains flowage of ice, and each is supported by experimental proof; but the last theory is most generally accepted as the one which explains the most of the conditions of glacial flow.

As geological agents, glaciers broaden valleys, level uneven surfaces, transport an amount of material limited only by the supply, and deposit débris, as a rule, in a heterogeneous, unstratified condition. Should the glacier, however, enter a body of water, and the water collect as a lake at its front, the rock-débris would be more or less stratified; but the polished, striated and polygonal form of the boulders would, in these cases, reveal the glacial origin of the material.

8. Summary.

Each of the chemical and mechanical agencies is engaged in base-leveling the river-basins and in reducing the entire continent to a peneplain. With sufficient time in which to operate and with no disturbing influences to counterbalance their activities, every mountain and highland would be lowered nearly to sea-level and the rock-fragments be distributed along the borders of the oceans and seas. A peneplain, through which the rivers flow without erosion, transportation or deposition of solid material, would be the final result of the activities of oxygen, carbon dioxide, water at rest, frost, wind, water in motion, and glaciers.

2. IGNEOUS AGENCIES.

The igneous agencies are mostly deep-seated, and their activities are made known at the surface largely through volcanoes and earthquakes. Kansas shows on her broad plains but few of the effects of the igneous activities of the earth's interior; but, as her elevation above the level of the sea and her drainage and climate are largely the result of the interaction of igneous and mechanical agencies, they should both be considered in our geological story. Therefore we should next study the interior heat of the earth, and the causes and effects of volcanic activity and of earthquakes.

1. Interior Heat of the Earth.

The wide distribution of volcanoes and the great heat of the lava as it poured forth from the earth's interior have led people generally to believe that the earth is a great ball of liquid rock covered by a thin crust of solid rock. This belief was strengthened when it was observed that the water from artesian wells is much warmer than water at the surface, and that the heat in mines increases very rapidly as the shafts are sunk to greater depths. Careful measurements were made of the rate of increase in mines and artesian wells, and it was found that the temperature of the earth's crust increases one degree for every fifty-five or sixty feet of descent. At this rate of increase, all known substances would become molten at a depth of thirty miles, and hence it was reasoned that all materials beneath this thin crust of thirty miles must be in a liquid condition, and that volcanoes were simply vents out of which this liquid rock poured when the crust sank to a lower level in this or some neighboring portion of the earth.

The fluid condition of the earth's interior was universally taught in the schools till the geologist and physicist found a number of serious objections to this teaching.

Prof. J. D. Dana, in studying the volcanoes of Hawaii, discovered that Mount Loa, 13,760 feet in height, might be in active eruption, while Kilauea, 4,000 feet in height and only a few miles distant, was perfectly quiet, though showing liquid lava in its crater. Evidently these volcanoes are not vents for the same interior sea of molten rock.

Next the physicists learned that rock which would melt at a temperature of three thousand degrees under a pressure of one atmosphere, would remain solid at this temperature when subjected to a pressure of many atmospheres. At a depth of thirty miles the pressure is enormous, and, though hot enough to melt at the surface of the earth, the rocks cannot melt under that enormous pressure. Should we fix two hundred miles as the depth at which the heat might be sufficient to melt all known rocks, we should find that the pressure had increased to sixty tons to the square inch, and also that the degree of heat might be insufficient. So one may not find molten rock even at the earth's center. The physicists also maintain that were the earth's crust but thirty miles in thickness, it must yield to the tidal influence of the moon and sun. As it does not do so, except to a very slight degree, they declare that the earth must be more rigid than a ball of steel of the same dimensions. These considerations have caused all scientific men to abandon the theory of the molten interior of the earth.

But experimenters have learned that rocks, which require a temperature of three thousand degrees to fuse them with dry heat, melt very readily at a temperature of eight hundred degrees in the presence of hot water or superheated steam. Should alkali be present in the water, the temperature of fusion may be reduced even to four hundred degrees. As water penetrates the earth's interior to a very great depth, especially through fissures in mountain ranges, it is probable that great pockets of molten rock exist at the bottoms of these fissures, and these may be the source of supply for such great fissure eruptions as the one which covered portions of the States of Washington, Idaho, Oregon and California with a bed of lava.

As the heat of the earth's interior escapes to the surface by conduction and by the eruptions of volcanoes, and is there radiated into space, the earth's interior must be constantly losing heat energy, and therefore be contracting. But some portions will naturally contract more rapidly than others, and hence broad depressions will exist here and there on the earth's surface. The geologist believes that in this way ocean basins were formed. Other effects following the loss of heat energy will be described under Structural Geology.

2. Volcanoes.

The fertility of the soil in the vicinity of volcanoes has always tempted man to cultivate the surface even to the crater of Vulcan's forges; but he usually repents of his temerity when showered with stones and ashes, and flees for safety to the more sterile lowlands.

Volcanoes erupt stones, lava, cinders, ashes, and various gases. The stones are usually fragments of the floor of the crater. The lava consists of molten rock material, which may have originated at various depths in the crust of the earth. The cinders and ashes are formed from liquid lava, which is thrown high into the air, and cooled as it falls as rock-spray upon the cone of the volcano and upon the surrounding regions. Such violent eruptions are usually accompanied with heavy rains, which wash the ashes into pools of water, where they consolidate into a semi-stratified rock called tufa. Nine-tenths and frequently ninety-nine hundredths of the gas erupted is steam or water vapor. The other gases are carbon dioxide, hydrochloric acid gas, and sulphur vapor.

Various theories are advanced to account for volcanic eruptions, but none satisfies all the conditions of the problem. Hot water and superheated steam are certainly important factors in producing the fusion and eruption of lava, and it is possible that they are the chief agents.

It has seemed to the author that the conditions and explanations of volcanic eruptions may be summarized as follows:

(*a*) Volcanoes are usually situated in mountainous regions, where the crust is wrinkled and fractured.

(*b*) In some cases the fissures are so open and so deep that water penetrates far into the crust of the earth. At the bottom of a column of water in a fissure one hundred feet deep, water does not boil till it has reached a temperature of two hundred ninety-three degrees; at the bottom of a column of water in a fissure twenty thousand feet deep, the water before boiling would be hot enough to produce the fusion of the most obdurate rock. Perhaps it should be stated here, that this fusion is termed hydrothermic fusion.

(*c*) Where wrinkles are formed in the crust of the earth, the strata lean against one another in such a way as to relieve the rocks beneath of a portion of the great weight resting upon them. They were almost hot enough to melt in the dry way in spite of the enormous weight resting upon them before the wrinkle or arch was formed above them. With the relief of pressure caused by the arch, and with the more easy fusion caused by the presence of superheated water, the rocks do melt and rise through openings in the arch to the surface.

(*d*) As the molten rock and superheated water slowly rise in the fissure, the relief of pressure caused by this ascent to a higher level enables the superheated water to change into steam of enormous tension.

(*e*) As steam takes nearly two thousand times as much space as water, the formation of steam causes the column of molten rock, steam and superheated water to rise quickly to higher levels. The relief of pressure at these higher levels causes all the water to flash into steam, and the whole mass is violently ejected.

(*f*) This is in part the explanation of the eruption of geysers in Yellowstone National Park; but the geyser fissure is only one or two hundred feet deep, and the water and rocks of the surface crust are not hot enough to produce hydrothermic fusion of the latter, so water alone is erupted with the steam.

3. Earthquakes.

Tremors of the earth are most common in mountains, in regions bordering mountain ranges, and in all countries undergoing elevation or subsidence. These tremors are believed to be usually caused by readjustments of the strata in the interior of the earth. In the production of mountains, arches are formed in the interior of the crust with a space beneath. One side or the other of the arch may fall, and a quake at the surface results. The jar at the centrum of the earthquake starts a series of vibrations with a spherical front, in all respects analogous to the vibratory movements set up in the air by striking a log with an axe or by exploding a cracker.

At the point on the surface of the earth directly above the centrum, known as the epicentrum, the vibrating movement is vertical, and little damage is done on the land. In the ocean a great column of water is lifted vertically and then oscillates down and up, setting in motion a great sea-wave which reaches to the bottom of the deepest ocean and so piles up the water on shallow coast-lines that cities are inundated and the inhabitants drowned. In the middle of the ocean this wave is very broad and not high, but in the shallow water along the coast nearest the epicentrum it may rise to the height of sixty feet.

At a distance of some miles from the epicentrum on land surface, the greatest destruction to property occurs. The vibratory movement reaches the surface obliquely, and the horizontal element of its motion shakes down buildings or cracks their walls.

Earthquakes are interesting geologically because of the fissuring of the crust which accompanies them, because of the faulting of the strata penetrated by the fissures, and because of the myriad of tiny fissures in crystalline rocks caused by the earthquake vibrations. By faulting, is meant the vertical displacement of the strata along fissures, one side slipped down so the strata no longer correspond on the opposite sides of the fissure. These faults are not uncommon in the strata of Kansas, and they probably mark places of great slips in the crust which caused severe earthquake shocks, much to the discomfort of Kansas water and land animals, the only inhabitants.

4. Gradual Elevation and Depression of the Earth's Crust.

The more rapid loss of heat energy from some portions of the earth's interior than from others, causes a more rapid settling of the crust in those parts and the consequent production of ocean basins with continental masses between. The cool and consolidated outer strata of the earth, known as the crust, adjust themselves with difficulty to the shrinking interior. On the continents, and probably under the oceans too, portions sink and others rise with no observable order or regularity. The earth is so large that a sinking or rising of four thousand feet is but one foot in a mile, an amount imperceptible on a globe five feet in diameter. But to the earth's drainage and inhabitants this amount produces serious disturbances.

When great masses of material are shifted from mountain regions to the deltas at the mouths of rivers, the deltas are found to sink under the load, and it is believed that a corresponding rise occurs in the mountain plateaus. The rise of the plateaus, however, does not keep pace with the erosion and transportation of the rock débris to distant regions, for it is known that the older ranges of mountains are much the lower, undoubtedly from the effects of erosion.

Risings and fallings of the earth's crust were most easily observed along the borders of the continents before the invention of instruments of precision for obtaining elevations. Since these instruments have been in use, too little time has elapsed to show marked changes in height of the interior of the continents by comparisons of the readings of such instruments. Hence proofs of gradual changes of elevation of the earth's crust have been sought along the coasts of the oceans.

A very ancient channel of the Hudson river extends along the bottom of the ocean some eighty miles southeast from New York. Its ancient mouth is submerged over two thousand feet.

In northern Scandinavia an old sea-beach may be seen some fifty miles inland, and it stretches along at heights varying from one hundred to six hundred feet above the level of the ocean. The beach contains shells of mollusks of kinds exactly the same as those found now in the ocean.

For six hundred miles along its southern coast, Greenland is sinking so rapidly that boat-stakes driven in the shore a few centuries ago may now be seen in deep water near the shore.

In similar ways it has been found that Labrador is rising, while the South Atlantic States are sinking.

For three thousand miles the coast of southern South America is rising. Old sea-beaches are found at heights of one hundred feet, one thousand three hundred feet, and three thousand feet. Alexander Agassiz found dead corals at an elevation of three thousand feet on the slopes of the Andes, of the same species as corals now living in the Pacific ocean.

Movements up or down in all portions in modern times may also be demonstrated by a study of the base-leveling action of rivers in downward and lateral corrasion; and many wonderful results in this direction have been obtained by investigators in recent years.

5. Summary of Igneous Agencies.

While the general effect of chemical and mechanical agencies is to lower the land surfaces to a peneplain, and to distribute the débris over the floor of the oceans adjacent to the continents, the general effect of the igneous agencies is to elevate the continents and depress the ocean bottoms.

If these agencies were equal in their effects, the relative areas of the continents and oceans would remain nearly unchanged; but that they are not so, is proven by the fact that the dry land is increasing in area at the expense of the ocean. The continents are likewise increasing in average elevation in spite of erosion and removal of débris.

3. ORGANIC AGENCIES.

All life-forms flourish only at or near the surface of the earth, either in the waters of the oceans, lakes and rivers, on the land surfaces, or in the air above. If their tissues are soft, little may remain of their bodies after death except some oils and gases; if their tissues are hardened by a deposit of cellulose, chitine, or carbonate of lime, they may be preserved and contribute to an increase in the thickness of the earth's stratified crust. Owing to the rapid decay of all tissues exposed to the action of atmospheric agencies, the skeletons of land animals are not preserved unless the animal was drowned in water or mired in a bog. Hence the fossilized skeletons of both land and water animals are preserved in the hollows of the land surfaces occupied by water, and in the border seas and oceans.

1. Vegetable Accumulations.

Little remains of vegetable matter which falls on land surfaces except the particles of carbon which give the black color to the soil. The greater bulk is lost through aërial decay and the attacks of other organisms. But when the vegetable matter is deposited in water, the form of decomposition is so different that fully one-fifth of the total weight remains. Should these vegetable accumulations under water be largely free from earthy sediments, they in time become peat, and later, coal.

Such places of deposit of vegetable matter under water are termed peat-bogs, and much of the fuel burned in many countries in northern latitudes is derived from these peat-bogs. The bogs and swamps of the Northern, Eastern and Southern States contain billions of tons of peat, which may serve for fuel when the coal supply is exhausted, unless some better method of obtaining heat is discovered in the meantime.

The vegetable matter of these bogs and swamps is derived mostly from water plants, such as algæ and sphagnum moss, and from the leaves of trees growing in the bog. As there are usually inlets as well as outlets to these swamps and bogs, some of the inlets may in times of freshets bring logs from the neighboring highlands, but as they would likewise bring in silt, such accessions are injurious to the purity of the peat. As a rule, coarse vegetation, such as reeds and rushes, grows in the mouth of the inlet and filters the water so that little silt is mixed with the decomposing algæ, moss, and leaves, trunks and limbs of larger plants growing in the swamp.

2. Bog-iron Ore.

Iron rust is ferric oxide, and bog-iron ore is ferric oxide more or less combined with water. Ferric oxide is not soluble in water, and hence it gives a fast red color to red clay, red shale, red sandstone, red brick, and red mineral paint. Before ferric oxide will dissolve in water, a little of its oxygen must be removed, reducing it to ferrous oxide. Ferrous oxide dissolves easily in water, and hence, green clays and shales, which owe their color to ferrous oxide or some other ferrous compound, will bleach when subjected to the solvent action of running water.

Red sandstones and many red soils contain a very large amount, in the aggregate, of ferric oxide, and as ferric oxide is a very valuable ore of iron, such rocks would be an important source of this mineral were it not for the trouble of separating it from the other ingredients of the sandstone and soil.

Man long since learned that green clay burns to a red brick. The chemist explains this by saying that the ferrous oxide when heated takes to itself some oxygen from the air and thus becomes ferric oxide, and this is red. Man likewise learned long ago that when he heated ferric oxide or iron ore with charcoal very intensely, he obtained iron free from oxygen. The heated charcoal had taken all the oxygen from the ferric oxide.

The geologist believes that all beds of iron ore (ferric oxide) were derived from red sandstones and other red rocks through the agency of decomposing vegetable matter and water. He has noticed that when there is much decomposed vegetable matter in a rock, the rock is never red. He has noticed, also, that it is useless to look for fossils in a red sandstone that is permeable by water. Putting his observations together, he says that decomposing vegetable and animal matter removes enough of the oxygen of ferric oxide in contact with it to reduce it to ferrous oxide. This dissolves in water and goes with it through some underground channel till it comes out to the open air in a spring. Here it takes to itself some oxygen from the air, becomes ferric oxide and insoluble in water, and settles to the bottom of the spring as a bed of iron ore.

This entire explanation of the method of deposition of beds of bog-iron ore is so important in its bearings on other questions in geology, that the student should study it till he is sure that he understands it and can remember it.

3. Coral Reefs and Islands.

Coral consists of the skeleton of one or the combined skeletons of several polyps. The polyp is one of the simplest animals that exist, and yet its structure is so strange that many people have difficulty in understanding it. Imagine a tube of flesh with a smaller tube within, both standing vertically; then imagine vertical partitions connecting the two tubes. Above, the tubes are connected by flesh which possesses a great many soft arms, usually busily engaged in pulling food into the opening of the smaller tube, the mouth. This smaller tube is its stomach, is open below, and is shorter than the outer tube. The polyp develops in its interior many eggs, which rise with the waste material through the stomach to the mouth and float away to start new polyps. But the polyp is very good eating for little fish; so in order to survive in the struggle for existence, he must take lime from the water and fill the skin of the outer tube and the partitions with it, about half-way to the top: thus the fish will not find much that is good to eat, especially as the polyp can, when disturbed, pull the upper half of its body and its arms down into the lower half.

Perhaps the strangest things about the polyp are: first, its power so to constrict the upper half of its body as to make two mouths and stomachs, or else to start buds from its sides which become mouths and stomachs; and second, its power to grow upward indefinitely, dividing or budding as it grows, till one polyp may become a million, and yet all be connected in one compound animal. The coral, too, is built up behind each mouth and stomach till the coral of one compound polyp may weigh tons. Thus many compound polyps may contribute to the formation of reefs thousands of miles in extent. Their fragments, too, broken off by the waves and ground into coral sand or mud, may contribute to the formation of thousands of square miles of limestone, hundreds of feet in thickness, as in the tropical Pacific ocean of the present and along the coasts of Florida and the West Indies.

