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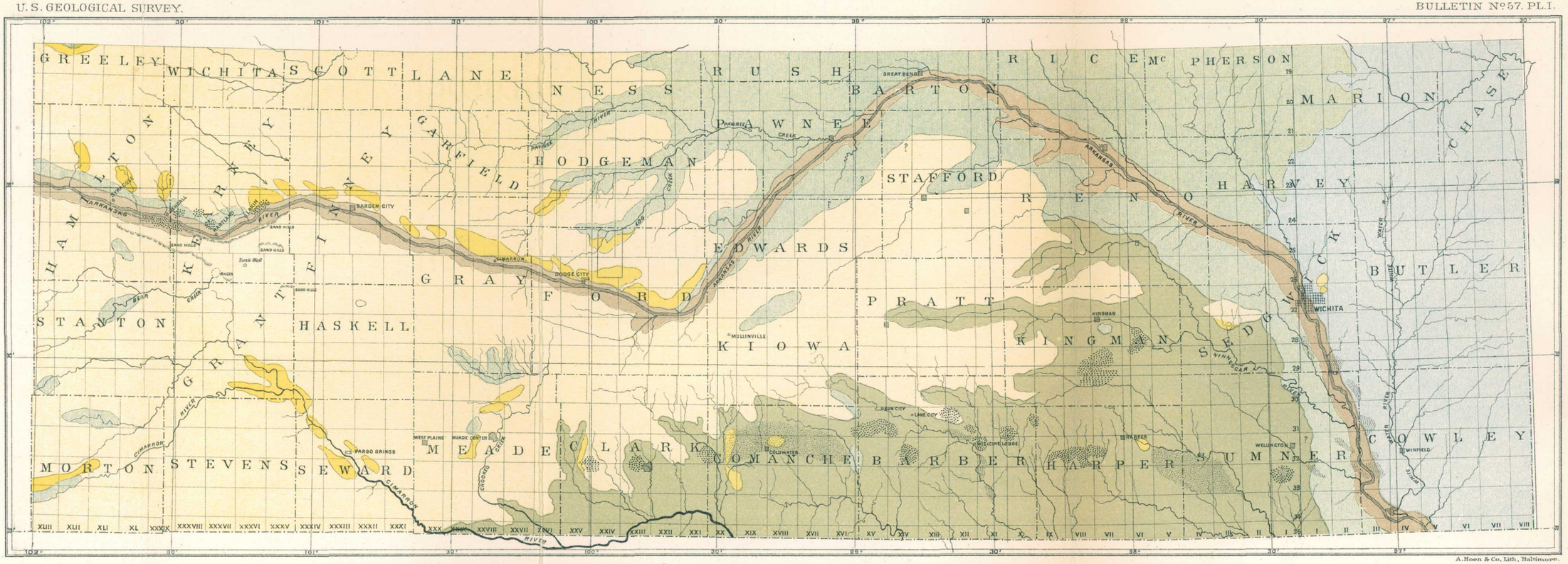


A. Hoen & Co. Lith. Baltimore.

GEOLOGIC MAP OF SOUTHWEST KANSAS

BY

ROBERT HAY.

Scale 1in=24 miles.

0 6 12 18 24 48 MILES

PLEISTOCENE.					NEOGENE.		CRETACEOUS.	JURA TRIAS.	CARBONIFEROUS.
Alluvium.	Loess	Gumbo	Gravel	Sand	Tertiary Marl	Tertiary Grit			

UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

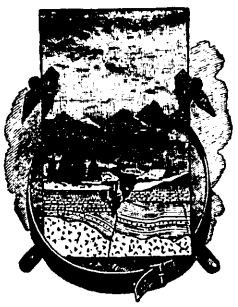
A GEOLOGICAL RECONNAISSANCE

IN

SOUTHWESTERN KANSAS

BY

ROBERT HAY



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CONTENTS.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
POTOMAC DIVISION,
Junction City, Kans., May 24, 1889.

SIR: I have the honor to transmit to you, by direction of Mr. W. J. McGee, chief of this division, a report of a reconnaissance in southwestern Kansas, made in the summer of 1885, with some additional matter incorporated therewith, as the result of other journeys into the same region made particularly for the purpose of determining the geological relations of the recently discovered beds of rock-salt and of continuing the observations into Colorado. The value of the work is enhanced by the kind encouragement received during its progress from my immediate chief, Mr. McGee. It is also proper to say that valuable aid was received from Hon. J. R. Mead, of Wichita, J. H. Simmons, of Wellington, and other citizens at Harper, Medicine Lodge, Kingman, Hutchinson, and Dodge City. The Atchison, Topeka and Santa Fé, the Southern Kansas, and the Missouri Pacific railways gave transportation facilities. Engineers of these roads, and also of the "Frisco Road," kindly supplied me with tables of elevations on their newly surveyed routes.

The determination of fossils has been made by Drs. C. A. White and W. H. Dall.

I am, sir, yours respectfully,

ROBERT HAY,
Assistant Geologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

INTRODUCTION.

By W J McGEE.

During the period of active prosecution of geologic surveys under State auspices within the Mississippi Valley, the structure of that region was definitely made out, and its formations were correlated with greater or less precision with those of the Atlantic Slope; but these State investigations were not carried forward to the region then commonly, as now occasionally, known as the Great Plains. During the partly contemporaneous and partly subsequent period of active exploration and scientific investigation of the western territories by the Federal Government, the geologic phenomena of the Rocky Mountain region were elucidated, and certain of the formations found there were correlated upon purely paleontologic grounds with those of the East and the middle West—the broad Mississippi Valley. But although a score of geologists traversed the Great Plains from time to time, and although half a dozen official and amateur geologists have systematically studied different portions of the region, there yet remains a great area, comprising considerable portions of Dakota, Nebraska, eastern Colorado, Kansas, Indian Territory, and Texas, within which little is known of the geologic structure through direct observation by trained specialists. The indefiniteness of knowledge concerning the formations of this great area and their distribution is strikingly indicated by the discrepancies in the various geologic maps covering it. There is thus a hiatus in geologic exploration within the Great Plains, which it is desirable to close.

The geologic history recorded in the Paleozoic rocks of the Mississippi Valley and in the degradation of the same region after its emergence, is exceedingly simple: During the Paleozoic, deposition was slow, and the formations are thin, remarkably uniform, and approximately conformable throughout great areas, and are indicative of slight and slow alteration in continental configuration; and the emergence of the land at the close of the Paleozoic was a simple vertical movement effected without material disturbance of the strata. During the Mesozoic there were occasional eras of quiet deposition of shoal water sediments, probably at one time extending as far east as the Mississippi

River from the confluence of the St. Croix southward; but during the greater portion of post-Paleozoic time the region has been above the sea, and yet so slightly elevated and so slightly disturbed by tectonic movements that degradation has reached but a small fraction of that suffered by most portions of the terrestrial surface. In the Rocky Mountain region, on the contrary, the various geologic phenomena record a complex history. During the Paleozoic, sedimentation was rapid but irregular, betokening great concurrent geographic changes; certain of the Mesozoic formations are of enormous thickness, while at other horizons occur great unconformities which together indicate repeated and important changes of sea and land. During portions of Cenozoic time, deposition was rapid, while during other epochs the land stood at such great altitude above the waters into which its débris was carried that erosion was wonderfully active; and the latest records inscribed in the rocks of the region are of almost unparalleled degradation, which during a brief period has removed many times as much matter from the surface as has been removed from the Mississippi Valley during its untold ages of slow degradation. There is thus a discrepancy between the testimony of the rocks in the Mississippi Valley and that of the Rocky Mountain phenomena which it is desirable to harmonize by studies in the intervening region, in order that geologic conceptions may be unified and geologic interpretation reduced to a common standard.

In the eastern United States there is a great blank in geologic history at the close of the Paleozoic, for the Triassic rocks of the east have not yet been, and perhaps never will be, fully interpreted. In the Mississippi Valley there is a great blank in the same portion of the geologic record, for the Mesozoic outliers upon the Paleozoic terranes, extending far towards the Mississippi River, represent not the commencement, but rather the close, of the Mesozoic. And in the Rocky Mountain region the Triassic rocks generally leave unrepresented a considerable interval between the Paleozoic and Mesozoic systems, and in their structure, composition, color, dearth of fossils, and many other respects fairly bristle with problems yet unsolved. So there is a hiatus in the American geologic section, and in the time it represents, which it is desirable to bridge; and since there occur within the Great Plains extensive rock-masses which have been tentatively referred by some geologists to the Paleozoic and by others to the later Mesozoic, it seemed probable when this reconnaissance was projected that by investigation there the blank might be filled.