Very many animals of low organization besides polyps, and many plants as well, deposit carbonate of lime in their tissues. They, including polyps, have been very numerous during all the ages of the earth to the present, and have given their skeletons to the formation of limestones, ancient as well as modern. Most of the limestones of Kansas are full of fragments of the skeletons of these organisms; and as this is also true of the limestones found in other States and in all parts of the world, their contributions to the rock structure of the earth's crust have been enormous in the aggregate.

These organisms, with very few exceptions, are all marine forms of life, and hence they tell the geologist of times when the major portions of the continents were covered by the oceans and seas. The continents could not have been deeply submerged, for the animals and plants whose skeletons constitute the greater bulk of the limestones were shallow-water species. The ripple-marks in the sandstones interstratified with the limestones confirm this conclusion. Chalk, however, forms in deep water.

4. Shell Deposits.

The forms of life considered in the preceding section are mostly fixed during their entire adult life; those considered in this, can, with few exceptions, crawl about or swim. Those which crawl have heavy external skeletons termed shells, and live for the most part near the shore-line of the ocean, or in rivers and lakes of fresh water. Probably all these shell-fish were once salt-water forms, but their ability to crawl has enabled some of them to ascend rivers, and thus to occupy regions where the struggle for existence is not so severe.

Great beds of shells are found in favorable positions along all shore-lines, and in most rivers whose water is hard.

Many animals of microscopic size, with very tiny skeletons of carbonate of lime and of silica, float in the ocean currents and drop their skeletons, as they die, on the floor of the ocean, like flakes of snow in a snow-storm. The Gulf Stream abounds in these rhizopods, as they are called, and great beds of chalk are forming in the bottom of the North Atlantic near England and France. The chalk-cliffs of England and France were formed in this way during the Cretaceous Period, when they were part of the floor of the ocean. The same statement is true of the chalk of west-central Kansas, only this was formed in some unnamed ocean current from the tropics, which swept over western Kansas and Nebraska to the Arctic ocean.

5. SUMMARY.

The organic agencies are all concerned in making deposits, mostly in the depressions of the earth's crust, from materials that float about in the water and air, and which are so generally diffused as to be of little service to man.

Vegetable life takes carbon dioxide from the air, combines it with water to make vegetable tissue, and this is laid down in bogs and swamps as peat, which finally becomes coal.

Decomposing organic matter renders widely diffused ferric oxide soluble in water, and thus takes it through underground passageways to the air, where it becomes again insoluble by taking in oxygen, and is thus deposited as a bed of iron ore.

All rivers are bearing to the sea great quantities of carbonate of lime. This makes ocean water very hard, but hard water is just what polyps need for coral reefs, and shell-fish require for the heavy, protecting shell of carbonate of lime, and other animals such as the rhizopods and crinoids must have for their skeletons. All skeletons of this character are finally deposited as great beds of limestone and chalk for the upbuilding of the bottoms of the seas and lakes, and for the use of man.

3. STRUCTURAL GEOLOGY.

1. GENERAL FORM AND STRUCTURE OF THE EARTH.

The general form of the earth is that of an oblate spheroid. Its diameter is about eight thousand miles and its circumference twenty-five thousand. The earth weighs nearly five and two-thirds times as much as a ball of pure water of uniform density of the same size. The surface rocks have a specific gravity of two and one-half, hence the rócks at the center must have a specific gravity of over sixteen. This may be explained by the presence of heavy metals at the center, or by the greater density there of rocks like those at the surface. These would be more dense at the center by reason of the great pressure upon them.

1. Surface Configurations.

The greater inequalities of the surface of the earth are believed to be due to the more rapid loss of radiant energy from some portions of the earth's interior than from others, and consequently the interior shrinks more rapidly in those parts, the crust follows the shrinking interior, and the ocean basins are formed with the continents between.

The cool and nearly consolidated crust, in accommodating itself to a shrinking interior, is thrown into folds or wrinkles, just as the skin of a baked apple is wrinkled in settling to an interior made smaller by the escape of water. But singularly enough, the troughs are formed first on the surface of the earth at some distance from one another, and by a process which will be explained later, become the mountain ranges, or the wrinkles.

The lowlands between ranges of mountains are called great valleys, and those between the minor wrinkles or ranges are lesser valleys, and the lesser wrinkles are termed ridges.

The erosive agencies cut these ranges, ridges, great valleys and lesser valleys into innumerable valleys and ridges of erosion. The final form of a ridge of erosion is frequently a peak. But the erosive agencies in the course of ages may so nearly obliterate the wrinkles and valleys that the entire surface becomes a peneplain.

2. Laws of Continental Form.

A continent may be defined as a body of land with at least two great systems of mountains separated by a great basin which has much of its area less than one thousand feet above the level of the sea. Continents and ocean-basins have never changed places, owing to the deep-seated cause of their existence, the unequal radial contraction of the earth; but the structure of the continents shows that all portions of their surfaces have at one time been covered by shallow seas. All of their rocks, except those derived from pockets of molten rock in the interior of the crust, show the sorting action of water, or at least the presence of water during their deposition.

The divergence of the two systems of mountains gives each of the continents a triangular outline; and in each case, the greater mountain system lies next to the greater ocean.

2. THE MORE COMMON ROCKS AND MINERALS.

The following table will show the principal kinds of rocks:

1. Sedimentary, material sorted and stratified.
   1. Fragmental, composed of débris little changed since deposition.
      1. Limestone, chiefly calcite.
      2. Sandstone, chiefly quartz (sand).
      3. Shale, chiefly alumina (clay).
      4. Soft coal, chiefly carbon and bitumen.
   2. Metamorphic, composed of sediments much changed through crystallization of material in the presence of water more or less hot.
      1. Marble, composed of calcite.
      2. Quartzite, pure sandstone metamorphosed.
         Gneiss, impure sandstone metamorphosed.
      3. Slate, metamorphic shale.
      4. Anthracite coal, metamorphic soft coal.
         Graphite, fully metamorphosed coal.
2. Igneous, material fused either by dry heat, or in the presence of water. In the latter case, these rocks resemble metamorphic rocks.
   1. Volcanic, erupted through tube.
      1. Stony lava.
      2. Glassy lava.
      3. Pumice.
      4. Tufa (volcanic ashes deposited in water).

2. Trappean, erupted through fissure.
    1. Porphyry.
    2. Basalt.
3. Plutonics, originally deep-seated, and may be forced up into the heart of mountains.
    1. Granite.
    2. Gabbro.
    3. Diorite.

NOTE.—The Washington School Collection, prepared by Edwin E. Howells, 612 Seventeenth street N. W., Washington, D. C., contains forty of these rocks. The cost is very small, and the collection is almost indispensable to Kansas schools, as most of these rocks are not found here, except in the drift in the northeastern corner of the State.

The different substances composing these rocks are termed minerals. A rock may be defined as material of the crust of the earth, more or less consolidated, and consisting of one or more minerals. Even soil would be a rock according to the geologist.

Minerals have a more definite chemical composition than rocks. Most of the minerals occur as crystals, of a geometrical form peculiar to each mineral, or as a substance of crystallization texture, such as marble. No one knows why quartz, for example, should be found in six-sided prisms capped at one or both ends by six-sided pyramids; yet such is the case, and the sides of the prism and pyramid, in a thousand quartz crystals, are always placed at an invariable angle with each other. Many crystals cleave easily in one or several directions, and the cleft sides are planes, but quartz is a notable exception.

The following summary of the properties of the more common minerals will assist the student in identifying minerals and rocks. Hardness is determined by applying the test to a fresh surface of fracture. The scale of hardness consists of ten standard qualities or degrees, the diamond possessing the tenth and the finger-nail the second:

1. Quartz, an oxide of silicon.
   1. Not scratched by a knife; hardness 7.
   2. Insoluble in pure cold water and in common acids.
   3. No cleavage planes.
   4. Glass-like, but of various colors.
2. Flint, nearly the same as crystalline quartz in composition and hardness, but never crystalline in texture or in form.
3. Feldspar, a silicate of alumina and potash, soda or lime.
   1. Not easily scratched by a knife; hardness 6.
   2. Two or three cleavage planes.
   3. Colors, flesh red, white, etc.
   4. The cleavage planes glisten in the sunlight.
4. Mica, a silicate of alumina and magnesia, potash and iron oxide.
   1. Cleaves easily into thin, tough, elastic leaves. Sometimes incorrectly called isinglass.
5. Hornblende, a silicate of alumina and magnesia, lime, and iron oxide.
   1. Hardness varies between 5 and 6.
   2. Cleavable, but folia brittle.
   3. Most common color, dark green.
   4. The fibrous varieties give toughness to many dark green rocks.

6. **Calcite, a carbonate of lime.**
   1. Easily scratched by knife; hardness 3.
   2. The application of almost any acid causes the carbon dioxide to escape in bubbles (effervescence).
   3. Color white, but stained yellow or buff by iron in limestone.
7. Gypsum, a sulphate of lime with water.
   1. Not easily scratched by finger-nail; hardness 2.
   2. Not acted upon by acids.
   3. When the water is driven off by heat, gypsum becomes plaster.
8. Augite, same in composition as hornblende, but rocks containing it are not so tough as those with hornblende.

Limestone is one of the most prominent and common rocks of the earth's crust, and as nine-tenths and possibly ninety-nine hundredths of it is derived from the skeletons of animals and plants, it is one of the most interesting rocks to the geologist. It is composed very largely of calcite, is easily cut and quarried, and is one of the most valuable building-stones.

The grains of quartz in the sandstone are held together by ferric oxide, carbonate of lime, or silica. The first kind is red, the second buff or yellow, and the third glassy. The first makes the best building-stone, the second, the best soil when it decomposes, and the third, the best paving-stone.

Shale, being so largely composed of silicate of alumina, or clay, is nearly impervious to water, petroleum and natural gas, and hence assists in making natural reservoirs for these substances. It is invaluable in brickmaking, and assists as clay in holding the elements of soil together.

Slate is metamorphic shale. According to Sorby, the enormous lateral pressure in the crust of the earth, when the wrinkles producing mountains are formed, causes each little flake of clay in shale to slide on its fellow-flakes till they are tilted into a vertical position. Tyndall claims that spherical pellets in shale would be flattened by this pressure so that their longer diameters would stand upright. Both theories are probably true. The slates used on roofs of houses, for blackboards, and for school slates, are obtained by splitting the beds of slate crosswise of the bedding.

Granite and gneiss are rocks found almost exclusively in the mountains and in the drift pushed out of the mountain valleys by glaciers. Northeastern Kansas contains many of these boulders. They are composed of quartz, feldspar, and some mica. On the decomposition of granite and gneiss, the quartz, when sorted from the débris by water, makes sandstone, and the feldspar, clay and shale.

Diorite is the name of a dark-green rock, composed largely of hornblende, found very abundantly in the drift of the Northern States. These rocks are exceedingly tough, and were much prized by the Indians for axes and hammers. The writer found an axe of diorite in Greenwood county, Kansas, and many more may probably be found in our State.

Basalt is a dark rock containing augite and iron. It is interesting, mostly because it is found in prismatic columns of various numbers of sides, in most places where molten rock has poured out of the interior of the earth through fissures, as along the Columbia, Hudson and Connecticut rivers, forming the palisaded mountains.

3. SOILS.

Soils all result from the disintegration of rocks and of plants and animals. Most soils are mixtures of various minerals, but they may be named and described from some dominant mineral.

1. Calcareous or Marly Soils.

Calcareous soils are derived from limestone and marble débris, and from the shells and skeletons of various animals. These soils are hot, and suffer much in times of drought; they are much improved by stable manures.

2. Silicious or Sandy Soils.

Sandy soils are derived from disintegrated sandstones, and are loose and porous in texture; they do not hold water and soluble manures; they are most productive in regions where the rainfall is abundant, but are soon exhausted; with a moderate admixture of clay, their retentiveness and value are increased.

3. Argillaceous or Clay Soils.

The clay of this soil is derived from beds of shale, from decomposed limestone, and from the feldspar of granite and gneiss. When pure, this soil is cold and heavy, and bakes in times of drought. Its fertility is greatly increased by a generous admixture of sand, rendering it more permeable to water and to the roots of plants.

4. Carbonaceous Soil.

This is not a distinct class, but is merely a superficial portion of all soils where vegetation has grown and decayed. Its depth is an indication of fertility, for the greater the depth the greater must have been the vigor of the vegetation which it supported.

The bottom lands of Kansas are composed of an admixture of the four kinds of soil mentioned above, in such proportions that they serve to produce a luxuriant growth of vegetation. The upland prairies in the eastern half of Kansas possess a soil that is largely the residuum of limestone decay, and is therefore a heavy clay soil. But it is rarely deep, and frequently is so situated that it receives a dressing of sand from a disintegrating sandstone. So this upland soil, avoided by the early settlers, takes rank next to the bottom-land soil in productiveness, for the limestone beneath retains the rainfall, and contributes several of the necessary plant foods.

4. ROCK STRUCTURE.

All rocks possess a certain structure which was given them at the time of their deposition, and another structure given them in drying, cooling, or by percolating water.

1. Stratification and Cleavage.

As the coarseness of sediments deposited in any one place changes from season to season and from year to year, all stratified rocks show thin layers, each of material of like sorts. These are termed laminæ. Slight cohesiveness in the material deposited in certain laminæ produces layers or beds in the rock, between such laminæ, These may be from a few inches to several feet in thickness. All the layers of one kind or rock—limestone, for example—constitute a stratum. A group of strata, formed in succession, without any unconformity in the layers or other serious break, is a rock-group or formation. Greater groups, such as a rock-series and rock-systems, correspond with the larger subdivisions of geological time.

When silt is deposited in water the particles arrange themselves in a horizontal position, so the rock splits or cleaves more easily in this direction than in any other. This is lamination cleavage. Lateral pressure causes these particles to slide on each other, so they stand in a vertical position, or at right angles to the force acting horizontally, as in mountain-making. This produces slaty cleavage in shale. The same structure and cleavage would be caused by the flattening of the spherules of clay by this horizontal force. The slates in both cases split crosswise of the bed.

Other kinds of cleavage are the crystalline and the organic. In the formation of crystals, such as salt from solution, the molecules arrange themselves in such a way that the crystal breaks more easily in the direction of certain planes than in other directions. This is crystalline cleavage. The cells of wood are arranged with their longest diameter extending lengthwise of the log or limb, so wood splits most easily in this direction. This is organic cleavage.

2. Joints and Fissures.

On cooling and drying, molten rock and mud shrink. Vertical shrinkage can usually take place without hindrance, and the stratum becomes thinner without fracture.

The trap dike, composed of molten rock that has cooled in a great fissure of the earth's crust, is the only exception to this rule. The sides of the dike are fused with the rock walls of the fissure, and hence, when the basalt cools, the shrinkage-cracks run crosswise of the fissure, and the columns of basalt lie horizontally like cordwood.

In limestones, sandstones and shales, the shrinkage-cracks are vertical, just as they are in dried mud by the roadside. Such cracks are termed joints. They are very serviceable to the quarryman in breaking layers of limestone and sandstone into pieces of convenient size for handling. In southeastern Kansas, water containing minerals in solution left the zinc and lead ores in these shrinkage-cracks.

Some of the fissures crossing layers of rock are many feet in depth and intersect many strata. These are termed great fissures, to distinguish them from fissures which intersect but a single stratum and are merely shrinkage-cracks. The great fissures cannot well be shrinkage-cracks, and are believed to have been caused by flexures of the crust during periods of elevation or depression, and especially during mountain-making. These great fissures are usually filled by molten matter, by deposits from hot water, or by the settling together of the walls of the fissure through the action of gravity. In this last case, the hanging wall of all inclined fissures slips down on to the foot wall, producing a fault, since the layers of the opposite sides of the closed fissure do not correspond. An earthquake undoubtedly accompanied the closing of the fissure. Where molten matter filled the fissure from below, the fact is made known through erosion, for the rock on either hand is softer than the basalt, wears away faster, and the basalt may stand as a ridge or dike of black rock above the general level. Ridges of this character forced the Connecticut river to abandon its former channel to New Haven Bay, and to make for itself a new channel to Long Island Sound, farther east, through gneiss and schists.

3. Mineral Veins.

The great fissures which are filled by the deposition of various minerals on the walls of the fissure are termed mineral veins, especially if the ores of some of the valuable metals are deposited with the other minerals on the walls of the fissure.

As these great fissures are most common in mountains, mineral veins are likewise found in these regions of crust foldings.

The less valuable minerals are called veinstuffs, and the more valuable are termed vein ores. The more common veinstuffs are calcite, quartz, heavy spar, and fluorspar. Among the valuable ores are gold, silver, copper and platinum, and sulphides, oxides and carbonates of all the common metals except gold and platinum.

Most of these ores and veinstuffs are deposited, it is believed, from hot-water solutions,—not all at once, but one after the other on the walls of the vein. The ores are usually deposited last, and hence are found near the middle of the vein. Not all veins contain ores, but they may do so; hence prospectors carefully search for them in hunting for ores.

5. ROCK CONTENTS.

Besides the various minerals which compose strata of rock, there are nearly always to be found certain structures which are interesting because of their form or composition. These are fossils and nodules.

1. Fossils.

Any impression or form dug out of the earth is termed a fossil if it teaches something about the plants and animals which once existed upon its surface. The fossil may be a footprint, a mold of the exterior of the animal or plant, a cast of such a mold, a cast of the interior (of a clam-shell, for example), a petrifaction of the substance of a plant or of the skeleton of an animal, or it may consist of the wood, bones or mummified flesh of the organism. Flesh never petrifies, for it too readily decays, or it does not set free in its decomposition the substances needed to precipitate the silica. Bodies said to be turned to stone in cemeteries are simply changed into spermaceti by fatty degeneration of the tissues.

The fossils in the succeeding strata differ widely from those of the preceding, and are so much alike in the same or corresponding strata of the entire earth, that they are the main reliance of the geologist in reading the earth's history. At the present time animals and plants are very sensitive to conditions of climate, soil, and food supply; and the geologist infers that animals and plants have always been equally sensitive. Hence a study of fossils gives the geologist a key to the conditions of climate, soil and food supply in the past ages of the earth.

The geologist has found, in tracing strata of the crust in the neighboring regions, that the fossil group (fauna and flora) of that stratum remains nearly unchanged in the adjacent regions. Should he find, on visiting a still more distant region, a stratum containing the same fossil group, he believes it must be of the same age as the one where he began his investigations, even though the rock material of the stratum may be different. By age of stratum is meant the period in which it was deposited. For example, we know that the coal-beds of southern Wales, Pennsylvania, and of eastern Kansas, are of the same age, because the fossil forms of plants and animals in the layers just above and below the coal are almost identical.

2. Nodules.

The flint nodules in limestone are most abundant in Kansas in the limestone of the Flint Hills of Elk, Greenwood, Butler, Chase and Lyon counties, and in the Mississippian limestone, containing the lead and zinc ores in the southeastern part of the State.

The silica of the flint may have been diffused through the limestone mud, and, by a creeping movement not well understood, may have become segregated in the mud or rock about various centers. Or the carbonate of lime at these centers was displaced by the silica of percolating water. It is known that silica is held in solution only by hot, alkaline water, and that such water drops its silica on cooling or when the alkali is neutralized by an acid. Decomposing organic matter in the limestone may have served the double purpose of neutralizing the alkali and causing the solution of the limestone, by giving off carbon dioxide.

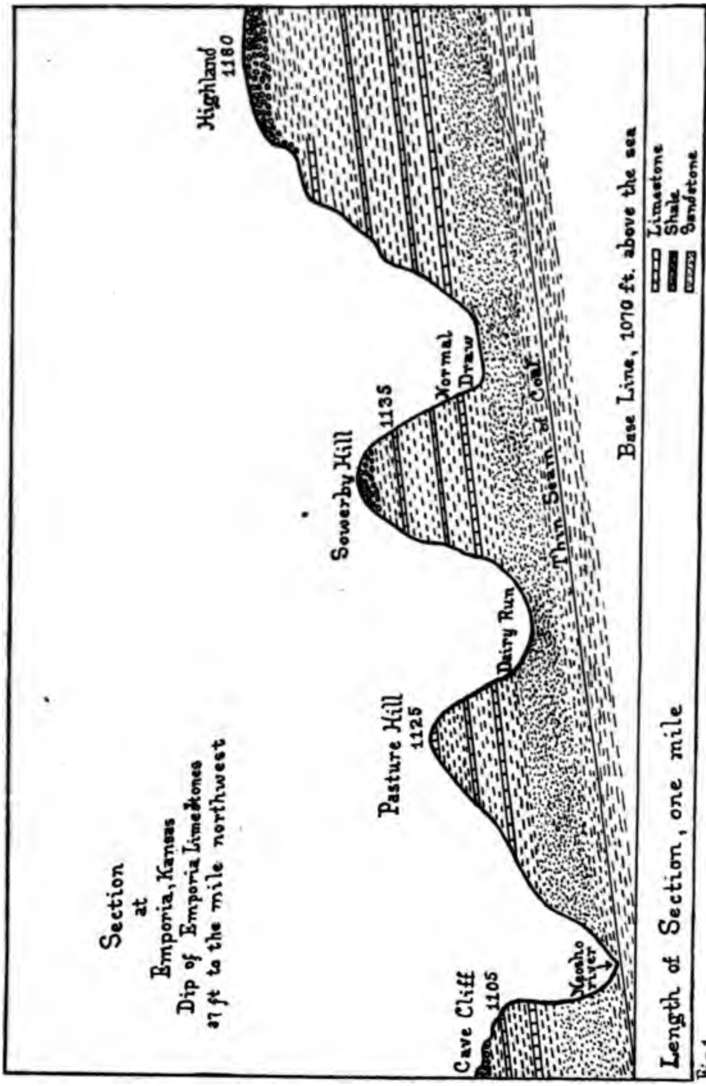
As has been already stated, lead and zinc ores are frequently deposited in connection with flint nodules.

6. ROCK FOLDINGS.

The shrinking interior of the earth leaves the cool and stiff outer crust unsupported, and it must accommodate itself to the diminished size of the interior. To do this, it must wrinkle either regularly over the entire surface of the earth, or along certain lines designated as lines of weakness. A study of the earth's mountain ranges proves that the earth's surface was not wrinkled uniformly, and that the lines of weakness were off-shore portions of the crust, which were receiving heavy deposits of sediments from lofty land masses. These sediments, fine as well as coarse, stopped near the shore-line, for the salt water rapidly precipitated the silt, and the undertow dropped the coarse material as it lost velocity.

Before studying more fully the conditions which have resulted in the production of mountain ranges, it will be necessary to define a few terms which we shall need to use.

Imagine a series of wrinkles and furrows, or examine those of your sleeve. The sides of the wrinkle lean against each other, and hence the wrinkle is termed an anticline. The sides of the furrow dip towards each other, hence the furrow is a syncline. A series of brick, stood on end, and then caused to knock one another down, would lie in positions termed monoclinal. The sides of some folds are steeper than those of others; they differ in dip. The angle of dip is given in degrees or in number of feet per mile. To find the angle of dip, say of the top of a school-desk, take a spirit-level and turn it about on the top of the desk till a position is found in which the level is horizontal or level. This is the line of strike. The direction of dip is at right angles to this line of strike. Turn the spirit-


Section
at
Emporia, Kansas
Dip of Emporia Limestones
17 ft to the mile northwest
Highland
1180
Sowerby Hill
1135
Normal
Draw
Pasture Hill
1125
Dairy Run
Thin Seam of Coal
Cave Cliff
1105
Neosho
River
Base Line, 1070 ft. above the sea
Limestone
Shale
Sandstone
Length of Section, one mile
Fig. 1

level till it lies in the direction of dip. Lift the lower end till the level is horizontal as shown by the bubble. The angle between the desk and the level is the angle of dip, and may be expressed in degrees.

Throughout Kansas the angle of dip of strata is generally less than one degree, and hence the usual method is to express the dip as so many feet to the mile. An inclination of one degree in a stratum would give a dip of over ninety feet to the mile. To get the dip of Kansas strata, whose inclination is generally less than one-fourth of a degree, it is necessary to find the elevation of the strata at points in the line of dip, separated by one or more miles. The difference in the elevation is the amount of dip. Figure 1 illustrates the method of obtaining dip, and also the method of preparing vertical sections of strata in surface contours. Only the major inequalities of the surface are represented. The elevations were obtained with an aneroid barometer, and are therefore only approximately correct. In cases where instruments for obtaining elevations are not at hand, eye-estimates, especially along railroad tracks, will be sufficiently accurate for class work in section-making.

Very few anticlines and synclines of marked height and depth exist in Kansas. One of the best examples of a syncline in the State, known to the writer, is exposed near Strong City, Chase county, where the Cottonwood river cuts through the Flint Hills. Near and in mountain ranges they are common. In ranges of mountains they are so obscured by the mashing together of the strata and by erosion that the anticlines and synclines are made out with difficulty.

By a mountain range is meant a single series of ridges and troughs made by one effort of Nature. A mountain system consists of two or more ranges made at different times, but extending in the same general direction along the same plateau. The Cordilleran system includes the Rocky, Sierra, Cascade and Coast ranges.

As the stiff crust adapts itself to the shrinking interior of the earth, it slowly sinks in one region and rises relatively but not equally in some other region. As has already been stated, the places of sinking are places receiving heavy deposits of sediments. It should also have been stated that a great accumulation of snow and ice accompanies sinking in that part of the crust, as in the case of Greenland and the Antarctic Continent; and the removal of glaciers by melting accompanies a rise in the part of the continents relieved of pressure, as has been shown was the case of the northern United States at the close of the Glacial Epoch. This addition of weight to any part of the crust or removal of weight from any part, then, seems to determine the elevation or depression of that region, the sea in both cases being the standard of height.

Estuaries of rivers and the off-shore borders of continents are receiving deposits of sediments, and are the places of greatest subsidence in the narrow belts. The continued deposition of sediments produces a constantly deepening synclinal trough. In the past history of the earth such troughs have not been uncommon.

The ancient estuary of the Connecticut river received heavy deposits of sand and other débris from the bordering hills, and sank, as the sediments accumulated, to a depth exceeding ten thousand feet. The tension on the bottom of the trough was so great that it broke, or it melted because of superheated water in the crust and sediments, and streams of molten rock pushed up through the fissures in the sandstone and spread upon its surface, making the trap dikes of Connecticut and Massachusetts in the Connecticut valley.

Lake Superior occupies part of a narrow synclinal trough which was depressed a total of over fifty thousand feet. This trough likewise broke or melted at the bottom, and numerous outflows of molten rock occurred in the basin. Some of these outflows now contain enormous deposits of pure copper, and one holds a vein of pure silver.

Why the narrow troughs did not yield sufficiently to compress greatly the sediments in them, is not easy to understand. Possibly the great outflows of molten rock may have permitted the bordering regions to settle and push semi-molten material under the trough and cause the sinking of the latter to cease. The sandstones at the surface in these two troughs are tilted somewhat, but are otherwise undisturbed.

The synclinal trough, which is formed off-shore by the deposition of sediments, is so broad and the sediments are so thick, that the final yielding of the bottom of the synclinal subjects the sediments to enormous lateral pressure, as the sides of the trough approach; and the sediments are squeezed, are thickened by side-flowage of semi-molten rock, are forced upward to a great height, and are metamorphosed and wrinkled just as we find them in mountain ranges.

The sides of the great synclinal trough where the

Alleghanies now stand approached each other till the distance between them was reduced in one place nearly eighty miles. Each six miles in width was pushed into one mile. The Pennsylvania geologists think that the sediments must have been forty thousand feet thick, and, as they were mashed together, that they must have upswelled into a range of mountains rivaling in height the most lofty ranges of the present time.

This, in brief, is thought to have been the history not only of the Alleghany Mountains, but also of every other range of mountains on the surface of the earth. All began in a synclinal trough, and hence a range of mountains is termed a synclinorium. The upswollen mass of sediments constitutes the plateau on which the ridges of the great range stand. Molten material may pour forth, but usually it is lost in the metamorphosed sediments.

The formation of mountain ranges is always attended with great changes of the strata involved. The sediments deposited in the synclinal trough hold a large amount of sea-water. As they sink with the down-bending crust toward the center of the earth, they become heated above the temperature required for fusion in the presence of alkaline water, and are reduced to a semi-liquid condition. In this condition the minerals become modified in chemical composition, and, as they slowly solidify in the heart of the mountain range, assume a crystalline structure or a slaty cleavage. Thus the sedimentary rocks become metamorphic rocks.

7. MOUNTAIN DENUDATION.

The moment a range of mountains appears above the level of the sea, the work of erosion and transportation, by the chemical and mechanical agencies, begins. The higher the range becomes, the more active are the agents of denudation.

Geologists estimate that a layer ten to eleven thousand feet thick has been removed from the surface of England, eight to twenty thousand feet from the Appalachian Mountains, twenty thousand feet from the Uinta Mountains, thirty thousand feet from the Wasatch Mountains, and an average of six thousand feet from the entire surface of eastern North America.

As has been stated under Mechanical Agencies, the Mississippi basin is lowered one foot in five thousand years by erosion and transportation of rock débris. To lower the basin six thousand feet would require six thousand times five thousand years, or thirty million years. Some of the most ancient mountain ranges are so old that they have been eroded nearly to sea-level, and nothing of their once massive ridges remains but their highly metamorphosed interiors. These ranges are estimated by the conservative geologists to be fifty million years old.

8. TOTAL THICKNESS OF STRATA THAT MAY BE DIRECTLY OBSERVED.

The activities described in Dynamical Geology are those still concerned in the production, modification and destruction of the earth's features.

The structure of the earth's crust, described in Structural Geology, is everywhere such as may be explained by referring every type of structure to causes still in operation.

The proofs of these propositions must be found in the crust itself, for no historian was present to record the mode of evolution of the earth's features.

The thickness of the earth's crust exposed to view is very small compared with the entire thickness to the center; but the part that may be studied is by far the richest in its records of past activities, as it has been the field of the most potent agencies engaged in preparing the earth for its inhabitants.

The means for studying the earth's crust are widely distributed over its surface. By the wrinkling of the strata in mountain ranges and the rapid erosion of the fractured anticlines, almost the entire thickness of sediments of the synclinal troughs is exposed to view.

The gorges and cañons on the flanks of the mountains and where waterfalls are receding from the margin of an ancient peneplain, expose to view strata which have been but slightly disturbed or tilted.

The lava of volcanoes and the drillings of deep wells give the student another means for studying the crust. Deep mines also enable him to penetrate some thousands of feet into the earth's interior.

Perhaps the best means for the study of the interior of the earth's crust is afforded by the shallow cuts made in the surface by rivers and railways. To understand why this means for investigation is so important, it will be necessary to recall some of the statements made in Dynamical Geology respecting the growth of the continents.

As the earth loses radiant heat energy it shrinks, and, as some portions conduct the heat to the surface more rapidly than others, the surface sinks more rapidly over these parts, and less rapidly over the other parts. The more rapidly sinking portions are the ocean basins; the less rapidly sinking parts the continents. As the continents rise continuously, more and more of the sedimentary strata are exposed to view, so that all might finally be above water in good condition for study if there were no revolutions to fold, crush and metamorphose the strata during the production of mountain ranges. It is for this reason that the great interior plains give the best opportunities for study of the earth's crust.

Should one travel from Wisconsin to Kansas and from Kansas to the Gulf of Mexico, avoiding mountain ranges, he would travel over almost the entire series of sedimentary strata deposited since the Algonkian revolution, twenty-seven million years ago.

Or we might start in the Ozark Mountains and travel to southeastern Kansas and thence to the northwestern part of the State, and cross a portion of the strata deposited in every age since the Archæan. The Kansas part of this section is so interesting that it is given in Figure 2, page 73.

It will be remembered that a general statement was made to the effect that later and later sediments are brought to view by the slow emergence of the continents from the oceans, and that the successive strata may be studied by traveling from the interior of the continent to the coast. It was further stated that the rise of a range of mountains increased the difficulty of reading the record of the earth's history. The upturned, folded and eroded strata are exposed to view in the mountains, and many things may be learned from a study of them there, but their metamorphosed condition, and the twisted and overturned condition of the folds, so increase the difficulties of their study that the geologist goes to the plains for the more complete and reliable records.

But even on the plains the geologist does not escape the influence of the mountain ranges. The erosion of their peaks and ridges, and the transportation of the débris to the ocean border, cause the mountain plateau and bordering plains to rise, and the ocean border to sink, according to the law that has been referred to several times in the preceding pages.

Now Kansas has the Ozarks on the east and the Rocky Mountains on the west, and thus has been tilted, first to the west and next to the east, by the rise attending the successive unloading of material from these ranges by denudation.

In its most ancient condition known to the geologist, the continent of North America lay to the northeast of Kansas. The Ozarks and the northern extension of the Ozarks were large islands to the southwest. An island of unknown extent and height extended north and south somewhere to the west of the site of the present front range of the Rocky Mountains in Colorado.

Kansas undoubtedly received most of the arenaceous and argillaceous sediments of her six thousand feet of sedimentary rocks from the Ozarks. The rise of the Ozarks, through denudation, would tilt the older sediments more and more to the westward. The accumulation of sediments between the Ozarks and the Rocky Mountain island would intensify this tilting movement. This action continued for twenty-six million years, and then the Rocky Mountains were formed, of enormous extent and height. Since that time, or for about one million years, according to geologists, the tilting movement has been reversed, and the western end of Kansas is higher than the eastern end. But the former tilting of the older strata in the eastern half of Kansas, to the westward, has not been entirely overcome by the rise of the Rocky Mountain region.

For this reason the section across Kansas presents the unique condition of strata dipping to the westward, while the surface slopes to the eastward.

In the section shown in Figure 2, no attempt has been made to do more than to give a general idea of the thickness of strata exposed in Kansas and the direction of their dip. The numbers given with the rock groups show approximately the thickness of these groups. The dip of the strata in eastern Kansas is about one-fifth of a degree to the northwestward; in western Kansas the dip is about one-sixth of a degree to the northeastward. By curving the route a little across Kansas from the southeastern corner of the State to the northwestern, a total thickness of over six thousand feet of sedimentary rocks may be studied. Adding to this amount the three thousand feet of Devonian, Silurian, Ordovician and Cambrian strata exposed in Iowa and Wisconsin, we would be able to study nine thousand feet of sedimentary rocks in a trip across Wisconsin, Iowa and Kansas.

Not all of the sedimentary strata are exposed along this route, and other journeys would need to be taken, especially through Ohio, New York and Pennsylvania, and through portions of Europe and the other continents, to bring all under the inspection of the geologist.

In all, some ten miles in thickness of sedimentary and metamorphic rocks have been studied by geologists throughout the world, and described in hundreds of volumes of geological reports.