The superficial deposits of the earth are numerous and variable and difficult of interpretation. They have generally been classified by conditions of genesis. Now the glacial drift of the northern United States has been extensively studied and is fairly understood; the loess extending from near the margin of the glaciated area towards the Gulf presents a riddle yet but partly read; the alluvial and littoral deposits of the Mississippi embayment are not fully interpreted;

the products of secular rock-disintegration under various conditions have only recently begun to receive serious attention; the great alluvial fans and taluses fringing the Rocky Mountain region, which have been accumulating ever since the emergence of the land or the birth of the mountains, have embarrassed American geologists just as their European homologue—the "Nagelfluh" etc.—has mystified the geologists of the Old World; and the superficial deposits upon the Plains, which have some of the characteristics of all these accumulations, present a many-sided problem whose solution will unquestionably facilitate the interpretation of each of the clearly differentiated deposits. Thus there is an immeasurable blank in our knowledge of composite superficial deposits which investigation in the Great Plains promises to fill.

There have been found in Petite Anse and adjoining islands on the Louisiana coast extensive deposits of salt associated with gypsum, the extraction of which is rendered difficult by the depth beneath tide. Now, reports of the occurrence of salt and extensive beds of gypsum have gone out from western Kansas, Indian Territory and contiguous parts of Colorado and Texas, and it is important to ascertain whether these reports are well founded and whether the occurrence of the minerals indicates the existence of either the same or equally extensive deposits of rock salt in these localities, for the obstacles to ready extraction met at Petite Anse Island do not exist there.

Carbonaceous shales and lignites are of frequent occurrence in portions of the Great Plains, and have led to brilliant expectations among the citizens of Nebraska, Kansas, eastern Colorado and Texas, and to costly prospecting and extensive investments in property, and it is desirable that the questions as to the existence within these States of lignites or true coals, and of their position, extent and value if found, should be definitively answered at an early day.

With the westward extension of settlements upon the plains the different occupations to which the various portions of the region are adapted—agricultural, pastoral, etc.—have come to overpass their natural limits. Thus agriculture presses upon the zone naturally adapted to stock-raising, and stock-raising presses upon the zone of variable climate in which the profits of a successful lustrum are swallowed up in the losses of one unsuccessful year. Now, in order that either agriculture or stock-raising shall reach the best results, it is essential that the character of the soil and its adaptability to given products be understood, that the capabilities of irrigation by surface waters be considered, that the possibilities of artesian water supply for irrigation and for other uses be determined, and that many other relations between the rocks of the earth and present and prospective industries and enterprises be ascertained.

These and other considerations have led to the inauguration of systematic investigation in the region described in the following pages, which comprise the preliminary report of a rapid reconnaissance.

The scientific and economic questions involved have not, however, been fully settled by the reconnaissance, but it is believed that Mr. Hay's report will be found to contain valuable contributions to our knowledge of a region important but little studied.

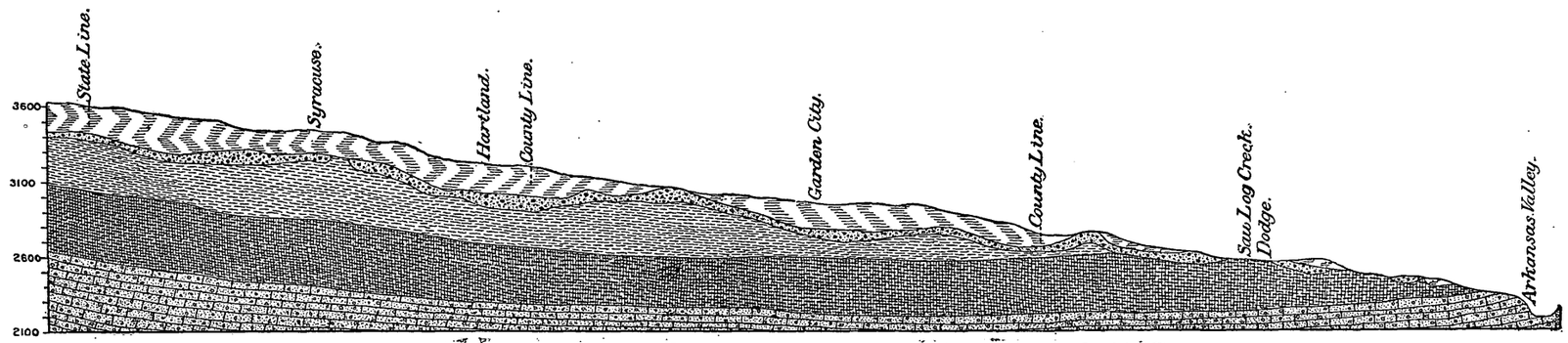
Although no attempt has been made to finally classify the formations examined or to trace their distribution in detail, the provisional cartography of the region is a substantial addition to American geology: The limits of the Carboniferous group of rocks, within which valuable coal beds unquestionably exist, have been defined; the structure, mineral contents, stratigraphic relations, and geographic extent of the puzzling gypsiferous "Red Rocks," which have been variously referred to the Permian, the Dakota formation of the Cretaceous, and to several intermediate horizons, have been ascertained, and the uncertainty as to their age and position has been materially narrowed; the character of the lignitiferous Cretaceous deposits has been made out, and the different formations have been correlated tentatively with those of the montanic region; the Tertiary formations have been defined; and several distinct superficial deposits have been discriminated, and their genesis has been determined in part.

Practical considerations prevented the extension of the reconnaissance into the montanic region, within which the geologic agencies have been so much more active than in the little disturbed Mississippi Valley; but throughout the investigation the agencies and processes have been considered as the products were studied, the significance of unconformities has been appreciated, and some progress has been made in reconciling the discrepant records of the two widely diverse geologic provinces.

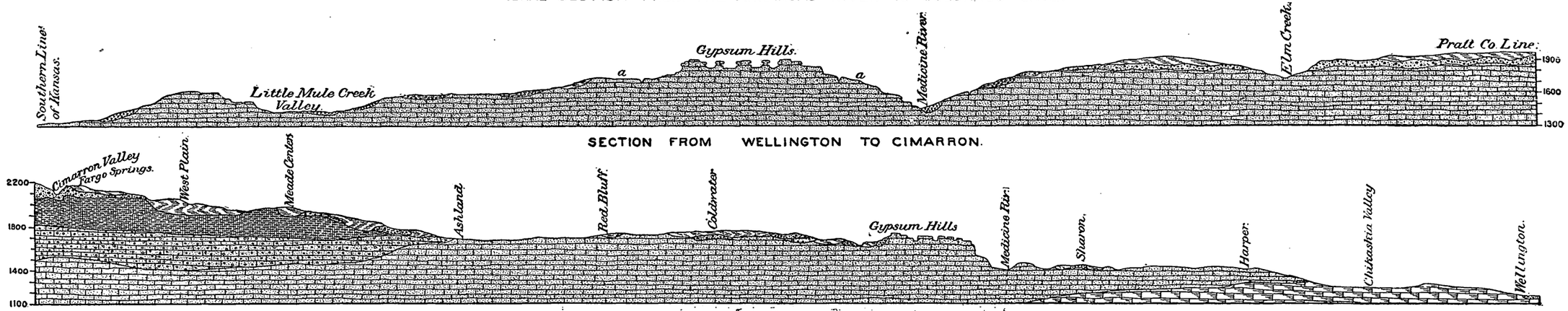
The correlation of the formations and the final interpretation of the early Mesozoic passage beds were unfortunately impeded by the dearth of fossils, and little has been done in this direction.

Although the questions as to the character of the soils, the extent and value of the salt, gypsum and lignites, the irrigation problem, the artesian well problem, and the various other economic questions considered, have not been specifically answered, the salient mineral characters of the rocks have been ascertained; and with the profiles of the country and the fall of streams, the composition and attitude of the strata upon which the artesian flow depends, etc., have been set forth in general terms, and a substantial foundation for more detailed future investigation has been laid.

It may be mentioned that Mr. Hay has been engaged in amateur geologic studies in Kansas for some years, and thus has brought to his task general familiarity with the phenomena of the region and many valuable data which could have been gained otherwise only at the cost of much time and labor; and it is just to add that although the expenses of the journeys were borne by the United States Geological Survey, his own labor and that of his assistant were performed gratuitously.



IDEAL SECTION FROM THE ARKANSAS RIVER TO COLORADO LINE.



SECTION FROM WELLINGTON TO CIMARRON.

SECTION FROM NORTH TO SOUTH THROUGH BARBER CO.

PLEISTOCENE. NEOCENE NIOBRARA. BENTON. DAKOTA. JURA-TRIAS. CARBONIFEROUS.

LOESS. GRAVEL. TERTIARY MARL. TERTIARY GRIT.

A GEOLOGICAL RECONNAISSANCE IN SOUTHWESTERN KANSAS.

By ROBERT HAY.

GENERAL STATEMENT.