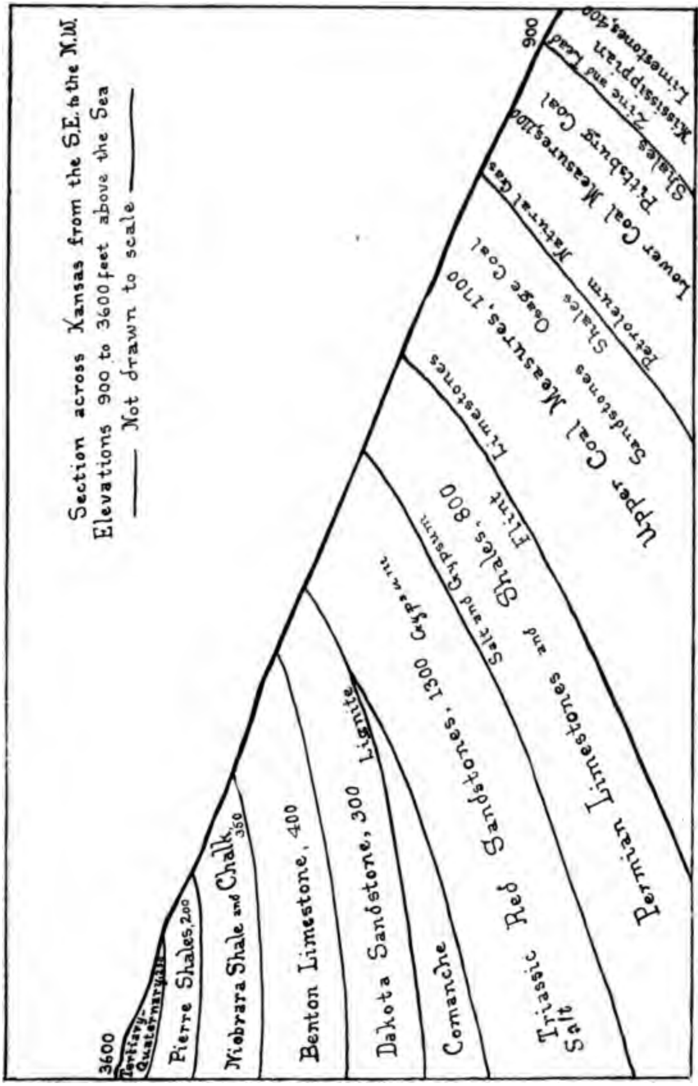

Section across Kansas from the S.E. to the N.W.
Elevations 900 to 3600 feet above the Sea
Not drawn to scale
3600
Pierre Shales, 200
Niobrara Shale and Chalk, 350
Benton Limestone, 400
Dakota Sandstone, 300
Lignite
Comanche
Triassic Salt
Red Sandstones, 1300
Gypsum
Salt and Gypsum
Shales, 800
and
Permian Limestones
Flint
Limestones
Upper Coal Measures, 1700
Sandstones
Shales
Osage Coal
Petroleum
Natural Gas
Lower Coal Measures, 1100
Pittsburg Coal
Shales
Zinc and Lead
Mississippian Limestones, 400
900

Fig. 2

Much remains to be done by earnest students everywhere, not merely in unexplored regions, but in every State and country.

In Kansas, sections should be made across every county. Each layer should be described as to its mineral constitution, and its fossil contents. The dip, thickness and commercial value of each stratum should be noted, and all ultimately embodied in an exhaustive report of Kansas Geology.

4. HISTORICAL GEOLOGY.

The geological history of Kansas is an inseparable part of the history of the North-American continent, and thus can be best understood by giving the geological story of our State in connection with the history of the entire continent.

The time covered by the geological story of America may be divided into eras, ages, periods and epochs by means of greater and lesser breaks in the evolution of the continent and its inhabitants. These divisions of time have their correlatives in the crust of the earth as shown by the following table from Le Conte:

Time.	*Rocks.*
Eras, Ages	Systems.
Periods	Series.
Epochs	Groups.

As in human history, the beginnings of the geological story are not known with any certainty, and may be designated mythological history. The first and second eras belong to this division; the third is very ancient, and has been deciphered only with difficulty; but the fourth, fifth and sixth eras are based on well-preserved records, and hence belong to authentic history.

1. OUTLINE OF GEOLOGICAL TIME.

1. Fire Mist Era.
2. Pyrolithic or Molten Rock Era.
3. Archæan Era, or Era of Ancient Rocks.
   1. Archæan Age, or Azoic Age.
   2. Algonkian Age, or Eozoic Age.
4. Paleozoic Era, or Era of Ancient Life.
   1. Cambrian Age, or Age of Trilobites.
   2. Ordovician Age, or Age of Brachiopods.
   3. Silurian Age, or Age of Mollusks.
   4. Devonian Age, or Age of Fishes.
   5. Carbonic Age, or Age of Amphibians.
5. Mesozoic Era, or Era of Middle Life Forms.
   1. Jura-Trias Age, or Age of Reptiles.
   2. Cretaceous Age, or Age of Birds.
6. Cenozoic Era, or Era of Modern Life Forms.
   1. Tertiary Age, or Age of Mammals.
   2. Quaternary Age, or Age of Man.

By an inspection of the table it will be seen that each division is characterized by some dominant form of life. This does not mean, for instance, that fish were more abundant during the Devonian Age than they have been since, for that is not true; nor does it mean that fish were introduced into the world at that time, for they were introduced in the preceding age;—but geologists have named the Devonian Age the Age of Fishes, because fossil fish remains are very abundant in the rocks of that age. Their rapid development and powerful weapons of offense prove that fish were masters of the seas at that time in a sense that they have not been since. The same is true of the method of naming the other ages.

Historical Geology is so largely a history of the development of life-forms, that a knowledge of the classification of animals and plants is indispensable. A brief outline of the Animal and Plant Kingdoms is given below.

If this Geological Story of Kansas serves a valuable purpose in education, it must be in the direction of stimulating and assisting the student in studying the story recorded in the rocks by himself. It is impossible to give illustrations of everything described here, but the student can easily find excellent illustrations in books of reference. Among such books, Webster's International Dictionary is preëminently first, because everywhere accessible. Let the student learn to investigate the dictionary, and he will be surprised to find what a wealth of scientific knowledge this book contains.

It is suggested that the student have the International Dictionary, or some other equally good, at his elbow, and look up the picture illustrating each form of life mentioned below, either in the body of the dictionary or in the back part of the book, where the illustrations are repeated in a few pages.

2. OUTLINE OF PLANT KINGDOM.

1. Algæ—Water plants like pond scum.
2. Fungi—Rust, smut, and mushrooms.
3. Mosses—Common plants in damp places.
4. Ferns—Well known for their beautiful fronds.
5. Scouring Rushes—Known by their harsh, jointed stems.

6. Ground Pines—Vines in northern woods, used in Christmas decorations.
7. Gymnosperms—Pines, spruces, and yews.
8. Endogens—Palms, corn, and lilies.
9. Exogens—Oaks, maples, willows, and most other trees and many flowering plants.

3. OUTLINE OF ANIMAL KINGDOM.

1. Protozoa—Rhizopods in chalk, and the so-called petrified barley in the rocks of Kansas.
2. Cœlenterata.
    1. Hydrozoa—Millepore coral, and probably honeycomb coral.
    2. Actinozoa—Cup corals and star corals.
3. Echinodermata.
    1. Crinoids—The so-called stone lilies; the joints of the stems are used for beads by children.
    2. Star-fish—Well known in museums.
    3. Sea-urchins—Their spines are common in certain strata in Kansas.
4. Vermes.
    1. Bryozoa—Incrusting, lace coral, common in Kansas rocks.
    2. Brachiopods—These have peculiar shells, and are found most abundantly in shales.
5. Mollusca.
    1. Lamellibranchs—Clams and oysters.
    2. Gasteropods—Snails.
    3. Cephalopods.
        1. Nautilus, orthoceratite and ammonite.
        2. Cuttlefish and belemnite.

6. Arthropoda.
    1. Crustaceans.
        1. Trilobites and sow-bugs. The latter are found under damp boards in cellars.
        2. Eurypterus and horseshoe crab.
        3. Lobster and crayfish.
        4. Crab.
    2. Millipedes, centipedes.
    3. Spiders.
    4. Insects.
        1. Biting insects—Dragon-fly and locust.
        2. Piercing insects—Bugs and mosquito.
        3. Nectar-loving insects—Butterfly and bee.
7. Vertebrata.
    1. Fish.
        1. Sharks.
        2. Gars, ganoids.
        3. Teleosts, perch, cod, and bass.
        4. Lung-fish, found in Australia, Africa, South America, and the United States.
    2. Amphibians.
        1. Salamander, mud-puppy.
        2. Frogs and toads.
    3. Reptiles.
        1. Snakes.
        2. Lizards, swifts.
        3. Tortoises and turtles.
        4. Crocodiles, alligators.
    4. Birds.
        1. Wading-birds—Heron.
        2. Scratching-birds—Hen.
        3. Perching-birds—Robin.

5. **Mammals.**
   1. Herbivores—Ox, deer, and camel.
   2. Carnivores—Cat, tiger, and lion.
   3. Apes and monkeys.
   4. Man.

The above classification has been adapted to the needs of the student in geology, and should be used purely for reference. If memorized at all, it should become familiar through using it in hunting for illustrations in books of reference and in the study of the forms of life of the several ages.

4. ARCHÆAN ERA.

The rocks of this era are so completely buried beneath later sediments that they can be seen at the surface in but a few States of the Union, though they can probably be found in all the States if borings are made deep enough. The larger areas at the surface are to be found in Canada, about Hudson Bay, in the Adirondacks, New York, in northern Michigan, Wisconsin and Minnesota, in Missouri, Texas, Colorado, Nevada and Arizona, and in a not well defined belt on the eastern slope of the Appalachian Mountains, buried in part beneath the Atlantic ocean. The duration of this era was about twenty-seven million years.

1. Archæan Age.

1. Distribution of Rocks.

The Archæan rocks are found in the Canadian V about Hudson Bay, and in the tributary areas in northern New York and in northern Michigan, Wisconsin and Minnesota, in the Blue Ridge near the Atlantic coast, in the

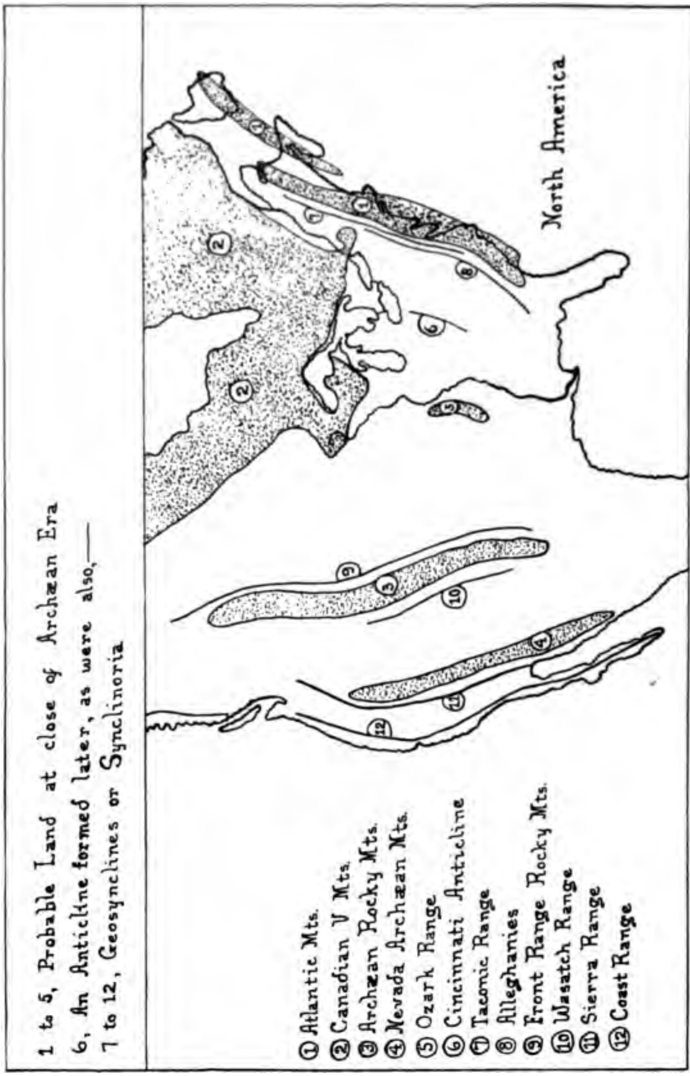

1 to 5, Probable Land at close of Archæan Era
6, An Anticline formed later, as were also,—
7 to 12, Geosynclines or Synclinoria
① Atlantic Mts.
② Canadian V Mts.
③ Archæan Rocky Mts.
④ Nevada Archæan Mts.
⑤ Ozark Range
⑥ Cincinnati Anticline
⑦ Taconic Range
⑧ Alleghanies
⑨ Front Range Rocky Mts.
⑩ Wasatch Range
⑪ Sierra Range
⑫ Coast Range
North America

Fig. 3

Ozarks, and in two islands in the western part of the United States.

2. Important Kinds of Rocks.

Archæan rocks are everywhere highly metamorphosed; and may have been eroded, deposited and metamorphosed many times in the ancient history of the earth. The mountains in which they are found are low, and possess all the signs of great age. The principal rock is gneiss. This rock has the same composition as granite, but the quartz, feldspar and mica are arranged in bands, thus preserving a trace of the former stratified condition of the rock.

3. Valuable Ores.

It is not certainly known that any ores of value are contained in Archæan strata, the rocks of this and the next age are frequently so intimately associated.

4. Evidences of Life.

This age is frequently termed Azoic, meaning without life; but life may have existed in spite of the lack of evidence, for the gneiss is so thoroughly metamorphosed that all traces of life must have been destroyed in the crystallization of the sediments.

5. Mountain-Making.

Many mountains may have been made in Archæan times, but if so, they have been leveled and buried beneath sediments derived from their own ridges and from other mountains. The areas named under Distribution of Rocks are mountain areas, and are the only ones known to the geologist in the United States and Canada. These mountains are so low that they scarcely deserve the name of mountains now. Once, judging from the amount of

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débris derived from them, they must have rivaled in height and extent the most majestic ranges of the present.

2. Algonkian Age.

1. Distribution of Rocks and Duration of Age.

The growth of the American continent has been mostly endogenous. So far as known, the Algonkian rocks lie on the inner borders of the mountains of Archæan Age, described above. The areas best known are those of the north shore of Lake Huron, of northern Michigan, Wisconsin and Minnesota, and of Iron Mountain in Missouri. Algonkian sediments are believed to have been seventeen million years in accumulating.

2. Important Kinds of Rocks.

Algonkian rocks are mostly quartzite, mica schist, chlorite schist, and limestone.

3. Valuable Ores.

Iron ore is so abundant and pure in the Algonkian of the region about Lake Superior and in Missouri, that this age is frequently termed the age of iron.

Iron peroxide exists in all red, brown and yellow sedimentary strata, but it is so largely mixed with other material that it must be concentrated to be of economic value. This work of concentration is done by Mr. Edison in New Jersey through the use of powerful electro-magnets; the same work is done in Nature by the reducing action of decomposing organic matter, by the transportation in water to a bog or spring, and by the aeration of the water. It will be remembered that decomposing organic matter reduces the insoluble peroxide of iron to the soluble protoxide, and that in springs the latter is reoxidized and deposited in the concentrated condition required by the iron smelter.

Besides the peroxide of iron, or hematite, the Algonkian rocks contain native copper on the south shore of Lake Superior, and native silver in an island near the north shore. The aborigines mined the copper and hammered or cast it into spear-heads and arrow-points. Their ancient mines in the copper range have been explored and their hammers and manufactured weapons discovered. Their copper weapons are likewise plowed out of the ground in great numbers by the farmers of Wisconsin.

Another mineral of wide distribution is graphite. Though not confined to the Algonkian, it is very abundant and widely distributed in rocks of that Age. One of the best mines in the United States is located at Ticonderoga, New York. Another bed of nearly pure graphite is now being developed in Portage county, Wisconsin.

4. Evidences of Life.

The evidences of life are indirect, but are none the less conclusive. Only one fossil has been discovered, but this is so poorly defined that some deny its organic origin. It may have been a sponge, or an aggregation of rhizopods, or possibly a mineral concretion.

The indirect evidence rests on the deposits of iron ore, of graphite and of limestone. As already explained, iron ore is concentrated in nature only through the aid of decomposing organic matter. Graphite is known to be highly metamorphic coal, and coal is derived from vegetable tissue decomposed under water. The great beds of limestone of the earth are composed largely of the more or less comminuted skeletons of animals and plants. Hence the presence of iron ore, graphite and limestone, and the somewhat problematical fossil, Eozoön Canadense, in Algonkian rocks, all combined, prove to the geologist that life existed in America during the Algonkian Age. It was probably made up largely of sea-weeds, bacteria-like fungi, rhizopods, sponges, and some of the lower orders of the higher branches of the plant and animal kingdoms.

5. Mountain-Making.

The rocks of the Algonkian Age are now highly metamorphic. Extensive metamorphism of strata is known to occur only during mountain-making. The Algonkian strata are highly folded, and mashed together; and numerous outflows of molten rock are found on their borders near synclinal troughs, as about Lake Superior.

In height, the masses of Algonkian rocks do not usually approach the condition of mountains, but they possess all the other characteristics of ranges. Low height would be a result of long-continued erosion, and as geologists estimate the time during which the Algonkian rocks have been exposed to erosive action at twenty-seven million years, the low altitude of these areas is readily explained. Nothing but the core of these mountains remains. The less highly metamorphosed strata on the surface and flanks of these mountains have been removed by denuding agencies, and hence a large part of the record of their formation has been destroyed. This break in the history is one of the longest in geology, and it is feared that it must be termed a lost interval, for no areas of non-metamorphic Algonkian rocks holding fossils have yet been discovered.

5. PALEOZOIC ERA.

Geologists estimate that twenty-seven million years have elapsed since the Archæan Era closed. Of these twenty-seven million years, seventeen and one-half million years are given to the Paleozoic. The term Paleozoic means ancient life, and a study of Paleozoic fossils shows them all to represent strange and primitive forms of life.

Paleozoic strata lie in the United States, for the most part, east of the one-hundredth meridian. This area, a rude quadrangle, is bounded on the north by the Archæan V, on the east by the Atlantic Archæan mountains, on the south by the later deposits of the Cretaceous and Tertiary, and on the west by similar deposits.

The eastern third of Kansas is occupied by Paleozoic strata. These rocks contain nearly all of her mineral wealth, and soil from them supports the major portion of her population. The Paleozoic Era, beginning with the Archæan lost interval, and closing with the formation of the Appalachian Mountains, is divided into five periods of time,—the Cambrian, Ordovician, Silurian, Devonian, and Carbonic Ages. We are especially interested in Kansas, in the last, the Carbonic.

1. Cambrian Age.

1. Distribution of Strata and Duration of Age.

The sediments derived from the Archæan and Algonkian rocks and deposited in the oceans and interior seas bordering the mountainous islands of those times, were slowly raised above the level of the sea by the gradual elevation of the land and deepening of the ocean basins, through the unequal radial contraction of the earth as it lost heat energy. The Cambrian rocks have been most thoroughly studied in northern New York, in central Wisconsin, eastern Minnesota, in the country bordering the Black Hills, and in eastern Missouri. Many other localities exist in the United States, but the areas named serve to give the student a good idea of the character and distribution of these strata, especially of the Upper Cambrian. Three other localities possess intense interest to the geologist, because his studies of the Cambrian strata there exposed enable him to partially bridge the gap between the Algonkian and Cambrian. These regions are, northeastern Vermont, eastern Massachusetts, and Nova Scotia and Newfoundland. The strata there exposed are termed Lower Cambrian.

Many other localities exist in the United States and Canada where Lower Cambrian rocks may be studied, and it is much to be desired that the strata in these regions be carefully studied that more may be learned of the primitive forms of life. Such rocks may be found in the vicinity of most outcrops of Algonkian strata. The northern Wisconsin and Michigan region is probably an exception, for molten rocks continued to pour forth on the borders of Lake Superior during Lower Cambrian time.

This Age continued two and one-half million years.

2. Important Strata.

In most places where the Cambrian rests upon Algonkian or Archæan rocks a coarse conglomerate is found. This represents an ancient beach, and is composed of water-worn pebbles and boulders derived from the metamorphic rocks of the Archæan and Algonkian period. In the more sheltered situations, clay, derived from the decomposed feldspar of the gneiss, was deposited, and formed beds of shale, such as those of Braintree, Massachusetts.

But the most widely distributed stratum is the Potsdam sandstone, named from a town in northern New York. The best known localities where Potsdam sandstone is exposed are in New York, Wisconsin, and Minnesota.

3. Valuable Ores.

With the exception of a small deposit of iron ore in Wisconsin and lead and zinc in eastern Missouri, the Cambrian contains little of value to the miner.

4. Kinds of Life.

The diversity of forms of life in the oldest known layers of the Cambrian is remarkable. All the branches of the animal kingdom are represented, except the highest, the Vertebrata. No protozoans have been discovered, but this is not remarkable, for only a few of this branch possess skeletons.

Sponges, corals and mollusks are quite fully represented by fossil forms. Numerous worm-holes are found penetrating the layers, with casts about the mouths of the holes, and brachiopods are abundant, though simple in structure. Crinoids and starfish, the lowest of the echinoderms, appeared before the close of the Cambrian Age. A large proportion of the mollusks were vegetable feeders, and were therefore low in rank.

The next to the highest branch of the animal kingdom, the Arthropoda, was represented by trilobites, crustaceans belonging to the lowest order of this branch. Trilobites are so abundant and so well developed that the Cambrian has been termed the Age of Trilobites.

The upper layers of the Mississippian abound in chert, or impure flint, and the ores of lead and zinc. The deposits of these ores are so extensive that this limestone is commercially one of the most valuable in Kansas. As it dips to the northwest under the Coal Measures, it is reached by shafts sunk in the counties bordering Cherokee county, and northward along the State line.

2. *Coal Measures of Kansas.*

1. *Lower Measures.*

On the map it will be seen that for Kansas these strata are limited by the State line and the Mississippian on the east and by the Upper Coal Measures on the west. Some difference of opinion exists as to what should constitute the upper limit of this group, but the writer, following a determination made in 1890, would place the upper limit at the top of the Iola limestone. This determination makes the thickness of the group about eleven hundred feet.

The shales, which reach great thickness in the lower part of the Lower Coal Measures, are very rich in organic matter. As a consequence of its decomposition, several thin beds of sandstone, in these shales, are permeated with natural gas and oil.

At ten different horizons, beds of coal are found of greater or less commercial value. There coal-beds are distributed somewhat equally from the base to the top of the Lower Measures.

At Cherryvale the shale is made into vitrified brick of excellent quality. Similar plants for making vitrified brick are situated at Iola, Coffeyville, and probably at several other points in this belt. Natural gas is used for fuel.

At Iola a peculiar combination of shale and limestone is made, which when properly burned, gives a cement equal, is is claimed, to Portland cement.

2. *Upper Measures.*

On the map it will be noticed that for Kansas these strata are limited on the east by the outcropping Iola limestone and by the State line, and on the west by the upper surface of the escarpment of the Cottonwood limestone. The thickness is about one thousand seven hundred feet.

This group of strata includes some nine limestone horizons. As these are eroded less rapidly than the intervening shales, an equal number of escarpments extend northeast and southwest across the State. Among those best marked, according to Dr. George I. Adams, are the Reece, Eureka, Howard, Elk Falls and Burlington escarpments, caused by the presence of limestone strata of the same names respectively. A section made by the writer in 1890 and extending from El Dorado in Butler county, across Greenwood county to Toronto, in Woodson county, will show the influence of these limestones on topography, and will likewise serve to illustrate the position of several coal and sandstone strata in the Upper Measures.

Sandstones are much better developed to the southward and southwestward. This seems to indicate that the sand came from some source of supply, either in Oklahoma or in northern Texas. The heavy deposits of sandstone of the Jura-Trias in Harper and Kingman counties support the same conclusion. The Chautauqua sandstones exposed in the Burlington escarpment are much heavier south and have but a limited extension north of this section.

region. This area, for a special reason, is also designated as the Driftless Area.

Some of the lead and zinc mined in southeastern Missouri is probably derived from strata belonging to the Ordovician.

4. Progress of Life.

The Cambrian forms of life continued through the Ordovician with constantly increasing numbers and diversity. Few if any Cambrian species continued into the Ordovician, but the great branches and classes of plants and animals continued. The evolutionist points out the fact that new species are constantly appearing, displacing the old species. The latter failed to adjust themselves to new conditions, and therefore perished, giving place to other species, better equipped through variation to survive in the struggle for existence.

Some of the types that appeared first during the Ordovician were ferns and possibly club mosses (Lycopods) among plants; cockroaches and scorpions among air-breathing Arthropods; eurypterid crustaceans, closely related to the horseshoe crabs of modern seas; and a few fish of simple structure, the first of vertebrate animals.

Corals, crinoids and brachiopods were the most abundant forms of life, and the Trenton and other limestones are largely composed of their skeletons. From the abundance of brachiopods this age is sometimes termed the Age of Brachiopods; but it might, with almost equal propriety, be called the Age of Corals.

5. Mountain-Making.

During the eight million years of the Ordovician, sediments were accumulating along the inner and outer borders of the Archæan-Algonkian quadrangle. At the north-

The Upper Measures contain some eight or nine beds of coal; but of these, not more than three or four are thick enough to pay to work them.

Nearly all the strata of limestone are quarried for building-stone, and are of excellent quality for this purpose, especially for foundations. The Cottonwood limestone, at the summit of the Upper Measures, and another heavy-bedded limestone, one hundred and seventy-five feet lower down, locally known as the Americus limestone, are perhaps most highly prized for dressed stone for walls and trimmings. Very extensive quarries exist in the Cottonwood limestone at Cottonwood Falls, Strong City, Dunlap, northern Lyon county, and thence north to Manhattan.

The shales which everywhere lie between the limestones are not used very extensively as yet for brickmaking; but they will some day prove a valuable source of supply of clay, not merely for brick, but for pottery as well. Some of the railroad companies have learned that shale makes excellent ballast after it is burned. Rejected ties and coal slack are laid down in alternate layer with shale and clay, and the mass is fired. The heat in the presence of air converts the ferrous compounds into insoluble ferric oxide, and an excellent ballast results. May not this burnt clay and shale serve as an excellent dressing for muddy streets?

Some attempts have been made to use the sandstones for building stones, but their color and degree of hardness are unsatisfactory. Some sandstones contain enough clay to give them flagstone cleavage, but frost soon disintegrates the stone, and it becomes worthless. For sidewalks, especially, the flagstones of the Coal Measures do not compare in durability with some of the thin-bedded limestones of the upper part of the Upper Measures.

3. *The Permian.*

The Permian strata extend across Kansas into Nebraska on the north and Oklahoma on the south. The outcropping Cottonwood limestone bounds the Permian on the east; and the Permian strata pass under the outcropping Red Beds at the southwest, the Quaternary marlites at the middle west, and the Dakota sandstone at the northwest.

The total thickness of the Permian is about eight hundred feet, or possibly nine hundred.

The strata are mostly limestones and shales. Many of the latter are arenaceous.

About one hundred and thirty feet above the base of the Permian is a remarkable stratum of limestone. Several layers contain large and small concretions of flint. Other layers of the stratum consist of a soft, white limestone valuable for the walls of buildings. The entire stratum is nearly forty feet thick, and is the chief resistant rock of the Flint Hills. Seventy feet above this stratum is another, about twenty feet thick, holding flint; and one hundred feet above the second is a third stratum, of similar character. These are named from localities where they are well exposed, the Strong Flints, Florence Flints and Marion Flints, respectively. The Strong Flints, at Strong City, are crushed for ballast for the Santa Fe tracks. The white limestone in the midst of the Strong Flints is probably the rock quarried near El Dorado for walls and trimmings of buildings. Twenty or twenty-five feet above the Florence Flints is the Fort Riley limestone bed, also much used for walls and foundations of buildings.

Near the top of the Permian are found the beds of salt and gypsum mined in central Kansas. The salt and gypsum were probably deposited at the time the continent was elevated in consequence of the formation of the westernmost range of the Appalachian Mountains and the deepening of the Atlantic ocean basin.

4. Valuable Ores.

The only ores occurring in sufficient quantities to pay to mine them are the zinc and lead ores of the Mississippian limestone in the southeastern part of the State. The ores are sulphides, and must be roasted to burn out the sulphur before the zinc and lead are fit for use. This is most cheaply done by heating the ores in a natural gas furnace with free access of air. This roasting frees the metals of sulphur and converts them into oxides. The oxygen is finally separated from the metals, especially from the zinc, by reheating them in a retort with coal. The sulphur driven off in the roasting is converted into sulphuric acid or is permitted to pass up the chimney and out into the air. But this last method is to be condemned, for the sulphur oxide will in time destroy the vegetation about the reduction works. The smelters at Cherryvale, Iola, and at other points in the natural gas belt, are among the finest in the world.

5. Origin and Distribution of Coal.

The coal of Kansas is undoubtedly derived from the vegetation of the numerous swamps that existed in eastern Kansas during the Carbonic Period. The proofs of this statement are found in the coal-beds and in the strata above and below. In the coal itself, the microscope reveals decomposed vegetable tissue. Leaves are found abundantly

2. IMPORTANT STRATA.

The Corniferous limestone, the Hamilton shales, and the sandstones of the Catskill group, are the strata of special interest.

The Corniferous limestone is so named because of the hornstone or flint found in it very abundantly at Buffalo, New York. This limestone may be traced westward into Ohio, north through the straits of Mackinac, and south and west into Kentucky and Iowa, respectively.

The Hamilton shales, like the Hudson river shales of the Ordovician, are full of fossil corals and brachiopods.

The Catskill sandstones are especially interesting because they represent in part the old red sandstone, described by the eminent Scotch geologist, Hugh Miller, in England and Scotland.

3. VALUABLE ORES AND OTHER MINERALS.

There are no deposits of valuable ores in the Devonian strata of North America. The rocks contain an increasing percentage of bitumen derived from the decomposing tissues of plants and animals. Some strata contain so much, that they are mistaken for coal, but they are much too lean to burn with profit. Some of the shales have been distilled for illuminating gas, with fair results. Many Devonian fossils contain bitumen in their cavities, and nearly all the strata have the odor of bitumen.

Oil and natural gas are found in Devonian rocks in Pennsylvania, Canada, Ohio, and Kentucky. More will be said under this head in describing the economic products of the Carbonic Age.

4. Progress of Life.

The life of the Devonian is characterized by the great development of the higher cryptogams and gymnosperms, among plants, and the great size and number of fish, among animals. The development and predominance of fish in the seas have given to this time the name, Age of Fishes.

The vegetation of the Devonian is so like that of the Carbonic Age that a fuller discussion of the kinds of plants will be given in the description of the Carbonic life. It should, however, be observed here, that many swamp areas existed along the coasts of the interior seas, and that the huge cryptogams of the swamps and the yews and cycads of the uplands constituted the forests of the Devonian.

Devonian fish comprised sharks and ganoids. The sharks were fitted for living on mollusks and on other fish. Those sharks fitted for feeding on mollusks had flat-topped teeth for crushing the shells; the others had sharp teeth, much like modern sharks.

The ganoids were of two kinds: plated ganoids and scaly ganoids. The plated ganoids appeared in the seas first during Silurian times, and were unwieldy creatures, armored with bony plates, like the steel plates of modern battleships. The scaly ganoids were much like the modern gar, so abundant in Western rivers, and were fully as well equipped with teeth for the destruction of other animals not protected by a bony armor.

The evolutionist is most interested in the peculiar make-up of these animals. All understand that each animal in developing from the egg, passes through several stages of in the shale above and roots in the shale below. If all this is not conclusive, an examination of the swamps and bogs of to-day will reveal incipient coal-beds. The peat is but coal in its first stages. All vegetable matter when it decomposes under water in the absence of air, becomes more and more bituminized till it is finally coal. If it decomposes in the presence of air, nothing but vegetable mold results. The plants which furnished the leaves for the coal were all cryptogams in the Kansas swamps, together with a few gymnosperms that grew on the uplands.

The beds of coal which are now found in the Kansas Coal Measures are not any of them very thick, and most of them are so thin that they are not worked. The swamps lasted longer in some places than in others, and hence the coal-beds are thicker in those situations. In the same swamp, also, some parts had a thicker deposit of leaves than others, and therefore thin coal-beds may thicken in portions of an area to such an extent that it pays to work the beds for the coal.

Osage, Leavenworth, Cherokee and Crawford counties each produced over one hundred thousand tons of coal in 1897; Cherokee and Crawford counties produced over a million tons each. The total product of coal in 1897 was over three and one-quarter million tons.

Careful estimates state that one-eighth of an inch of coal represents the growth of swamp vegetation for a century; therefore a ten-inch bed of coal represents the growth of swamp vegetation for eight thousand years.

The coal-beds of Kansas are from two inches to forty inches in thickness; few beds are worked which have a thickness of less than ten inches. The following table will give the thickness of the principal beds in Kansas:

Weir-Pittsburg Beds	30 inches
	40 inches
	18 inches
Fort Scott Bed	20 inches
Pleasanton Bed	36 inches
Atchison Bed	17 inches
Lawrence Bed	16 inches
Neosho Rapids and Lebo Beds	16 inches
Osage Bed	22 inches
Total workable coal	215 inches
Eleven beds unworkable (estimated),	48 inches
Total coal in Kansas (estimated)	263 inches

The thickest bed of coal, the one of forty inches, represents a swamp growth and deposition of peat for thirty-two thousand years; the total thickness of workable coal in Kansas, two hundred and fifteen inches, and the forty-eight inches in beds too thin to work, represent a swamp growth of vegetation for over two hundred thousand years.

6. Origin and Distribution of Natural Gas and Petroleum.

Wells bored or drilled to a depth of four hundred to six hundred feet in the natural gas belt of the Lower Coal Measures, encounter a gas pressure in the thin sandstone beds of the Cherokee shales, of about two hundred pounds to the square inch. The productive gas belt is a narrow one, and extends from Iola to Coffeyville. Wherever the sandstone beds are absent, no gas is obtained. The richest sub-areas of this belt have Iola and Cherryvale for their centers.