This report relates to a reconnaissance which was made under instructions from the chief of the Potomac Division, dated May 27, 1885. Those instructions, as far as they directly relate to the work to be done, were as follows:

We need a section through Kansas from east to west which shall exhibit the relations of the various formations of the State, particularly those of post-Carboniferous age. I think it possible to construct such a section along the Arkansas River from the border of the Carboniferous in about longitude 98° W. to the eastern line of, or perhaps one or two hundred miles within, the State of Colorado. In case there are not sufficient exposures there, some other line might be chosen. In the collection of material for the section it is desirable that attention should be given not only to the eastern margins of the Mesozoic and Cenozoic formations as they now exist, but to the erosion that the formations have suffered about their peripheries, in order that the positions of the successive shores of these ages may be determined. The formations themselves and the contained fossils should also be subjected to careful examination in order to ascertain, if possible, whether they were deposited in saline, brackish, or fresh waters. The physical condition of the sediments should also receive attention, since such condition may indicate the depth of the waters in which they were laid down and the positions of the shores.

The phenomena due to post-Pliocene agencies should also be studied. There is in Texas and in Indian Territory, and, so far as I can learn, in Kansas, a superficial deposit of gravel and siliceous pebbles. A related gravel also occurs in the northern portion of the great plains in western Nebraska. The origin of this gravel (including the sources of the material and manner of its distribution) should be ascertained, and also its relations to present drainage, to "second bottoms," and to any other fluvial or littoral terraces that may exist in the region.

Certain limitations as to cost accompanying these instructions, the journey made could be only a reconnaissance. It lasted seven weeks. Since then I have spent ten days in the neighborhood of Pueblo, and have also made another brief trip to Barber County, Kansas, and several trips have since been made into different parts of the region. All of these have added to the material used in this report. The actual routes taken will appear farther on and are indicated on the map.

The region explored has been somewhat of a terra incognita, geologically. Though several statements have been made concerning it, some of them semi-officially, yet no definite account of its geology has been made public, and it is not known that any reliable geologist has done more than make a hasty trip to some part of it.

There has been a general impression among scientific men in Kansas that an irregular line slanting from east of north to south of west, and crossing the thirty-ninth parallel near its intersection with the Sixth Principal Meridian, approximately indicates all across the State the eastern boundary of the Cretaceous formations, the lowest of which in Kansas—the Dakota—has been found particularly rich in fossil leaves of dicotyledonous plants. This formation is seen in many places resting directly on rocks well known to be of Carboniferous age. Carboniferous strata, yielding good building stone—the so-called magnesian limestone—appear all across the State from the fortieth to the thirty-seventh parallel, and are known to be continuous both north and south beyond the boundaries of the State. It has been presumed that the Dakota was also continuous southward across the Arkansas River to and beyond the State line, this opinion having been formed without actual observation by geologists, mainly because red sandstone rocks were reported to exist in southern Kansas and Indian Territory.

It was also assumed that the Benton and Niobrara epochs are represented with a still wider development south of the Arkansas. In the Northwest it has been known that Tertiary deposits have covered the Cretaceous, and these deposits have usually been referred to as Pliocene. Prof. B. F. Mudge many years ago suggested that some part of this Tertiary covering was possibly Miocene, as also did Prof. E. D. Cope, but they gave no stratigraphic descriptions upon which distinction of the rock masses could be based. From the trend of the Tertiaries in the northwestern counties—north of east to south of west—it was inferred that there could be little or no development of these formations south of the Arkansas River, where it was supposed the Cretaceous deposits extend to and beyond the Colorado line. As will appear later, these assumptions as to both Cretaceous and Tertiary were erroneous.

In the years 1884–'85 numerous mammalian fossils were found in northwestern Kansas (*Aphelops*, *Camelus*, etc.) and the Tertiary beds yielding them were thereby identified as the Loup Fork, which Prof. Cope has pronounced to be of Miocene age. A little later, in a "Preliminary Report on the Geology of Norton County,"[1] made to the Kansas Academy of Science, November 21, 1883, I gave a description of the stratigraphic relations of the Loup Fork to the newer Tertiary above it and the Cretaceous (Niobrara) below it. It was then shown verbally and by diagrams that the Cretaceous strata had been extensively eroded before the deposition of the Loup Fork, and that the Loup Fork had in its turn been eroded, largely on the same lines, before the deposition of the later Tertiary, which was pronounced provisionally to be the Equus beds of Cope. The erosion since has also been nearly on the same lines as the pre- and mid-Neocene. This report will show that these distinctions obtain extensively south of the Arkansas River.

[1] Trans. Kansas Acad. Sci., Vol. IX, 1885, pp. 17–24; and also published separately.

In 1866 Prof. G. C. Swallow described as "Triassic" what is now known as the Dakota, and F. H. Bradley's geologic chart of 1875 marks the same area as Jurassic. As this is now known to be erroneous for the region north of the Arkansas River to the Nebraska line, it was assumed that it was also wrong for the territory south of that river, where the Jura-Trias has been affirmed to exist both by Le Conte and Dana. The explorations of this summer verify the statements of these last authors, which were probably made on the authority of Dr. George G. Shumard's descriptions of the gypsiferous deposits of the Red River in Marcy's Report of the Exploring Expedition of the year 1852, the extension of those deposits north of the Canadian being known and referred to as reaching to the Arkansas. By reference to the map it will be seen that the Jura-Trias covers a large, irregular triangular area extending over several counties.

The routes actually traveled in this investigation lie mostly within the great bend of the Arkansas River, i. e., south and west of it. Some examinations of outliers of the Tertiary formations and of the loess were made on the east of the river near Wichita. In this neighborhood the Tertiary deposits hereinafter called the Tertiary marl and the Tertiary grit were found over a limited area resting on rocks apparently of Permian age. Some exploration was also made from Winfield, where the so-called magnesian limestone is extensively quarried for building purposes, along the line of the Southern Kansas Railway westward to the river. Crossing the river, the line of railway was followed through the counties of Sumner and Harper, with some divergence north and south at the county seats, Wellington, and Harper. From Attica, then the terminus of the railway, the route taken was circuitous to Medicine Lodge, where bad weather occasioned some delay, though a portion of the time was utilized in short journeys to the northern part of Barber County and southwest to the Gypsum Hills, and southeast to the so-called Cedar Mountains. Resuming the forward route, the western part of Barber County was passed through, and northern Comanche (since organized as Kiowa County), Edwards and Ford Counties, to Dodge City. The investigations thence were north of the river to the Colorado line, the last thirty miles, however, giving a mere glance at the geology, as immediate return from this point became a necessity. It will be seen from the map that the Cretaceous formations appear in this region as a fringe of bluffs, the higher ground behind being of Tertiary age. The river was crossed at Lakin and passing through the sand hills which bound the south side of the river valley we crossed the high prairie to the North Fork of the Cimarron. Passing down the stream for some miles we crossed the divide to the South Fork, or main river, down which the route led for about twenty-five miles to the new town of Fargo Springs, in Seward County. In all this region south of the river the Tertiary deposits and sand hills composed the entire geological phenomena. Proceeding eastward, out-

crops of Cretaceous formations were found when the middle of Meade County was reached. The return journey through Clarke County touched the former route at Coldwater, in Comanche County, and came back by a more southerly route to Medicine Lodge, whence the journey to Wichita was made more rapidly through Kingman and Sedgwick Counties by stage and railway.

The basis for the accompanying map is the United States Land Office map of Kansas. For the topography, as shown in the sections, elevations furnished by the engineers of the Atchison, Topeka and Santa Fé, and the Southern Kansas Railways have been used. Some observations with the aneroid barometer, where return to a starting point was possible, as in Barber County, have given results which may be regarded as approximately correct. For the other districts away from the railways estimates only were possible, but these were made with as much accuracy as the nature of the circumstances permitted.

The geology of the northeast parts of the region, as shown in the map, is taken from maps of the Kansas State Board of Agriculture, prepared by Prof. B. F. Mudge and Prof. O. H. St. John; but my own explorations and observations partially confirm them. The extreme southwest and parts north of the Arkansas River in the west, marked Tertiary, are so indicated for the first time, as a legitimate inference from the observations and inquiries made during the reconnaissance.

The region of the exploration as shown on the map is included between the ninety-seventh and one hundred and second meridians, and covers little more than a degree of latitude, its southern limit being the southern boundary of the State, 37° N., and extending in the Arkansas Valley north of the thirty-eighth parallel.

THE GEOLOGIC FORMATIONS.

The first investigations of the reconnaissance were made in formations of Tertiary and Quaternary age, but the general development of strata on the journey westward being in the ascending geologic order, it is deemed best to discuss their development in that order. In their natural relations the formations examined are—

1. Quaternary ....
   - The Alluvium.
   - The Later Gravel.
   - The Loess.
   - The Earlier Gravel.
   - The Gumbo.
2. Tertiary .....
   - The Tertiary Marl.
   - The Tertiary Grit.
3. Cretaceous .....
   - The Niobrara formation.
   - The Fort Benton formation.
   - The Dakota formation.
4. Jura-Trias.
5. Carboniferous.

CARBONIFEROUS.

The Carboniferous strata (sometimes denominated Permian or Permo-Carboniferous) were observed only as a starting point. Near Wichita they were found dipping westward towards the river at an angle of about 15°. The following section shows this dip with the loess resting on the eroded surface.