Natural gas is never found in paying quantities except in strata holding the remains of salt-water plants and animals. The vegetable and animal matter deposited in sediments in salt water undergo a peculiar decomposition which results in the production of natural gas and oil. The gas may accumulate in any porous rock, usually a sandstone, provided there is an impervious rock, such as shale, above. Fissures extending deep into the earth, as at the summit of anticlines, may allow the gas and oil to escape to the surface and be lost to man. As the gas and oil are usually found in quantities only on the slopes of anticlines, or in gently dipping strata, it is possible that the gas and oil are forced by the enormous rock pressure to make their way slowly to the surface, along the inclined strata. If this is true in Kansas, our gas and oil wells may be fed from the great deposits of sediments containing organic matter lying to the westward in the inclined Cherokee shales. To the eastward of the gas belt, where the shales come to the surface, no gas under pressure is found, for it there readily escapes. If this supposition is true, it will give no warrant for the excessive use of the gas, for the experience gained in the gas-fields of Indiana and Pennsylvania proves that the accumulation of gas in the deeper-seated portions of a stratum is exceedingly slow.

After a heavy flow of salt water is reached in a well, little gas may be expected by sinking the well deeper. The gas seems to be forced upward by the salt water.

West of the gas belt, all wells fail to find gas in quantities. Possibly the pressure is so great on gas under strata over eight hundred or a thousand feet thick that it cannot accumulate, but is forced to flow to the eastward where the pressure is less.

Petroleum is found in Kansas under a small area, with

Neodesha as its center. The oil wells average deeper than the gas wells, but the oil is not under sufficient pressure to force it to the surface. The supply of oil is limited, and the number of paying wells is rapidly diminishing.

7. Origin and Occurrence of Rock-Salt and Gypsum.

Sea-water contains both salt and gypsum, and these minerals are obtained artificially by evaporating the water by sun heat or by furnace heat. Gypsum is less soluble than salt, and consequently, as the brine is concentrated, the gypsum is deposited first, and then the salt after further concentration.

In Nature, whenever any portion of sea-water is so separated from supplies of river-water and from the ocean that it no longer receives any material supply of ocean-water or river-water, the sun heat causes the salt water to concentrate by evaporation. First the gypsum is deposited, then the salt. If, while the brine is depositing gypsum, new supplies of water are received, the brine may continue to deposit gypsum till a bed of great thickness is formed. Should no accessions of ocean or fresh water be received, a bed of salt forms at the bottom of the inland lake or sea.

Near the close of the Permian period in Kansas, such an inland sea extended from south of Kingman to Salina. It may have been a series of seas instead of one. The salt is obtained at several points in this belt by borings, by shafts, and from springs. In all deep wells in Kansas, east and west, salt water is found at some depth, but the greatest deposits of salt are found in the uppermost strata of the Permian.

Rock-salt is mined at Lyons and Kingman. It is dissolved and pumped at Hutchinson by forcing fresh water down one tube into the stratum of rock-salt, and thence up through a small tube within the other to the evaporating-pan at the surface.

Gypsum is mined in Saline, Dickinson, and in several of the neighboring counties, where the upper strata of the Permian outcrop, or may be easily reached by shafts. The gypsum of Barber county is found in Mesozoic strata.

8. Progress of Life.

The fossil remains found in strata of the Carbonic Age show that nearly all the classes and many of the orders of plants and animals continued into this age from the Devonian. Among plants, ferns were very abundant, as were also sigillaria, lepidodendrons, and calamites. Beautiful fronds of ferns are found in nearly all the shales and in sandstones immediately above or below the shales. The fossil sigillaria, as the name signifies, are trees whose trunks are covered in vertical rows with seal-like leaf-scars. Some of these scars are over an inch in diameter, indicating that the leaves may have been as long as those of the modern palm, a tree which the sigillaria resembled in general appearance. The lepidodendrons differ from the sigillaria principally, in having the leaf-scars arranged in a spiral row about the trunk. The calamites, found fossilized in shaly sandstones, are very much like the modern scouring-rush, only many times larger.

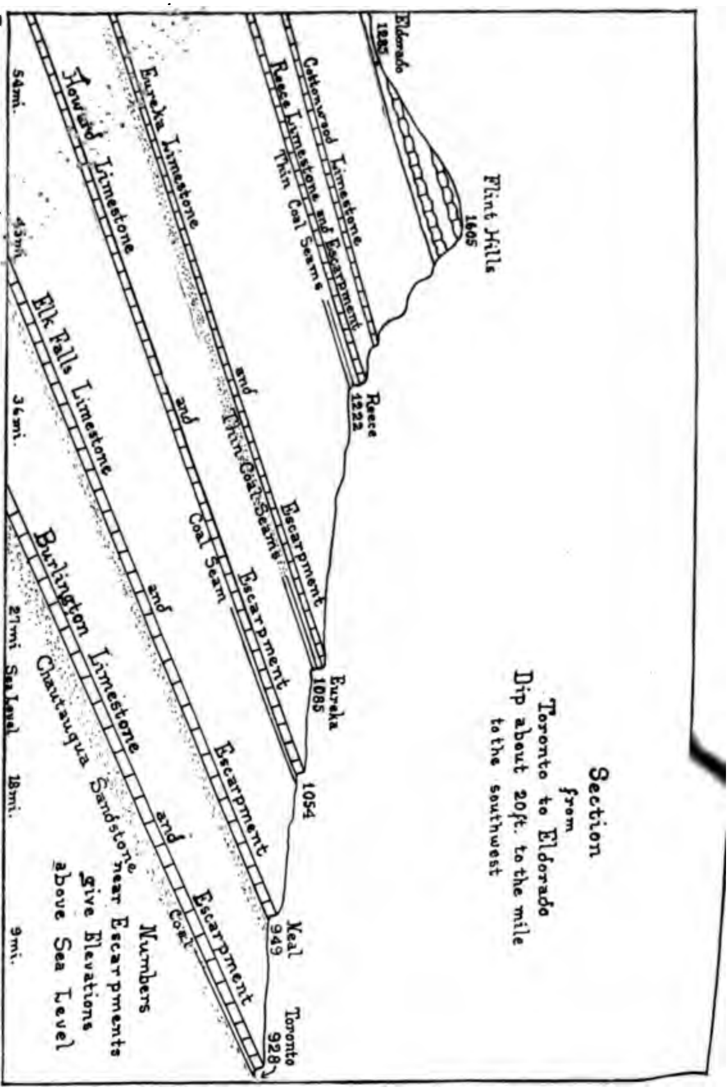
The evolutionist has studied these ancient cryptogams with the greatest care. He has found that the wood near the heart of the tree has a very close resemblance to the wood of exogens. The wood of the highest modern cryptogams has not the slightest resemblance to the wood of exogens. Hence he concludes that the lepidodendrons, sigillaria and calamites of the Coal Measures are the ancestors of modern (cone-bearing) exogens as well as the ancestors of the modern ground pines and scouring-rushes. (The ground pine of the northern woods, used in Christmas decoration, is one of the highest modern cryptogams, and closely resembles the ancient lepidodendrons and sigillaria, except in size and wood-structure.)

In the vicinity of the swamps, on the uplands of Kansas, were forests of true exogens. These were gymnosperms closely resembling the Mesozoic cycads and the modern yews. But no flowering exogens or endogens have been discovered in the Coal Measures of Kansas or of other countries. The evolutionist thinks that these were evolved from ferns later.

After the clear seas of the Mississippian period were replaced by the swamps and seas of the Carbonic period, the salt-water corals, crinoids and mollusks of the former period occupied eastern Kansas alternately with the various sorts of swamp animals.

The Carbonic period was remarkable for the number of times the land was depressed beneath the sea and elevated a few feet above its level. The strata of the Coal Measures were alternately salt-water sediments and fresh-water sediments. There were at least twenty of these changes, and as the rocks containing the remains of salt-water animals are more than twelve times as thick as the rocks containing fresh-water forms of life, the salt-water animals had possession by far the better part of the time. It should be noted, however, that all the swamps may not have

Fig. 5


Section
from
Toronto to Eldorado
Dip about 20ft. to the mile
to the southwest
Flint Hills
1605
Eldorado
Reece
1222
Eureka
1085
1054
Keal
949
Toronto
928
Cottonwood Limestone
Reece Limestone and Escarpment
Thin Coal Seams
Eureka Limestone
and
Thin Coal Seams
Escarpment
Howard Limestone
and
Coal Seam
Escarpment
Elk Falls Limestone
and
Escarpment
Burlington Limestone
and
Escarpment
Coal
Chautauqua Sandstone
Numbers
near Escarpments
give Elevations
above Sea Level
54mi.
45mi.
36mi.
27mi
Sea Level
18mi.
9mi.

The Upper Measures contain some eight or nine beds of coal; but of these, not more than three or four are thick enough to pay to work them.

Nearly all the strata of limestone are quarried for building-stone, and are of excellent quality for this purpose, especially for foundations. The Cottonwood limestone, at the summit of the Upper Measures, and another heavy-bedded limestone, one hundred and seventy-five feet lower down, locally known as the Americus limestone, are perhaps most highly prized for dressed stone for walls and trimmings. Very extensive quarries exist in the Cottonwood limestone at Cottonwood Falls, Strong City, Dunlap, northern Lyon county, and thence north to Manhattan.

The shales which everywhere lie between the limestones are not used very extensively as yet for brickmaking; but they will some day prove a valuable source of supply of clay, not merely for brick, but for pottery as well. Some of the railroad companies have learned that shale makes excellent ballast after it is burned. Rejected ties and coal slack are laid down in alternate layer with shale and clay, and the mass is fired. The heat in the presence of air converts the ferrous compounds into insoluble ferric oxide, and an excellent ballast results. May not this burnt clay and shale serve as an excellent dressing for muddy streets?

Some attempts have been made to use the sandstones for building stones, but their color and degree of hardness are unsatisfactory. Some sandstones contain enough clay to give them flagstone cleavage, but frost soon disintegrates the stone, and it becomes worthless. For sidewalks, especially, the flagstones of the Coal Measures do not compare in durability with some of the thin-bedded limestones of the upper part of the Upper Measures.

3. *The Permian.*

The Permian strata extend across Kansas into Nebraska on the north and Oklahoma on the south. The outcropping Cottonwood limestone bounds the Permian on the east; and the Permian strata pass under the outcropping Red Beds at the southwest, the Quaternary marlites at the middle west, and the Dakota sandstone at the northwest.

The total thickness of the Permian is about eight hundred feet, or possibly nine hundred.

The strata are mostly limestones and shales. Many of the latter are arenaceous.

About one hundred and thirty feet above the base of the Permian is a remarkable stratum of limestone. Several layers contain large and small concretions of flint. Other layers of the stratum consist of a soft, white limestone valuable for the walls of buildings. The entire stratum is nearly forty feet thick, and is the chief resistant rock of the Flint Hills. Seventy feet above this stratum is another, about twenty feet thick, holding flint; and one hundred feet above the second is a third stratum, of similar character. These are named from localities where they are well exposed, the Strong Flints, Florence Flints and Marion Flints, respectively. The Strong Flints, at Strong City, are crushed for ballast for the Santa Fe tracks. The white limestone in the midst of the Strong Flints is probably the rock quarried near El Dorado for walls and trimmings of buildings. Twenty or twenty-five feet above the Florence Flints is the Fort Riley limestone bed, also much used for walls and foundations of buildings.

Near the top of the Permian are found the beds of salt and gypsum mined in central Kansas. The salt and gypsum were probably deposited at the time the continent was elevated in consequence of the formation of the westernmost range of the Appalachian Mountains and the deepening of the Atlantic ocean basin.

4. Valuable Ores.

The only ores occurring in sufficient quantities to pay to mine them are the zinc and lead ores of the Mississippian limestone in the southeastern part of the State. The ores are sulphides, and must be roasted to burn out the sulphur before the zinc and lead are fit for use. This is most cheaply done by heating the ores in a natural gas furnace with free access of air. This roasting frees the metals of sulphur and converts them into oxides. The oxygen is finally separated from the metals, especially from the zinc, by reheating them in a retort with coal. The sulphur driven off in the roasting is converted into sulphuric acid or is permitted to pass up the chimney and out into the air. But this last method is to be condemned, for the sulphur oxide will in time destroy the vegetation about the reduction works. The smelters at Cherryvale, Iola, and at other points in the natural gas belt, are among the finest in the world.

5. Origin and Distribution of Coal.

The coal of Kansas is undoubtedly derived from the vegetation of the numerous swamps that existed in eastern Kansas during the Carbonic Period. The proofs of this statement are found in the coal-beds and in the strata above and below. In the coal itself, the microscope reveals decomposed vegetable tissue. Leaves are found abundantly in the shale above and roots in the shale below. If all this is not conclusive, an examination of the swamps and bogs of to-day will reveal incipient coal-beds. The peat is but coal in its first stages. All vegetable matter when it decomposes under water in the absence of air, becomes more and more bituminized till it is finally coal. If it decomposes in the presence of air, nothing but vegetable mold results. The plants which furnished the leaves for the coal were all cryptogams in the Kansas swamps, together with a few gymnosperms that grew on the uplands.

The beds of coal which are now found in the Kansas Coal Measures are not any of them very thick, and most of them are so thin that they are not worked. The swamps lasted longer in some places than in others, and hence the coal-beds are thicker in those situations. In the same swamp, also, some parts had a thicker deposit of leaves than others, and therefore thin coal-beds may thicken in portions of an area to such an extent that it pays to work the beds for the coal.

Osage, Leavenworth, Cherokee and Crawford counties each produced over one hundred thousand tons of coal in 1897; Cherokee and Crawford counties produced over a million tons each. The total product of coal in 1897 was over three and one-quarter million tons.

Careful estimates state that one-eighth of an inch of coal represents the growth of swamp vegetation for a century; therefore a ten-inch bed of coal represents the growth of swamp vegetation for eight thousand years.

The coal-beds of Kansas are from two inches to forty inches in thickness; few beds are worked which have a thickness of less than ten inches. The following table will give the thickness of the principal beds in Kansas:

Weir-Pittsburg Beds	30 inches
	40 inches
	18 inches
Fort Scott Bed	20 inches
Pleasanton Bed	36 inches
Atchison Bed	17 inches
Lawrence Bed	16 inches
Neosho Rapids and Lebo Beds	16 inches
Osage Bed	22 inches
Total workable coal	215 inches
Eleven beds unworkable (estimated),	48 inches
Total coal in Kansas (estimated)	263 inches

The thickest bed of coal, the one of forty inches, represents a swamp growth and deposition of peat for thirty-two thousand years; the total thickness of workable coal in Kansas, two hundred and fifteen inches, and the forty-eight inches in beds too thin to work, represent a swamp growth of vegetation for over two hundred thousand years.

6. Origin and Distribution of Natural Gas and Petroleum.

Wells bored or drilled to a depth of four hundred to six hundred feet in the natural gas belt of the Lower Coal Measures, encounter a gas pressure in the thin sandstone beds of the Cherokee shales, of about two hundred pounds to the square inch. The productive gas belt is a narrow one, and extends from Iola to Coffeyville. Wherever the sandstone beds are absent, no gas is obtained. The richest sub-areas of this belt have Iola and Cherryvale for their centers.

Natural gas is never found in paying quantities except in strata holding the remains of salt-water plants and animals. The vegetable and animal matter deposited in sediments in salt water undergo a peculiar decomposition which results in the production of natural gas and oil. The gas may accumulate in any porous rock, usually a sandstone, provided there is an impervious rock, such as shale, above. Fissures extending deep into the earth, as at the summit of anticlines, may allow the gas and oil to escape to the surface and be lost to man. As the gas and oil are usually found in quantities only on the slopes of anticlines, or in gently dipping strata, it is possible that the gas and oil are forced by the enormous rock pressure to make their way slowly to the surface, along the inclined strata. If this is true in Kansas, our gas and oil wells may be fed from the great deposits of sediments containing organic matter lying to the westward in the inclined Cherokee shales. To the eastward of the gas belt, where the shales come to the surface, no gas under pressure is found, for it there readily escapes. If this supposition is true, it will give no warrant for the excessive use of the gas, for the experience gained in the gas-fields of Indiana and Pennsylvania proves that the accumulation of gas in the deeper-seated portions of a stratum is exceedingly slow.

After a heavy flow of salt water is reached in a well, little gas may be expected by sinking the well deeper. The gas seems to be forced upward by the salt water.

West of the gas belt, all wells fail to find gas in quantities. Possibly the pressure is so great on gas under strata over eight hundred or a thousand feet thick that it cannot accumulate, but is forced to flow to the eastward where the pressure is less.

Petroleum is found in Kansas under a small area, with

Neodesha as its center. The oil wells average deeper than the gas wells, but the oil is not under sufficient pressure to force it to the surface. The supply of oil is limited, and the number of paying wells is rapidly diminishing.

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8. Progress of Life.

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The fresh-water animals were of the usual swamp orders, but of very different species from those now found in swamps.

It will be remembered that fish, possessing many reptilian characteristics, were the rulers of the Devonian seas. The Devonian sharks, scaly ganoids and plated ganoids still continued to rule the deep seas during the Carbonic Age; but great frog-like creatures, and, at the close, true reptiles, found home and safety on the land and in the swamps and border seas.

The tracks of these frog-like amphibians are found in shore-formed limestones and shaly sandstones of the Carbonic period. Slabs crossed by their tracks are occasionally seen in the sidewalks of the cities situated on the Coal Measures. Eureka, Greenwood county, and Osage City, Osage county, have used such slabs in their sidewalks. In other States the skeletons of some of these amphibians have been discovered, and it has been found, to the delight of the evolutionist, that some of these creatures combined frog-like characters with others that are mammalian. Their teeth, for example, very closely resembled the teeth of mammals. They had incisors, canines, and molars. True amphibians and reptiles have simply holding-teeth like the conical teeth of fish. Hence the evolutionist says that the Labyrinthodonts and Theriodonts, the amphibians just described, were the ancestors of modern amphibians and mammals, and probably of reptiles and birds.

A few water-loving insects have been discovered in the swamp deposits, and some fresh-water snails. Some of the dragon-flies had a spread of wings measuring twenty-four inches. No members of the three highest orders of insects have been discovered in the rocks of the Carbonic Age.

9. MOUNTAIN-MAKING AND CONTINENT-MAKING.

The great geosynclinal trough that had been receiving sediments during the seventeen and one-half million years of the Paleozoic Era from the Atlantic Mountain range on the east, yielded to lateral pressure at the close of the Paleozoic. The water-laden sediments had sunk forty thousand feet and the subjacent crust and the sediments at the bottom of the syncline became so hot that they finally fused, and the sides of the great trough moved toward each other. This lateral movement was so great that in one part of the range ninety-five miles of original extent were reduced to sixteen miles. There may have been more than one geosyncline in the western Appalachians, but this enormous lateral pressure and movement so mashed the sediments together, and the great heat, derived from the interior and from the friction of crushing, so metamorphosed the strata, that the exact number of geosynclines may never be known. The difficulty of study is also increased by the great faulting of the strata. In one case a slip of twenty thousand feet has been discovered, and, as the fossils were mostly destroyed or have been removed by denudation, great difficulty is experienced in tracing the strata across the range. The rise of this western part of the Appalachians probably continued during the major part of the Permian period. The range must have equalled in height at the close of the Paleozoic the loftiest ranges of the present, for the mountains have since lost, according to geologists, more material by denudation than they now contain.

The entire continent seemed to tremble under the great stress of lateral pressure before the Appalachian Revolution began. This accounts for the alternation of swamps and seas throughout the interior basins during the Carbonic period. At the close of the Permian period these interior basins, including the eastern third of Kansas, were permanently raised above the level of the sea, and thus the northeastern part of the American continent was finished. Some finishing touches were given in later times to the Atlantic and Gulf borders, and great glaciers scoured the surface of the northern half; but the great mass of the continent east of central Kansas was never again covered by salt water.

6. MESOZOIC ERA.

The seven million years of the Mesozoic Era gave to Kansas the second third of her area. During this era salt-water sediments were deposited on the Atlantic and Gulf borders, in the great interior sea occupying the westernmost of the basins of the quadrangle, in the basin west of the Archæan Rocky Mountains, and on the Pacific border of the Nevada Archæan Mountains.

The name Mesozoic means middle life; the old Paleozoic forms were largely replaced by animals and plants which were much more like modern types. Not a species passed from the Paleozoic to the Mesozoic, but many classes, orders, and a few genera did so. For instance, the

Fern family continues from the Devonian Age to the present, but no species of fern does so, nor even from age to age.

1. Jura-Trias Age.

In Europe and in some parts of the United States the Triassic and the Jurassic rocks are plainly distinct in rock strata and life-forms; but in other parts of the United States, including Kansas, these strata cannot be classified on the European basis; therefore the writer describes them as though they belonged to one age.

1. Distribution of Strata and Duration of Age.

On the Atlantic border the Jura-Trias rocks were laid down mostly in estuaries and in synclines on the eastern slopes of the Appalachians. In the west, the Jura-Trias strata are found on the Kansas and the Archæan Rocky Mountain borders of the great inland sea. Still farther west they border the Archæan islands outside the Paleozoic deposits. The estimated duration of this age is three million five hundred thousand years.

2. Important Strata in Kansas.

The brown and red sandstones of the Connecticut valley and northern New Jersey, and of the eastern slopes of the Rocky Mountains, are highly prized for their beauty and durability as building-stones. Many of the finest buildings in New York and Denver are constructed of this sandstone. There are very few fossils in this rock, but these and the age of the strata above and below place the sandstone in the Jura-Trias.

For similar reasons, the Red Beds of south-central Kansas, and western Oklahoma and Texas, are classed as

Jura-Trias. Unfortunately for those who would use sandstone for walls of buildings or for trimmings for red brick buildings, the Red Beds are too little indurated for such purposes.

3. Valuable Minerals in Kansas.

At Kingman, some of the argillaceous layers of the Red Beds contain so much ferric oxide that they are ground for mineral paint with fair results.

Near the top of the Red Beds occur the gypsum deposits of Barber, Comanche and Kiowa counties. The increasing demand for plaster, for fertilizer and for use in hardening cements, renders these deposits of great commercial value.

The principal bed of gypsum is from twenty to fifty feet in thickness and extends from southern Kansas into Texas, making this area the greatest in the United States in extent and in the amount of gypsum it contains.

4. Progress of Life.

The life of the Jura-Trias is preëminently reptilian in its character, and this age is therefore termed the Age of Reptiles.

Modern types of coral appear in this age, and modern mollusks and many modern insects. All the insects, however, had jaws, or possessed sharp beaks for suction, like our squash-bugs.

The reptiles were easily the masters of the seas, shores, and the dry land. There were swimming reptiles, called fish-lizards (Ichthyosaurs), wading and dry-land reptiles, called terrible lizards (Dinosaurs), and flying reptiles called wing-finger lizards (Pterosaurs). I have avoided giving any except the general scientific names, for we shall not use them often enough in this story to enable one to memorize them in the proper way. They can be found in the larger works on geology, should it seem desirable to know the specific names.

The lizards which walked along the sand-flats of the shore regions of the Jura-Trias left foot-prints which constitute the only fossil remains in the red sandstone mentioned above. At first these tracks were believed to be bird-tracks, for they were three-toed and in other respects resembled the tracks made by birds. But the shales above the sandstones have in them no fossil skeletons of birds, only those of lizards. But many of these lizards had only three toes, and hence the famous Connecticut sandstone "bird-tracks" are now called reptile-tracks. In Europe, however, a fossil bird has been discovered in some very fine-grained Jurassic rocks, known as lithograph slates. This bird was as large as a robin, and had a tail as long as its body, and holding-teeth in its jaws. The tail differed from that of the modern bird in having the backbone extending through it for almost its entire length. The tail feathers were arranged along the sides of the tail, with only a few short ones at the tip. Every feather of the tail was beautifully preserved in the slate, and so there is no question about it.

There were also many amphibians. Some of these had bills like birds and others had teeth of three sorts, incisors, canines and molars, like mammals.

The evolutionist takes great comfort studying these ancient amphibians, reptiles and birds, for he thinks that they prove the truth of his theory. In some of the amphibians he can see the ancestors of reptiles, in others the ancestors of birds, and in still others the ancestors of mammals. Indeed, mammals of the type known as marsupials became quite abundant in the Jura-Trias times. These were insect-eating little creatures somewhat resembling the opossum, and became quite abundant in America. These were intermediate, however, between marsupials and insect-eating mammals, and possessed some amphibian characteristics.

5. Mountain-Making.

During the seventeen and one-half million years of the Paleozoic and three and one-half million years of the Jura-Trias, sediments were accumulating on the flanks of the Archæan Rocky Mountains and on the borders of the Archæan Nevada Mountains, and were somewhat widely distributed to the east and west. Geosynclines slowly formed under these sediments; and the Archæan mountains, which contributed the major part of the sediments, were greatly reduced in height and breadth. Near the close of the Jura-Trias, the Sierra, the Coast and the Cascade geosynclines slowly yielded to lateral pressure and the mountains of the same names were begun. The Sierras and Coast Ranges seem to have been formed in twin geosynclines, or, in the mashing of sediments, an immense synclinal trough was formed at about the middle of one great geosyncline. The Sierras were not completed at this time, nor were the Cascades.

In Kansas, the only increase of dry land was in the region of the Red Beds in the south-central part of the State. Here the increase was caused by the slow elevation of the continent, or by an undulating movement of the crust as it adjusted itself to a shrinking interior.

2. Cretaceous Age.

1. Distribution of Strata and Duration of Age.

In the United States, Cretaceous rocks are found along the Atlantic, Gulf and Pacific borders, and in the interior basins east and west of the Archæan Rocky Mountains. The deposition of Cretaceous sediments continued three million five hundred thousand years; or until the great interior basins were filled nearly to the water-level and large areas of dry land were added to the Atlantic, Gulf and Pacific coasts.

The oldest strata of the Cretaceous in Kansas are found in Barber, Comanche and Clark counties, on the border of the Red Beds; and the newest strata are found beneath the Tertiary in the western part of the State. The exact distribution of the Cretaceous in Kansas may be learned by consulting the map on page 98 of this story.

2. Important Strata in Kansas.

The strata are described in the order of their age, beginning with the oldest:

1. The Comanche group consists of a coarse sandstone at the bottom, and of shales and a thin bed of limestone above. The sandstone contains fossil wood and leaves of dicotyls, and the shales and limestone above hold many invertebrate and vertebrate fossil remains. At the base of the shales is a gypsiferous stratum.

2. The Dakota group contains as its most characteristic member a dark-brown sandstone, heavy with ferric oxide. Above this sandstone are, first, the lignite horizon; second, the saliferous shales; and third, the gypsiferous shales. Just above and below the saliferous shales are thin sand-

stone beds which yield an abundance of water for wells. The water from the saliferous shales is of course impregnated with salt and salt springs abound along its line of outcrop.

3. The Benton group is characterized by a light-brown limestone, very valuable for sidewalks and fence-posts. It is sawed readily into slabs or posts. Above this fence-post limestone is another limestone, holding a great abundance of oyster-shells. This limestone readily disintegrates and forms a very productive soil, made fertile largely by the shells. In marked contrast with this soil is that produced by the disintegration of the Blue Hills shales, a stratum one hundred feet thick at the top of this group, barren of fossils and nearly so of good soil-producing qualities.

4. The Niobrara group consists of two important strata, the Fort Hays limestone and the blue chalk beds.

Just below the Fort Hays limestone is a thin stratum which contains many flattened concretions. When these are seamed on their surface they are termed septaria.

At the same horizon in the foot-hills of the Rocky Mountains in Colorado, the concretions are of the shape of cannon-balls, and frequently contain a fossil as their nucleus.

The Fort Hays limestone is usually too soft to be of much value as a building-stone, but it may be sawed into fence-posts, and, as the stone hardens somewhat on exposure, these serve excellently for fences, as timber is scarce in this part of the State.

The blue chalk beds usually bleach on exposure to the air, and become yellow or buff. Some layers, however, are pure white, and have been mined for shipment.

5. The Fort Pierre group is represented in Kansas by yellow and blue shales, exposed beneath and in the midst of Tertiary strata in the northwestern corner of Kansas. Some of the layers contain fossiliferous concretions.

6. The Fox Hills group is not certainly known to be represented in the State, but some shales in Cheyenne county may prove to belong in this group.

7. The Laramie group, strata which are transitional between the Cretaceous and Tertiary, is not known to have a representative in Kansas. During the progress of the Laramie epoch, great swamps existed in Colorado and Wyoming, west of Cheyenne, north of Denver, and near Cañon City. Also swamps existed in other parts of Colorado and New Mexico. From the vegetable growth in these swamps came the coal of Wyoming, Colorado, and New Mexico.

3. Valuable Minerals in Kansas.

As has already been stated, considerable gypsum is found in one stratum of the Comanche. Between the brown sandstone of the Dakota and the saliferous shales above, is a bed of lignite coal of varying thickness and purity. Perhaps the best development of the lignite coal is found in Lincoln county. This bed of lignite supplies the local demand for fuel, and it is said will amply repay a much larger expenditure in its development. The bed is from six to twenty-six inches in thickness.

The chalk of the Niobrara group is not very pure, except in a few layers. These may sometime be of great commercial value.

4. Progress of Life.

During the Cretaceous Age reptiles culminated in size and numbers, and dicotyledonous plants, nectar-loving insects and reptilian birds were introduced. Reptilian birds were found in the Jura-Trias of Europe, but only one fossil bird, and that of doubtful affinities, has been found in the Jura-Trias of America.

The chalk of the Niobrara is composed quite largely of the tiny shells of rhizopods, very like in most respects the rhizopods of the chalk of England and France. The chalk of these countries is of the same age as the chalk of Kansas.

Corals, crinoids and mollusks were much like those of the present time in their general characteristics. Several beds contain a great abundance of oyster-shells, and chambered shells like our pearly nautilus were common. Some, however, of the chambered shells, were straight like a cane, and all had curious pockets where the partitions joined the outer shell. There were also naked mollusks like the cuttle-fish, for the internal bone and the ink-bag have been discovered. In some instances the ink has been so well preserved that drawings have been made of these fossils with their own ink.

The lignite coal of the Dakota group is composed quite largely of leaves of trees such as we now see in swamps. These leaves are from oaks, willows, maples, sassafras, dogwood, hickory, beach, poplar, walnut, laurel, sycamore, fig and sweet-gum trees, very many of which have swamp varieties even now.

The evolutionist has wondered where these plants originated, and the discovery of some curious leaves in the upper Jurassic and the Lower Cretaceous beds, leads him to think that they may have sprung from ferns, for these curiously formed leaves are certainly intermediate between the leaves of ferns and of dicotyls.

With flowering plants came nectar-loving insects, such as butterflies and bees; thus provision was made for cross-fertilization of dicotyls, almost as soon as they appeared; and the dicotyls undoubtedly prepared tempting cups of nectar in their blossoms to repay the insects for their assistance.

The Benton group contains true bony fish or teleosts, among the first in the history of America. These are related to the salmon.

The Niobrara shales have long been celebrated for their very abundant reptilian remains. The skeletons found in Kansas show that the interior sea and its marginal shores swarmed with reptiles. Among the water forms were mosasaurs, long, snake-like lizards, which reached a length of thirty-five to forty feet; plesiosaurs, lizards with very long necks and boat-shaped bodies; and turtles, some of which were ten or twelve feet in length.

Among the shore animals were crocodiles, and huge three-toed dinosaurs, lizards capable of standing erect on their hind legs and tail like the kangaroo. In the air above the shore and sea were also flying reptiles in those days. While they were toothless like birds, and probably had jaws protected by horny bills, they were most nearly akin to the lizards. They were the great kingfishers, and were of all sizes and very numerous over Kansas. One of the largest measured twenty-two feet from tip to tip of its wings and had jaws four feet in length.

But the reptilian birds of Kansas are the most interesting to the evolutionist. These abounded in the Niobrara epoch, and were fitted for flying and swimming, and had conical teeth for holding their prey. These were true birds as shown by their skeletons and feathers, but they had many reptilian characteristics, proving to the evolutionist that birds developed from reptiles. Some of the most interesting of the fossil birds were discovered in 1872 by Professor Mudge, formerly of the Kansas Agricultural College, and sent by him to Professor Marsh of Yale, who described these, the first toothed birds found in the world. Professor Mudge discovered these fossils near Sugar Bowl Mound in northwestern Kansas.

Tracks in the Dakota sandstone have been observed, and Dr. Williston, of the State University, believes that they are tracks of four-toed birds.

As yet no mammalian remains have been discovered in the Cretaceous of Kansas, but they may sometime be found in the uppermost beds, as they occur in the Kansas Tertiary, and have been found in the topmost layers of the Cretaceous elsewhere in the United States. Where found, the mammals are all of the order marsupials, and are the lowest of the class. Indeed, they are not far removed from the theriodonts, the very interesting amphibians of the Jura-Trias. But the great abundance of nearly all the orders of mammals at the very beginning of the Tertiary indicates a remarkably rapid development of these higher orders, or their remains have thus far escaped the eyes of the collector in the Upper Cretaceous strata.

5. Mountain-Making and Continent-Making.

By the close of the Cretaceous Age, the continent of America had reached very nearly its present outlines. Tertiary deposits are found on the Atlantic, Gulf and Pacific slopes, but the great interior was dry land, except where large fresh-water lakes existed in the vicinity of the Rocky and Sierra mountains, east and west of each range.

The great lake that occupied most of the plains belt covered nearly one-third of Kansas at the western end. Into this lake was washed the débris derived by erosion from the Cretaceous and Carbonic strata in the eastern part of the State. In all likelihood, the principal drainage of the State was to the westward into this interior sea, till about the middle of the Tertiary Age, when the increase in elevation of the Rocky Mountains reversed the slope of the State, and the rivers flowed eastward as now.

The Mesozoic Era closed at the west, as did the Paleozoic at the east, with a great period of mountain-making. The Rocky Mountains, the Wasatch, the Uinta, the high plateaus of Utah and Arizona, and the mountains of western Texas and Mexico, date from this time. Some of the ranges of mountains did not reach their full altitude till about the middle or close of the Tertiary, but their chief development occurred at the close of the Laramie Epoch of the Cretaceous. The Mesozoic Era, then, is the third great period of mountain- and continent-making.

7. CENOZOIC ERA.

The Cenozoic, or era of recent life, brings our story of Kansas to the present. The strata of Kansas were all deposited by the middle of the Cenozoic, her rivers had gradually carved out for themselves broad valleys, myriads of animals had flocked to her pastures, and a luxuriant growth of vegetation had covered her plains. The great fresh-water lake which covered the western third of the State gradually filled up, and, with the completion of the Rocky Mountains, became dry land.

1. Tertiary Age.

1. Distribution of Strata and Duration of Age.

Tertiary rocks are found at numerous points along the Atlantic coast and islands; constitute a broad belt along the Gulf coast; are found along the Coast Range; and occupy great basin areas in the northwestern part of the United States and on the eastern and western slopes of the Rocky Mountains. The entire period of time covered by this age is believed to be two million years.