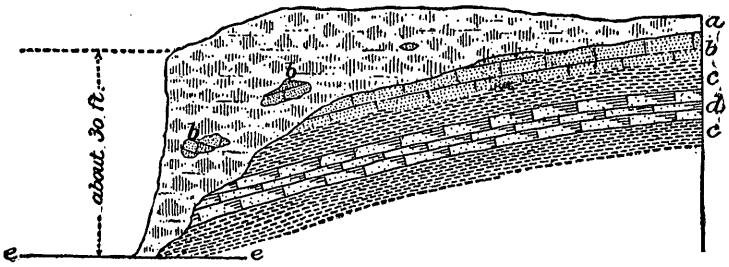


FIG. 1.—Section 5 miles south of Wichita.
a, loess; *b*, sandstone; *c*, shale; *d*, limestone: *e e*, level of river.

Northeast of Wichita a ravine and a cutting in the line of railway show Carboniferous shales and limestone covered by Tertiary formations, which is the only case of the kind yet recorded in this State. Near Winfield the Carboniferous limestones make valuable building stone, being in the massive ledges fine grained and entirely free from fossils. Thinner and more friable strata as well as shales, however, yield characteristic remains which, though rarely perfect, indicate the Carboniferous age of the formation. These are *Chonetes*, *Athyris*, *Hemipronites*, *Pecten* and *Productus*. On the ridge between the Walnut and the Arkansas the Carboniferous is mostly covered up by loess, and in the valley the alluvial sands are extensively deposited. From near Wellington westward, formations are extensively shown in thin ledges of limestone and thick shales which, while having some Permian (Carboniferous) resemblances, have also a different general appearance and a notable absence of fossils, giving them closer affinities with higher rock groups, as will appear further on.

The Carboniferous shale has been penetrated by well-borings to a depth of 180 feet. It is interbedded at intervals of from three to ten feet with hard ledges from two to six inches thick. It contains sulphate of lime, and the water from it is strongly impregnated. One of the hard ledges is of a peculiar shaly structure. It outcrops in ravines over an area of several miles. The slabs of it have a notable resemblance to a pan of biscuits fresh from the oven, only its surface is more regular in the smoothness of its domes. If a single dome be examined it is found hollow beneath. Both its surfaces are smooth, and it is thickest at the top of the dome. It will also separate into several thin concentric domes as would the layers of half an onion. Single layers of these have locally been taken for fossil shells. That this was a shore forma-

tion seems certain. Was the mud thus shaped by escaping gases modified by the action of the waves?

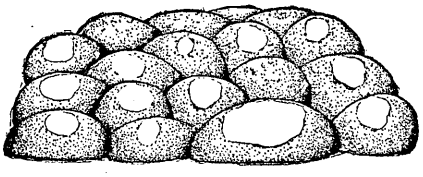


FIG. 2.—Biscuit shale (one-third natural size).

The heaviest Carboniferous shale is dark colored—the so-called "slate" of coal mines. Further west we find bands of buff and greenish clay-shales, and one, over a foot thick, of rich maroon color. On the west line of Sumner County the Carboniferous, or, as we shall see reason hereafter to call it, the Saliferous series disappears under the extensive sands of the Chikaskia, whose broad valley is a mere depression in the high prairie. This concealment by alluvial deposits is very extensive both south and north, so that the indication in the map of the western border of the Carboniferous development must be taken as only approximately correct.

Only incidental attention was given to the Carboniferous deposits, and no effort was made to ascertain their systematic relations. They are indeed only denominated Carboniferous by me in accordance with general usage.

JURA-TRIAS.

An extensive region, triangular in shape, whose northern apex is near the northern part of the Great Bend of the Arkansas River and whose base in Kansas runs on the southern boundary of the State from the ninety-eighth to beyond the one hundredth meridian, would be called by superficial observers the region of red rock. The area of the formation expands across the Indian Territory to the Red River and Texas.

This red rock, being overlain on some of its borders by dark brown and reddish ferruginous sandstones of the Dakota period, has been by many regarded as of Cretaceous age. It will be apparent, however, on a consideration of the facts which have been observed by me, that those geologists who have attributed the red rock to an earlier portion of the Mesozoic era are correct. In places these red rock strata present appearances which are similar to those which elsewhere have been called Permian. But though the relation of these to the uppermost Carboniferous (Saliferous) of their eastern border was not made out in the first reconnaissance, yet the stratigraphic differences of the beds themselves, as compared with deposits east of the Arkansas River, are on the whole so marked, that it is not possible for the writer to consider them as of Paleozoic age. On the other hand, in three places, at considerable distances from each other, strata of Dakota age were observed resting with erosive unconformity on the red rock series, which is the case with un-

doubted Permian strata in northern Kansas. The striking characteristics of the stratification of this formation, described later, appear to give sufficient reason, until paleontological considerations set it aside, for naming this formation the *Jura-Trias*, or it may be better to say only Trias. If a descriptive name were wanted we should call it the *Red Rock Formation*. The whole country is red. The soil, even where it contains much carbonaceous matter, is ruddy, the sedentary soil, just forming on the steeper slopes is ruddier, flooded rivers glance in the sunlight like streams of blood, steep bluffs and the sides of narrow cañons pain the eye with their sanguine glare.

Some buildings in the town of Harper are built of a brownish red-stone, which is obtained from quarries south and southeast of the city. Here and elsewhere the harder ledges are from two to eighteen inches thick, and they are intercalated with arenaceous clays and clay shales and clays of richer color. The hard ledges are persistent for long distances and give a definite contour to weathered bluffs and ridges. The clays are frequently of such toughness as to resist the weathering agencies as well as the harder ledges, which are sufficiently laminated and jointed to prevent their overhanging. Hence there are red walls by the streams, which are absolutely perpendicular. A specimen of one of the harder laminated layers from eastern Barber County, and a specimen of sedentary soil formed from that and adjacent ledges have been submitted to G. H. Failyer, professor of chemistry at the Kansas State Agricultural College, who says: "Both are strongly ferruginous, both rich in calcium carbonate. The stone is an impure limestone, containing ferric oxide, clay and sand. Of course the soil contains the two latter in excess." The ledges hard enough to supply building stone are comparatively rare. The thinner laminæ very frequently exhibit ripple-marks, raindrops and other signs of a littoral formation. Not unfrequently the upper surface of a lamina is brightly glazed, and at the foot of the bluff out of which a glazed specimen is taken may be found occasionally an illustration of the method of its formation in the glazed surface of dry red mud recently deposited from the overflow of a little stream washing the material both of the deposit and the glaze from the cliffs where it has so long been solidified.

The whole country increases in elevation westward and northward.[1] There is an undulation of the dip which is not often perceptible, with an average inclination westward of very small amount, while in some parts of the western half of the area there are local depressions southward as well as eastward. The elevation of the country combined with the average dip gives increasing thickness to the Jura-Trias as we proceed westward.

[1] This is well illustrated by the fact, given by the engineers of the Southern Kansas Railway, that Medicine Lodge, in the deep trough of the Medicine River, is fifty feet higher than Harper, which is situated on the high prairie. The descent southerly from Medicine Lodge to New Kiowa is 150 feet.

It will be seen from the map that the Medicine River at Medicine Lodge turns suddenly southward. The reach of the river above that place gives a section from the Cretaceous formations above far down into the red rock. The lower reach of the river, to the State line and beyond, exhibits a section across the red rock. The eastern side is flanked by the Cedar Mountains or Hills, whose sides are scored by cañons not deep but narrow, with sides perpendicular, and with ridges and amphitheatres carved and pinnacled like oriental temples. West and south of the river are the Gypsum Hills.

The Gypsum Hills form the striking feature of the red rock country. Throughout the entire region the laminated arenaceous ferruginous limestone has in it globose spots of greenish white. This is apparently a fine sand. The spots, in many places regularly distributed and like small peas in size, sometimes aggregate into streaks. Occasionally the streak becomes a layer. One of these layers south and west of the Medicine River becomes persistent over a considerable area. The erosion of the valley has left this layer nearly at the top of the area in which it appears, which shows as an irregular plateau sloping east and north to the river. The layer is, in its outcrop, bleached and in places has the consistency of stone. We therefore call this the White Sandstone Plateau. This plateau is cut by deep cañons and its spurs occasionally terminate at the river as perpendicular red walls from twenty to thirty feet high. The upper reach of the river valley narrows westerly and the plateau narrows with it. The lower valley broadens southerly and the plateau increases with it. In neither direction is the plateau very wide. In the lower valley the western boundary of the White Sandstone Plateau is a solid wall of red rock, rising above it nearly two hundred feet, surmounted by a great white coping of gypsum from twelve to fifteen feet thick. The wall runs southward for several miles with some openings and terminates abruptly by a turn directly west. Northward its termination is a bold promontory, and the neck, with gypsum absent from it in places, is only wide enough on the top for one person to walk. From this point the wall retreats, forming a huge amphitheatre with isolated buttes and towers and caps, and all up the western valley towers, pinnacles and buttresses are repeated, advancing towards or retreating from the river. Approached nearer, the lights and shadows on the gypsum have the appearance of quaint gables and mansard roofs. Where the gypsum has disappeared single peaks are capped by projecting layers of the red rock. The butte I have called "Mansard" is within the amphitheatre on its western side. Some of these features are shown in Figures 3 and 4.

In ascending to the gypsum, we find that the red rock gives way frequently to seams of selenite and laminated layers of greenish sandstone. Again are found harder layers of the red rock, and anon seams of nearly transparent satin spar (fibrous gypsum), one of which is persistent for a great distance and two inches thick. These are in strata

of clay or shale. Both the sandstone and satin spar layers are ripple marked. The top reached, we find all these pinnacles and buttes are but the remains of another plateau whose floor was this solid gypsum, which stretches away to the south and west, broken by broad valleys and profound cañons, reappearing beyond the Cimarron, on the Canadian and Red Rivers, and on the edges of the Llano Estacado. Views in Marcy's Report of the Red River Expedition in 1852 would serve to illustrate this region of southern Kansas. Over the gypsum westward are fragments of a hard gray limestone stratum, and again red rock. The gypsum has caves and underground channels, in which the sound echoes and reverberates when horse or vehicle passes over.

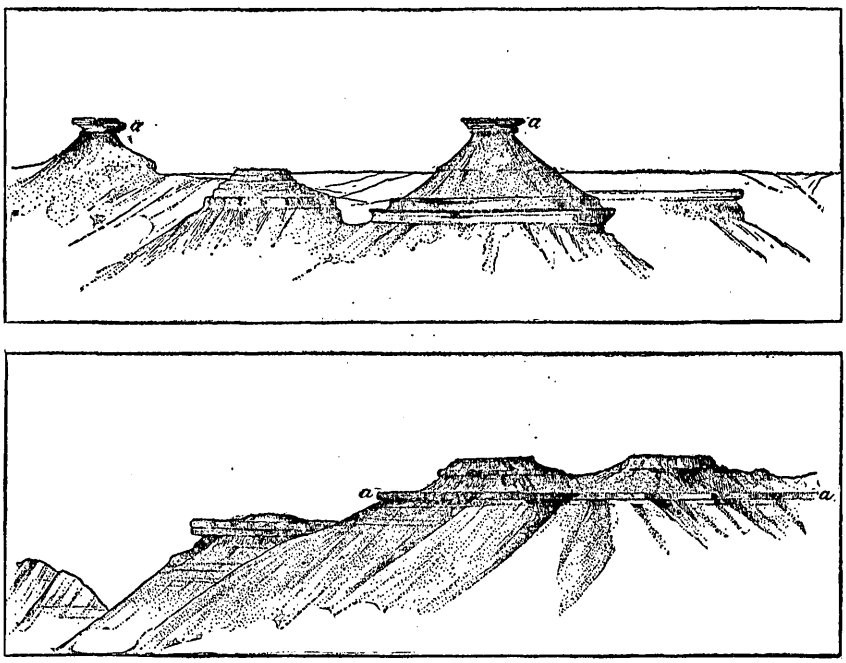


FIG. 3.—Red Rock buttes, Gypsum Hills.
The lower view represents the northeasern promontory of the Gypsum Hills. *a*, the gypsum cap.

Neither gypsum nor any of the red rocks or shales or clays have hitherto yielded any fossils. The constant evidence of littoral formation, however, suggests the expectation that sometime reptilian or other tracks may be found in this formation that will serve to synchronize it with undoubted Mesozoic formations.

Wells in the valley of the Medicine are somewhat impregnated with sulphate of lime. Some waters are also saline. But neither from the testimony of well sinkers nor from personal observation does it appear that there is any seam of gypsum, satin spar or selenite below the horizon of the White Sandstone Plateau, except a little selenite in some wells on the town site of Medicine Lodge. Nor does it appear that there is any such seam above the horizon of the massive gypsum. It

would therefore appear that there are three well-defined parts of the Jura-Trias in Barber County which may be possibly recognized elsewhere. Only the lower one appears in Harper County. The thickness is given with hesitation. It may, however, be an approximation to the truth.

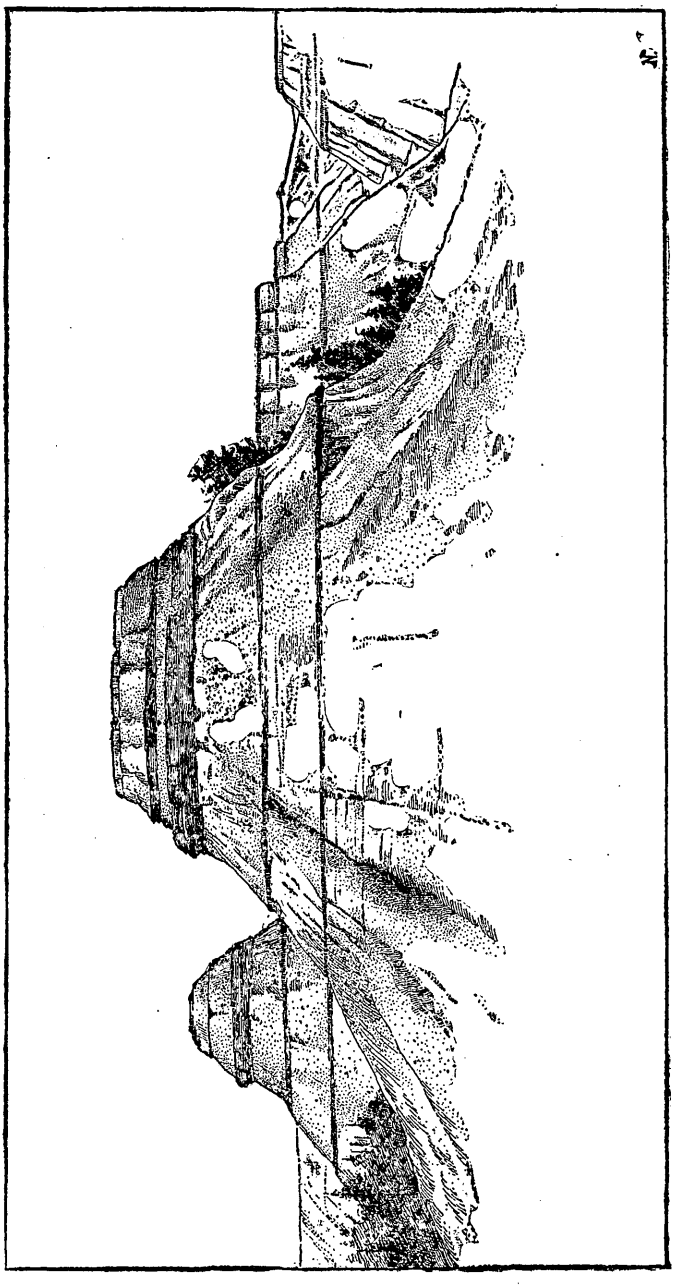


FIG. 4.—Mansard buttes, Gypsum Hills.

	Feet.
A. Upper red rock, above the gypsum plateau	100
B. Gypsum series, including the selenite seams and the massive gypsum	200
C. Lower red rock, from the White Sandstone Plateau downward (mostly without selenite seams)	250
Total thickness	550

Several of the features described above suggest that the formation represents the Jura-Trias. These may be summarized as follows:

(*a*) The formation is lithologically quite distinct from the subjacent Carboniferous strata.

(*b*) The prevailing color of the formation is dark red, brown, and sometimes lighter red, like the Triassic generally in Europe and America.

(*c*) The lithified layers alternate with beds of clay and clay shale, as do the stony layers in the Triassic of the Atlantic slope and in much of the Jura-Trias of the West.

(*d*) A massive layer of gypsum and numerous seams of selenite and satin spar appear in the formation, in which respects it corresponds with deposits farther southwest, which have been referred to the Jurassic or Triassic on both petrographic and paleontologic grounds.

(*e*) There are frequent shore-marks, ripple-marks and rain-drops, in which the formation simulates the Triassic of the Atlantic slope and many other regions.

(*f*) There is a marked absence of fossils, a characteristic of the Triassic generally.

(*g*) The formation is continuous to Red River and appears to be stratigraphically connected with similar rocks beyond, which have already been referred to the Jurassic or Triassic on various grounds.

(*h*) The surface of the formation was deeply eroded before the deposits of the Dakota or other Cretaceous formations were laid down.

In brief, the lithologic characters, in so far as they may be regarded as criteria in the correlation of formations, and the stratigraphy alike suggest that the red rocks of southern Kansas represent the group of strata elsewhere found between the base of the Cretaceous and the summit of the Carboniferous; and although the evidence is not sufficient finally to demonstrate the age of the rocks, it is sufficient to warrant the provisional application to them of the name Triassic.