2. Important Strata in Kansas.

It has already been stated that the Tertiary strata of Kansas are composed largely of sediments derived by erosion from the Cretaceous and Carbonic rocks in the middle and eastern portions of the State. These sediments were deposited in a shallow sea, for the most part, and the carrying power of fresh water and the winds and the waves aided in their distribution. In the eyes of the geologist, however, this work was not well done, for there was no order or discoverable system about it. He finds mortar-beds, marls, limestones, shale, black sand, and coarse and fine gravel in all positions and in every order conceivable. He therefore describes sections without attempting to correlate them, since that would be impossible.

Just at the base of these Tertiary deposits is usually a layer of sand which yields water for wells and springs, and is therefore of chief interest to the stockmen of western Kansas.

About the close of the Tertiary, the great elevation of the Rocky Mountains reversed the movement of sediments, and from this time they were derived from Colorado.

3. Valuable Minerals in Kansas.

No valuable ores are known to occur in Kansas, and the only other minerals of account are the marls and mortar-beds. Some of the deposits of calcium carbonate serve as a natural cement. Nearly all the coarse materials of the Tertiary deposits are cemented together by calcium carbonate, possibly derived from the water of the interior lake when it evaporated.

4. Progress of Life.

The Tertiary deposits of the great interior fresh-water lakes contain almost countless fossil remains of mammals. The luxuriant vegetation of the margins of the shallow lakes tempted herb-eating mammals, and these in turn attracted flesh-eating mammals, and the skeletons of all were buried and preserved in the miry bottoms of the lakes. Possibly the elevation of the mountains at the close of the Cretaceous in the west drove the mammals from those regions and greatly increased the number of mammals about the lakes, and thus intensified the struggle for existence.

The mammals were very unlike those we see to-day, and yet were strangely like them. The Coryphodon resembled the tapir and the bear; the Dinoceros combined in itself some of the characteristics of the elephant and the flesh-eater; the Tillodonts were like a gnawing animal, a bear, and a hoofed animal; the Brontotherium combined some of the characters of the rhinoceros, the tapir and the dinoceros; the Oreodon was part hog, part deer and part camel; but the Dinotherium was most interesting of them all in being part elephant, part tapir, part hippopotamus, part dugong, and part marsupial. Not all of these are found in Kansas, but the deposits elsewhere in the plains belt contain all these and many more; the richest fossil region of the world.

The list of mammals of the Tertiary is a long one, and students should refer to the manuals of geology, and to the reports by Cope and Marsh in the United States Geological Survey Reports, for a complete statement of the present knowledge of geologists of these animals. It will be possible here to make only a brief summary of the discoveries of the many collectors in this field.

The importance of the study of the mammalian fauna is so great that little need be given about the lower forms of life further than to say that the plants, corals, echinoids, mollusks, crustaceans, insects, fish, amphibians, reptiles and birds developed by slow degrees into the types of plants and animals known on earth to-day. The change was not a sudden one from the strange forms of the early Tertiary to the familiar forms of to-day; but was made gradually, the fossils in the later and later beds showing intermediate conditions of structure.

According to Le Conte in his Elements of Geology, there were from ten to twelve complete changes in the forms of mammals on the earth in the Tertiary. The first mammals were neither flesh-eaters nor herb-eaters exclusively, but combined the characters of both; their brains were small, little larger than their spinal cords, and they walked on their digits and heels, as do the bears. The line of development followed by mammals brought about five well-marked changes: first, from plantigrade to digitigrade; second, the heel became increasingly higher; third, from walking on their toes, they walked on their nails or hoofs;

fourth, the number of toes was reduced from five to two or one; and fifth, from omnivorous molars they advanced to the possession of the cutting-teeth of the flesh-eater and the complex mill-stones of the herb-eater.

The development of the horse was along these lines. The earliest horse discovered had four toes on his fore feet, and a rudiment of a fifth. Later horses had successively fewer and fewer toes till the modern horse was evolved.

The road followed in development by each of the orders of mammals is one exceedingly interesting to the evolutionist for study. He carefully notes where types separated, and diligently searches for the ancestral mammal from which the types sprung. It should be specially noted by the student that the common or synthetic ancestral forms of the orders of mammals were soon lost in their descendants. For example, no monkey descended from an ape, nor any ape from a monkey, but both descended from a common ancestor among the Tertiary mammals.

The Tertiary deposits of Kansas contain numerous fossil remains of mammals, but much study must be given to these fossils before definite statements can be made respecting them. Some so-called Tertiary deposits contain the remains of Quaternary mammals, showing that there may not have been a sharp line of separation between the Tertiary and Quaternary deposits of our State, and that it is impossible for our geologists to discriminate sharply between the deposits of the two Ages.

5. Mountain-Making and Continent-Making.

The Tertiary Age covers the period during which all the ranges of mountains in the west received their finishing touches. Great faults occurred along nearly all the ranges, and volcanic outbursts were numerous. A great thrust fault along the eastern side of the Sierras and another along the western side of the Wasatch Mountains doubled the elevation of these ranges. Along the Rocky Mountains, Sierras, and especially along the Cascades, numerous craters and fissures opened, and enormous quantities of lava poured forth, covering thousands of square miles of surface with igneous rocks.

As has already been stated, Kansas, during the later Tertiary, received the uplift at her western end which gives an eastern slope to her surface. The end of the Age found the entire continent almost as we know it to-day. The remaining disturbances during the Quaternary consisted in local oscillations of the crust, up and down, as the crust adjusted itself to the interior.

2. Quaternary Age.

1. Subdivisions and Duration of Age.

The Quaternary (qua-ter′-nary) deposits, one-half million years in accumulating, are to be found spread over the strata of all the preceding Ages. They are found in the highlands, plains, and lowlands. The character of these deposits is as diverse as the situations in which they are found. They are fine and coarse, stratified and unstratified, loose and indurated, angular and rounded, thick and thin, and are composed of limestone flour, sandstone débris, pulverized shale, and pebbles, boulderets and boulders of all known rocks.

The subdivisions are based on certain conditions brought about by changes of level, especially of the northern portions of North America and Europe, and on marked variations of climate in the same regions.

The time of great elevation at the northeast in America and northwest in Europe, and of a cold climate, is termed the Glacial Epoch. The time of low elevations in these portions of America and Europe, and of warm climate, is the Champlain Epoch. The time of partial re-elevation of the northern latitudes and of cool climate is the Recent Epoch.

2. Characteristic Work of Each Epoch.

The Glacial Epoch, as its name implies, was a time during which glaciers occupied regions far removed from their present situations. It has been proved that in northeastern America glacial ice covered the surface as far south as the Ohio river and the northeastern portion of Kansas, as far east as Cape Cod, and as far west as the Dakotas and beyond. This glacial ice did not present an even front, nor did it occupy all this surface at the same time.

The glaciers, apart from some that originated in the Cordilleras, radiated from the highlands about Hudson Bay. Those that moved to the south and east had their source in the Laurentide ice-sheet; those that moved to the south and west had their source in the Keewatin ice-sheet; and those that moved in various directions from the Cordilleras of British Columbia had their source in the Cordilleran ice-sheet.

It is believed that the first great glacier to enter the United States from Canada was the Albertan, from the Cordilleran sheet. The second was the Kansan; the third, the Illinois glacier; the fourth, the Iowan; and the fifth, the Wisconsin glacier. The second, third and fourth came from the Keewatin sheet, and the fifth from both the Keewatin and the Laurentide sheets.

Between these great ice invasions were inter-glacial conditions brought about by the melting of the ice of these great glaciers. These were times of floods, during which the débris of each glacier was spread more evenly over the surface by the water, and distributed along the drainage channels beyond the limits of the glaciers.

No universally acceptable theory has ever been advanced to account for the cold which caused the formation of the several glaciers and the warmth which caused the ice to disappear. The difficulty of explanation is intensified by the fact that during the Glacial Epoch there were five cold periods and five warm periods alternating. For a discussion of this interesting subject the student is referred to any of the Manuals of Geology named in the Author's Preface.

During the Champlain Epoch the climate became much warmer, northeastern America had sunk to a level much lower than its level during the Glacial Epoch, or even than now, and great fresh-water lakes and sluggish rivers received the deposits left by the melting ice of the glaciers.

The Recent Epoch is characterized by those conditions with which we are familiar to-day. The northern lands slowly rose, the rivers increased their velocity, their channels became narrower, and the drift débris in their banks became terraced. The extent of this rise is indicated by the fact that old beaches of the Champlain deposits along the Atlantic coasts are now fifty feet above the level of the ocean in southern New England, one hundred feet above this level at Boston, two hundred feet along the coast of Maine, four hundred and seventy feet in the Gulf of

St. Lawrence, and fifteen hundred feet on the coast of Labrador.

3. Drift Deposits of Kansas.

The second great glacier, the Kansan, advanced from Canada southward across Minnesota, the Dakotas, Iowa, Nebraska, Missouri to the Missouri river, and pushed across Kansas to points south of Lawrence and Topeka.

This great glacier brought with it, mostly in front and frozen in its bottom, great numbers of boulders derived from the Archæan and Algonkian ledges of Minnesota and Canada. These boulders are found in great abundance about Lawrence, Topeka, and over all the counties in the northeastern part of the State. Nearly every boulder bears upon its surface the marks of the grinding to which it has been subjected in the front and at the bottom of the glacier.

The bed-rock in Kansas likewise suffered. The author, in company with the county surveyor of Nemaha county and several members of a county institute then in session, visited, in the summer of 1892, a quarry a few miles south of Seneca, where we found the bed-rock, a limestone, smoothed, planed and striated by the Kansas glacier as it passed over this region. Every transverse ridge then existing must have been leveled and every transverse valley filled by the irresistible action of the moving ice. The grit and boulders frozen in the bottom of the glacier made the ice a planing and scouring machine of great power, which easily overcame all resistance and planed and striated the bed-rock, over which it moved, in a manner peculiar to itself.

These striæ are very interesting, for they show the direction of the ice movement. On the surface of the bed-rock at the quarries visited near Seneca, the striæ trended on the average south twenty-two degrees west.

After the disappearance of the ice, the ground moraine of a glacier is termed till, and consequently the confused heap of débris known as the front moraine of the glacier, terminates the till on the south. Beyond the terminal moraine of the till are the alluvial fans and overwash plains composed of sediments left by the glacial lakes and rivers.

The terminal moraine of the Kansas till-sheet, or what is left of it, may now be traced through Washington, Pottawatomie, Wabaunsee, Shawnee, Douglas and Johnson counties by following the boulder trains and hillocks of drift. Northeast of this moraine, the till-sheet varies in thickness from only a few feet, or none, to one hundred feet. Buried logs of pre-glacial forests are reached by wells in several localities at a depth of sixty to ninety feet.

At the time of maximum development of the Kansas glacier, the ice filled the valley of the Kaw river, and the great rivers from the northwest and the water from the melting glacier were forced to find exit by way of the Arkansas, Cottonwood, Neosho and Osage rivers. A partially buried river valley in McPherson county now connects the Smoky Hill valley and the Arkansas valley. This was undoubtedly a part of the great drainage system of the glacier and of the Republican, Solomon, Saline and Smoky Hill river valleys during the Glacial Epoch.

During the Champlain Epoch, when the great depression of the northern portions of the continent and the elevation of the southern portions made all the rivers of the Mississippi system extremely sluggish, great fresh-water lakes abounded everywhere in middle and northern latitudes. The great till-sheets were leveled and the river valleys filled with silt. Ice formed on the surface of these lakes, and when it broke up in spring-time the wind must have driven it, with whatever drift it may have contained, to distant regions. The sluggish current setting to the southward would also aid in distributing the ice and drift to the southward. Boulders frozen in the ice would be carried by the ice-floes far beyond the moraine of the glacier.

East of Eureka, on the bluffs bordering the Verdigris river, the author found a boulder of granite, weighing four hundred pounds, which must have been brought in one of these floes from the moraine near Lawrence or Topeka. This boulder is now in the museum of the State Normal School at Emporia, and plainly shows the planing, smoothing and striating action of glaciers. Another boulder, but of coarser granite, was found a few miles west of Eureka. These boulders must have been brought by the Kansas glacier from Minnesota. Frozen in the bottom of the glacier, they furrowed the subjacent rock over which the ice passed, and were in turn planed, polished and striated by its resisting surface.

Many other drift boulders and pebbles probably lie outside the moraine of the Kansas till-sheet in central and eastern Kansas, and ought to be especially abundant along the old Smoky Hill-Arkansas river channel and south of Wichita in the Arkansas river flood plains.

4. Progress of Life.

The Quaternary forms of life were so like present forms that little need be said respecting them. All forms below mammals were essentially identical with forms we know on earth to-day. Many new structures and functions appeared by variation, and, where these enabled the variety to better meet its environment, such variations were preserved; where they did not, they disappeared with the destruction of the variety.

Mammals culminated in the early Quaternary in size and numbers. There were gigantic horses, oxen, deer, elk, elephants, mastodons, sloths, rhinoceroses, bears, hyenas, and tigers.

The remains of many of these are found in the deposits of Kansas. The Kansas State University has bones enough of the Kansas rhinoceros to make a complete restoration of its skeleton. In most of the Quaternary river deposits of our State are found the bones of gigantic Kansas horses. The author has a tooth in his possession, found at Eureka at a depth of twenty-eight feet, which has a crown over three inches in length. This tooth was found in the midst of other bones of the Kansas horse in a buried channel of Fall river.

Most counties in Kansas have produced portions of the skeleton of the American elephant, and several counties have given to science the huge bones of the mastodon, all preserved in what must have been ancient mire-holes.

Before Columbus discovered America, all of these great mammals, including the horse, had disappeared. Whether the fierce saber-tooth tiger and other powerful carnivores destroyed these huge creatures, or whether man destroyed the balance of power and helped in their extinction, we may never know, though the discovery of a stone hammer in close proximity to the crushed skull of a Quaternary horse lends support to the latter hypothesis.

Undoubtedly the greatest event in the geological story of the world was the appearance of man. He came last of all, and has shown himself to be greatest of all. He is not greatest because of his body, for in several respects the bodies of lower mammals are more highly specialized than his, and give the possessor a more decided advantage in the struggle for existence.

It will be remembered that the early mammals of the Tertiary had brains but little larger than their spinal cords. The later mammals developed larger and larger brains. This line of development culminated in man's brain, an organ nearly three times as large in proportion to the body as the brain of the next highest mammals, the apes. As an animal, it is alone the possession of this organ which has enabled man to conquer all other animals in the struggle for existence and to dominate the world.

Man's skeleton is so rarely preserved for more than a few centuries in the earth in which it is usually buried, that his fossil remains are generally sought in caves or in peat bogs. The evidence of the antiquity of such skeletons is very conflicting, but certainly proves that man was on the earth during the floods of the Champlain Epoch.

His works are more enduring. Man early made rude implements of stone, and it is claimed that these have been found in glacial drift, and possibly antedate the Glacial Epoch. The chronology that the author has been following in this story is an average one, and makes the duration of the several ages and epochs about three-fifths as long as the times given by Dana in his Manual of Geology. It will be remembered that the Quaternary Epoch is estimated in this chronology to be one-half a million years in length. According to this estimate, then, man has been upon earth something less than one-half a million years.

Whence man came, whether by evolution from some Tertiary mammal, or by creation from the dust of the earth, no geologist can say. The recent discovery of the skeleton of an ape-man in the Island of Java, gives a little comfort to the evolutionist. The author is not so much concerned as to how man's body and animal nature originated, as he is that we should all grow into the spiritual image of Jehovah, in which likeness man's spiritual nature was created.

5. Origin of the Present Topography of Kansas.

During the Paleozoic and Mesozoic Eras the drainage of Kansas was to the westward, into the great interior sea. The later strata toward the western end of the State derived much of their rock-material from the eastern and pre-existing strata. This condition continued till nearly the close of the Tertiary Age, when the completion of the Rocky Mountains lifted the western end of the State, and reversed the drainage and transportation of rock débris. During the Glacial Epoch, the elevation of northern lands and the depression of southern lands turned the rivers to the southward. The Kansas glacier made this course of the water a necessity by blocking up the channels of the Kaw and the Missouri rivers. In the Champlain Epoch, the depression of northern lands and the elevation of southern lands brought drainage nearly to a standstill, and great lakes and sluggish rivers occupied the State.

Finally, in the Recent Epoch, the partial re-elevation of northern lands and the subsidence of southern lands restored the drainage of glacial times, with the exception that no glacier now obstructs the channel of the Kaw and the Missouri rivers. Thus, after many changes and much wavering, our present drainage system became established.

CONCLUSION.

The geological story of Kansas has treated of such vast periods of time, of such radical transformations in the physical conditions of the State, and of such marvelous changes in the forms of life, which have appeared, lived, fought and perished within the borders of Kansas, that the story may seem more like a fairy tale than a sober narration of facts well attested by thousands of skilled observers. The author trusts that all who find any difficulty in grasping the significance of the many marvelous transformations which have come to our State during the eons of the past, will go at once into the presence of Kansas bluffs, Kansas ledges and Kansas rivers, and there drink deeply at Nature's own fountain of truth. He will find much to puzzle him, and he may need to visit other States and other lands to get the whole truth; but the facts all await his coming, and will yield to him their secrets if he but intelligently and patiently listen to their story.

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