In 1887 the prospector's drill, boring for natural gas or coal, struck rock salt at Kingman, Ellsworth, Hutchinson, Lyons and Anthony, and in 1888 other places to the west of the more southerly of these made the same discovery. At an earlier date a boring at Wellington had given a similar result, but the thickness of only a few feet had not attracted the attention that the reports of hundreds of feet from the other borings did. A great industry has been rapidly developed. At all the places named, and at others, fresh water is put down the wells to the salt beds and comes up the pumps a saturated solution, from

which almost absolutely pure salt is extracted by the usual methods of evaporation.

The wells at Kingman and Anthony are in the red rock (Triassic) region, and the salt is obtained from strata *below* the red rock. The writer has visited all the localities named, and examination of the drill records showed that beneath the alluvia of the Arkansas Valley at Hutchinson and beneath Dakota formations at Lyons and Ellsworth the drill pierced several hundred feet of red rock, and as at Anthony and Kingman the salt was obtained below it. Early in 1888 I found outcrop of Triassic (red rock) strata in limited areas just south of the southern bend of the Smoky River in northern McPherson County. Borings east and west of Ellsworth showed the absence of red rock at Salina and Russell. It is thus apparent that the triangular form of the Triassic area, as shown in its surface development in southern Kansas, is prolonged northward under other deposits, and that Ellsworth is near the apex of the triangle. The strata with which the salt beds are associated, and which overlie them beneath the red beds, are mostly gray shales with some harder ledges. In a map and section illustrating a paper on the salt discoveries, read at the American Association for the Advancement of Science at Cleveland, in 1888, the writer has denominated these beds the saliferous horizon. The tendency of the evidence is to the effect that the strata of the saliferous horizon are continuous, without break, from the so-called Permo-Carboniferous beds which outcrop east of the Arkansas River. Further, these beds are continuous upward, without break, into the Triassic red beds. Thus we have a continuous series, absolutely unbroken, from Paleozoic into Mesozoic time. Recent investigations show that the shales and other exposures around Wellington belong to the saliferous horizon, and they, like the red beds, are absolutely without fossils. The deepening of a railway cut six miles west of Wellington shows there the superposition of red beds conformably on the upper gray shales, with a copper bearing horizon in the latter. This sequence is seen also at Caldwell. The results of these last observations would be to bring the eastern boundary of the Triassic red beds to the east side of the Chikaskia. A more extensive examination of outcrops of the saliferous horizon in Sumner County also confirms the writer's opinion, previously formed, that the saliferous beds, though probably continuous with the Permo-Carboniferous rocks below, have more affinities with the red beds above, and so justifies him in associating them at least provisionally with the Triassic series in estimating the total thickness, which in the southern part of the State from Anthony westward must exceed a thousand feet where not considerably eroded. The saliferous horizon differs from the red beds mainly in color, but it has what may properly be called a Mesozoic lithologic facies, difficult to describe but not difficult to understand by those who have worked in both Paleozoic and Mesozoic strata. The absence of fossils characterizes, as we have already seen, both the gray shales and the red beds. The gypsiferous horizon, which is a marked feature of

the highest beds of the Permo-Carboniferous period in northern and southern Kansas, may perhaps be taken as a premonition of the salt measures which succeed them in southern Kansas but which are altogether missing in northern Kansas. There the Dakota beds rest with erosive unconformity on the Upper Permian. Salt deposits in the Cimarron Valley, below the State line and the Meade County salt pool probably indicate another salt horizon above the Triassic gypsum.

In this report I have used the term Permian and also Permo-Carboniferous, for the highest Paleozoic beds, but do not intend to commit myself to the final use of the terms, which I will discuss elsewhere in connection with other investigations.

CRETACEOUS.

The formations referable to this epoch which came under observation in the reconnaissance, as provisionally identified, are in natural order:

(1) The Niobrara.
(2) The Fort Benton.
(3) The Dakota.

THE DAKOTA.

Pebbles and nodules of the dark ferruginous sandstones of this formation are found in the gravels which overlie both the Trias and the Carboniferous, and these evidences of the existence of the parent beds increase westward, and among the red-rock bluffs north of Sharon a small patch of the Dakota was found in situ, manifestly deposited in an eroded hollow of the Trias. South of the town of Kingman, in the county of the same name, about half an acre of the ferruginous sandstone of the Dakota, that suggests volcanic action to the farmers of the Dakota regions, is similarily situate in a hollow of the red rock. Near the Barber and Comanche County line the same unconformity was observed, the Dakota being mostly composed of yellow, greenish, white and red sandstones. It also contains lignite, the reports of which warrant the belief that its beds are somewhat persistent. The brilliant coloring of these sandstones and their weathering into vertical cliffs and isolated "pulpit rocks" render the district one of remarkable variety both in color and in form. One stratum of darker ferruginous stain seemed identical with the nodule-yielding Dakota north of the Arkansas River, but we found no locality yielding the fossil leaves. The accompanying section (not drawn to scale) approximately represents the appearance in bluffs about six miles southwest from Sun City, and exhibits the changing conditions under which the lignite was found deposited. (See Fig. 5). The lignite itself is largely mixed with sand and has in it much pyrites.

THE FORT BENTON.

With reserve we are inclined to place the stratum called the "shell bed" in Fig. 5 in the Fort Benton group. A conspicuous feature of the lower part of the Fort Benton in northern Kansas is an extensive bed

of *Inoceramus* shells. It is from eighteen to twenty-four inches thick, is a white limestone, and can be traced just above Dakota sandstone a hundred miles. The shell bed of the diagram is of similar thickness, not so white, but also very extensive. Its shells, however, are not *Inoceramus* except to a very limited extent. They are almost entirely *Gryphæa*, mostly of the extremely variable form *G. pitcheri*, with an occasional *Exogyra*. We found a small patch of the bed in the hills north of Sharon, as well as farther south beyond the Barber and Comanche

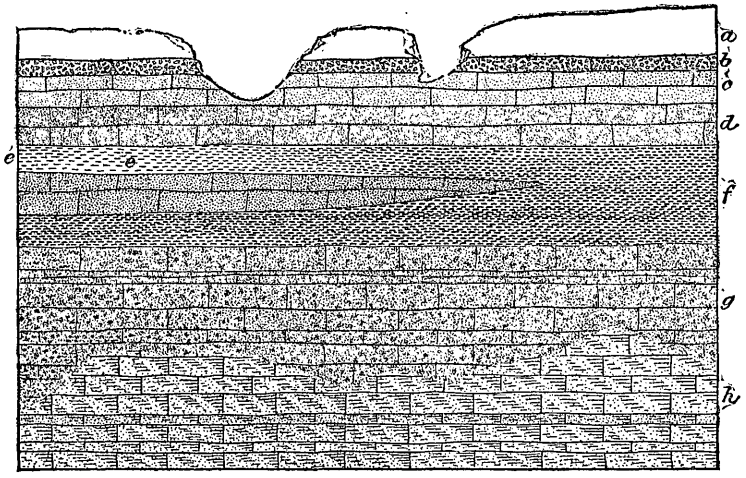


FIG. 5.—Section of Dakota strata resting on eroded surface of Jura-Trias.

a, slope of prairie; *b*, shell bed; *c*, yellow sandstone; *d*, red sandstone; *e*, shale; *f*, lignite; *g*, variegated sandstone; *h*, red rock (Jura-Trias).

line, and specimens of the shells were given to us from localities near the northwest corner of Barber County and the neighboring part of Edwards. The bed at the three localities where we observed it was composed almost entirely of small shells in a matrix of a limy conglomerate, the pebbles being very few, the shells making up three-fourths of the mass. We found them in all stages of preservation in the stream channels more than thirty miles from any development of the bed. We afterwards saw strata on Kiowa Creek (see Fig. 11) and on Spring Creek in Meade County (Fig. 6) which we refer also to

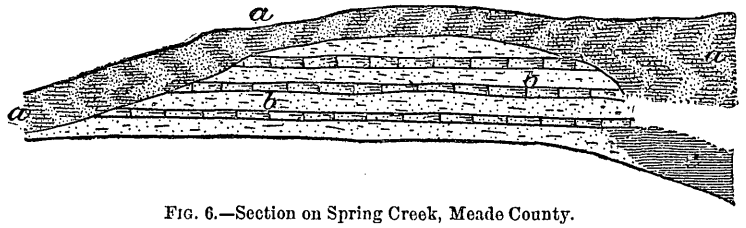


FIG. 6.—Section on Spring Creek, Meade County.

a, alluvium; *b*, Tertiary marl; *c*, Cretaceous.

the Fort Benton. Again, on the north of the Arkansas River, near the head of Saw Log Creek, there are shales and limestone (see Figs. 12

and 13), whose fossils—*Inoceramus*, *Nautilus* and *Belemnites*—seem certainly to proclaim their Benton age. The line of contact between the Fort Benton and the Niobrara in northern Kansas has not been worked out, and in the region of this reconnaissance it is scarcely possible to do it at all, as the surface deposits cover the Cretaceous formations so extensively.

In connection with the statement that the shell beds (*Gryphæa*) of northwestern Barber County and neighboring districts were with reserve attributed to the Benton epoch, it is interesting to know that in the same season in which the reconnaissance was made Prof. O. H. St. John made a hasty trip through this region and made some paleontologic collections of value. Besides reading so much of Professor St. John's results as were published in the Fifth Biennial Report of the State Board of Agriculture, I have had the advantage of personally comparing notes with him and going over his collections. It does not appear that Professor St. John examined the particular section shown in Fig. 5, but the shell beds were seen by him in several places, and he says in the report just mentioned that they "are charged with fossils, mostly belonging to a species of *Gryphæa* resembling *G. pitcheri*, an *Exogyra*, *Trigonia*, *Turritella*, etc. The latter also occurs in the upper portion of the underlying shales. The association of species and abundance of individuals strongly recall occurrences in Texas. The *Gryphæa*, however, is noticeably somewhat larger, though otherwise very similar to the *G. pitcheri* prevalent in the latter region, offering in this respect specific differentiation, recalling that which to-day obtains with the common oyster in passing northward along the Atlantic coast." (Fifth Bien. Rept. Kansas State Board of Agriculture, 1887, part II, p. 144.) These remarks relate to beds regarded by the observer as lying above Dakota sandstones, and recognized as different from the Dakota of northern Kansas, but not named Benton by him. He also hesitates to use the name Fort Benton for beds containing *Inoceramus* observed at no great distances from those described above, apparently on account of the absence of the northern Kansas bed of *Inoceramus*. He also says that these *Gryphæa* beds indicate the northern limits "of this peculiar southern fauna of the Cretaceous." I would observe that the specimens of *Gryphæa* seen by me in situ were all smaller than those collected by Prof. St. John and by others farther up the Medicine River than he went, and are exactly similar to specimens brought to him from Texas. Since the time of this reconnaissance Prof. Robt. T. Hill has located in Texas a lower Cretaceous series, to which has been given the name of the Comanche series, and the identity of the Barber County beds with the Comanche series has been suggested. If it existed it would apply not only to the shell beds, but to the sandstones below them, as they could not be Dakota if higher beds were a still lower Cretaceous. Before giving up the Dakota age of the sandstones (one bed in particular) I will have to reexamine the region, for it is certain the isolated patches at Sharon

and Kingman are Dakota. The sandstones in question are certainly unconformable with the red rock series. It is probable that the red rock series is Triassic; and it may be that the sandstones above are late Jurassic or early Dakota, and pass upward into Cretaceous shell beds without break, and are synchronous with beds elsewhere recognized as Dakota or even as Benton. The actual series of stratigraphic succession may possibly be worked out in the defiles of this region and the Indian Territory, but it will be a work of difficulty, as Tertiary and Quaternary deposits cover such large areas. If the stratigraphy be satisfactorily determined, it is possible that some paleontologic conclusions may have to be revised. In the shell beds referred to I obtained fossils that seemed without doubt to be casts of *Inocerami.*

Professor St. John found outcrops of Dakota sandstone near the Colorado line, and also of higher Cretaceous between the Cimarron and the Arkansas in the western counties; and he has since observed strata in northern Meade and southern Ford Counties, which he regards as Benton as certainly as those on Saw Log Creek north of the river, which they greatly resemble, though the characteristic shell bed of northern Kansas is missing. These localities, all small in area, have been indicated on the map illustrating the paper on the salt discoveries before referred to, which was read for me by Mr. W J McGee at the meeting of the American Association for the Advancement of Science at Cleveland, August, 1888. The estimate of their altitudes confirms the conclusions of the foregoing report on the easterly dip of the Cretaceous strata of western Kansas.

In Meade County there are indications of a sandstone horizon below the Benton which is probably Dakota. An artesian well in the Dakota formation on the west line of Clay County in northern Kansas, in connection with the easterly dip just mentioned led, me to suggest that artesian wells might also be made in southwestern Kansas that would yield water of fair quality at small depths. This has been verified on Crooked Creek, where numerous wells have a good flow of soft water from sandstones at depths of little over one hundred feet. These are nowhere on the high prairie, but are confined to the valley. They suffice for the irrigation of many farms. At Coolidge, in the Arkansas Valley, close to the Colorado line, the Dakota sandstones yield a limitless flow of water from an artesian well less than two hundred and fifty feet deep. Like that of other deep wells, this water is considerably mineralized.

THE NIOBRARA.

Rocks—shales and soft and hard limestones—of Cretaceous age are a conspicuous feature of the bluffs on the north side of the Arkansas River from Hartland west to the Colorado line. The yellow and white chalk and blue shale so characteristic of the Niobrara in the valleys of the Smoky Hill, Solomon and Prairie Dog Rivers are, however, not there. The fossils obtained were imperfect. *Ostrea congesta* was plen-

tiful in spots, and fragments of a large *Haploscapha* and *Scaphites*. Whether any part of this Cretaceous outcrop should be referred to formations above the Niobrara I will not undertake to say, as I believe it will need much more stratigraphic investigation than I was able to give and some careful paleontologic work to determine the point. Meanwhile I assume provisionally that the exposures west of Hartland are of Niobrara age. The dip of the Niobrara strata in one place was found to be northerly, but generally all the Cretaceous rocks seen in the Arkansas valley had an easterly dip nearly corresponding with the general slope of the country.

In the sections (Pl. II, Figs. 2 and 3) the three Cretaceous formations are distinguished, but on the map they are indicated by one convention only. The full showing of all Cretaceous outcrops can be made only by a thorough study of the region.

THE POST-CRETACEOUS EROSION.

The main fact with regard to the Cretaceous formations brought out in this reconnaissance is that the Cretaceous surface was greatly eroded before the deposit of the Tertiary formations that follow. That this erosion was very extensive is evident. Its amount can not be easily determined, but that the result was a contour not very different from the present one in its main lines appears to be certain. There seems to be reason to suspect that the Laramie formation has some development in the northwesterly portion of Kansas, and possibly also in the extreme southwest. If this extended east, then the erosion was during the whole of Eocene time, or possibly longer. That the erosion was enormous is shown even by the facts observed in this reconnaissance. Its full elucidation will require much longer time. The presentation of the facts observed in relation to the erosion of the Cretaceous strata will be best made in recording the observations on the Tertiary formations.

It is further to be observed that west of Dodge City the Cretaceous rocks have almost no surface development in the Arkansas Valley. The exposures west of Hartland are precipitous bluffs, mostly capped by the Tertiary formations. Occasionally these bluffs are terraciform, where the floor of one of the steps is a Cretaceous rock. Even the mere fringe indicated on the map is therefore an exaggeration if the scale be taken into account.

TERTIARY.

Two apparently distinct formations of Tertiary age have been found in all parts of the region explored. Occurring in isolated patches in the eastern part of the area, they are more largely developed as we proceed westward, where they are of such thickness and so related to the previous erosion as to completely hide other formations from view. Feeling sure of the identity of these formations with similar deposits in

northwestern Kansas, I am inclined to use the nomenclature of Professor Cope, and call these respectively the *Loup Fork* (Miocene) and the *Equus Beds* (Pliocene). But having regard to the extensive area over which the beds are developed and the comparative infrequency of fossils in the latter formation, I deem it best to designate them by purely provisional names and leave others to fix them more specifically when they have been examined over the whole region of the Great Plains and their subdivisions made out. These Tertiary formations then we name in ascending order: (*a*) *The Tertiary grit;* (*b*) *The Tertiary marl.*

THE TERTIARY GRIT.

The term grit is descriptive of this formation everywhere, yet it is of varying constitution. In places it encloses a fine powder, but the powder is largely siliceous, is useful as a polishing powder, and appears to be volcanic in its origin—wind-blown volcanic glass from the Tertiary centers of eruption in the west. Elsewhere the grit is an aggregation of sand and lime, which we call its mortar-like form. Again the lime exceeds the sand in quantity, and it is sufficiently fine to be used for inside plastering. Then we have the mortar form, enclosing abundant pebbles, quartz, feldspar, diorite, greenstone (hornblende), and more rarely granite with other igneous rocks. Then the limy matrix almost disappears, and we have a heavy conglomerate of water-worn pebbles of the rocks above mentioned, with jasper, quartzite and agate from the size of a nut to that of a large apple. Sometimes also there is a bone or a piece of completely silicified wood. The mortar-like form often hardens into a building stone, and its softer beds contain hard, tough nodules like indurated—not silicified—chalk. The conglomerate form changes at times into beds of a fair quality of sandstone. In some places it shows as a hardened bed of gravel, with well-marked cross-bedding. The mortar-like form is often a fossil bed, yielding bones of mastodon, *Aphelops* and turtle. There are in many places root-like concretions penetrating the softer forms of the grit, and where these softer forms are of considerable thickness—they attain in places a depth of fifteen to twenty feet—they are characterized by harder ledges at intervals of from two to three feet, which give very bold forms in weathering. The conglomerate is also manifested in abrupt breaks and rocky ledges.

Nearly all the foregoing characteristics of the grit were familiar to me in northwestern Kansas, so that there was no difficulty in identifying it in the region of this reconnaissance; but some of its occurrences were so far east that my note-book shows that I hesitated at first to recognize their identity. The increase of the area covered by the patches westward, and traces of remains of it in the form of thin gravel on slopes otherwise lacking signs of its presence, and its persistent occurrence as ledges a little below the highest prairie slopes, and, further still, its occurrence low in the river courses, indicated it as one of the

most extensive deposits of the western part of the State. I was further enabled to define more particularly two features of the grit which had been indefinite before. (*a*) In the Arkansas valley the conglomerate of the grit is mainly composed of pebbles of dark red feldspar. This is so marked a feature that its exposures, covered with the loose pebbles, can be recognized at long distances by their ruddy glow in the sun. In the valley of the Cimarron and in counties farther east the conglomerate is more often composed of quartz pebbles and pale feldspar, giving a whitish or grayish tint to the exposures. This will appear further in the discussion of Quaternary phenomena. (*b*) In several well marked instances I found the mortar form and the conglomerate together, indicating that they are not, as I had supposed, local variations of synchronous deposits. I found the mortar form below the conglomerate, the former having in those places its usual scant supply of pebbles. Rocky Point, a bold ledge of the conglomerate five miles west of Dodge City, gave this juxtaposition of the two forms, the mortar form showing only on the eastern or lower slope of the point and disappearing under the conglomerate. Elsewhere I found the mortar form embedding not only the pebbles of igneous rock, but also pebbles, both water-worn and angular, of the Cretaceous rocks of the region, these fragments being more or less silicified. A small patch of white sandstone, of which there were several near in Harper County (Sec. 5, T. 32, R. 5 west) had similar relation to the underlying red rock (Jura-Trias). The red rock, a nodular clay, shades upward into the sandstone, the intermediate part being a conglomerate of quartz pebbles in a pasty matrix of the red rock material. The sandstone itself has some pebbles of smaller size, and in the conglomerate the larger pebbles are below and the least amount of the coloring matter—the pasty matrix—above. The following sections show the positions of the sandstone and the red rock at this place:

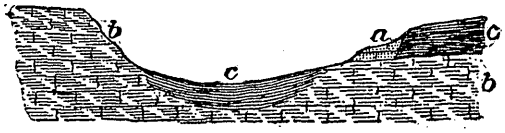


FIG. 7.—Section across a small ravine in Harper County.
a, sandstone; *b*, red rock (clay and nodules); *c*, alluvium.

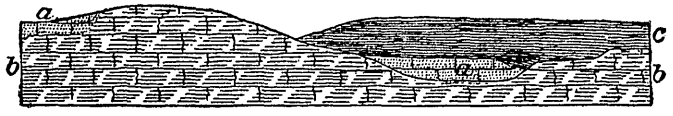


FIG. 8.—Section down the east side of small ravine in Harper County.
a, sandstone; *b*, red rock (clay and nodules); *c*, alluvium.

The above sections show another fact, viz: the erosive unconformity of this Tertiary grit with the formation beneath. It is manifest that the grit was deposited in hollows of the eroded surface of the Triassic. Further, the depressions then were where there are depressions

now. This feature is seen in every exposure which shows the rock on which the grit rests. In places where the underlying rock is not seen it is observed to follow the slope of a side ravine toward the main valley, so that it is manifest that not only was the erosion extensive, but it was on nearly the same lines as that of to-day. The grit filled up the valleys to a considerable extent and was laid over the top of the higher land to a considerable height. Other illustrations I shall give when discussing the higher Tertiary formation. I give one other section (Fig. 9) which shows that these formations were laid in similar manner on Carboniferous (Permian) deposits. It is not far west of the ninety-seventh meridian, on the east of the Arkansas River, in a cutting of the Frisco road, three miles northeast of Wichita. The height shown is from eight to ten feet, and the length thirty to forty rods.

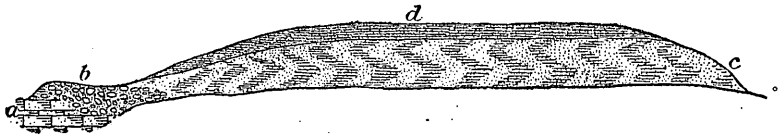


FIG. 9.—Section near Wichita.
a, Carboniferous limestone; *b*, Tertiary conglomerate; *c*, Tertiary marl; *d*, surface soil.

The illustrations of the post-Cretacious but pre-Neocene erosion are so common, that almost every ravine has evidence of it in the Cretaceous district, and it is as common in the Jura-Trias region. Near the south line of the State, in the region a little west of the one hundredth meridian, several sections like the following could be seen at once in the banks of small streams.

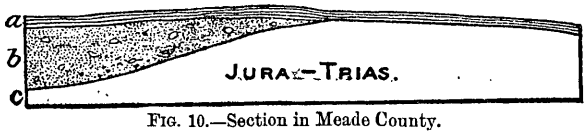


FIG. 10.—Section in Meade County.
a, alluvium; *b*, Tertiary grit; *c*, Jura-Trias.

Similar sections may also be found in Barber County, both north and south of the Medicine River.

Fossils—fragments of turtle bones, as well as foot bones of *Aphelops* and some horse teeth—have been found in parts of Barber County. Horse teeth and some specimens of *Ostrea* (the latter apparently worn) were obtained from an exposure on Kiowa Creek. (See Fig. 11.) At the same place was obtained a fragment of a small mammalian jaw. A neighboring exposure also yields pretty specimens of *Lymnophysa caperata*. Ampler exploration would undoubtedly reveal fossil deposits rivaling those of the bone beds of Phillips and Norton Counties, which yield remains of the larger mammalia by the ton. The fossils, with the exception of an occasional petrified fragment of bone or wood, are never found in the conglomerate. It is in the softer forms of the mortar grit that they abound.

The upper surface of the grit is much eroded. Its deposition was succeeded by a long period of subjection to sub-aerial agencies which

washed off a large part of its substance, rivers and smaller streams cutting it away nearly on the lines of the old valleys and nearly down to former levels. Then came another period of submersion and deposition, the material deposited making one of the most extensive and homogeneous formations of the Great Plains—the widely developed later Tertiary marl.

THE TERTIARY MARL.

Superficially this marl is not unlike the loess of the Missouri Valley, and in the middle of northern Kansas seems to shade into it, although in southern Kansas the loess is sufficiently distinct. The marl is arenaceous, argillaceous and calcareous in its texture. It is not at all like the mortar form of the Tertiary grit, except in a very few localities, where, owing to each having a predominance of sand, there is some difficulty in distinguishing them. Its color is very uniform. It is a buff marl everywhere. We saw no place where it was colored by the red rock of the Jura-Trias. It is buff on the yellow chalk of the northwest, on the Cretaceous limestones, on the Dakota sandstones, on the Jura-Trias, and on the Carboniferous strata. (See Fig. 9.) It contains chalky nodules irregular in shape, some root-like, resembling those in the Tertiary grit. Its texture is nearly the same everywhere. Where its bluffs are high its lateral exposures are wrought into rounded and symmetrical pillar-like forms, tapering to the top. Some views of it suggest the mauvaises terres of Nebraska.

In this reconnaissance evidence was found in two places of a subdivision of the marl into two deposits, the lower one in each case being more arenaceous than the upper one. (See Fig. 15.) The lower arenacious stratum seems also to be indicated in wells where it yields the water after the marl has been pierced. But a later visit to the place figured showed considerable wearing in the face of the bluff and the sharp line no longer existed, but only a gradual increase downward of arenaceous structure.

We find the Tertiary marl resting on eroded surfaces of Permian, Jura-Trias, Cretaceous and Tertiary grit formations. It is sometimes low down, buttressing the flanks of other formations, but its best development is at the greatest elevations. It forms the dead level of the high prairie between the great rivers, thinning off towards their valleys, but following the slope of the tributary dales. This thickening on the high prairie is manifest in almost every county—Barber, Pratt, Edwards, Meade, Ford, Hamilton, Seward, Scott, Graham, Norton—from Indian Territory to the Nebraska line. Wells pierce it in most of these counties over one hundred feet, and in Meade County and in Graham from one hundred and forty to one hundred and eighty feet, before the grit is reached. The grit has a supply of water; the marl seems quite dry except in its lower stratum. Walls of dugouts and cisterns excavated in it may be plastered or cemented without the intervention of other material. The Buffalo grass is attached to the marl. It remains on it after wire grass and others have taken posses-

sion of sedentary soils of the grit or other formations. Where the sod has been broken by the plow, it has been found that the marl in a few years ceases to be so dry. It can then be broken by the spade, where before a pick was necessary.

The marl yields comparatively few fossils. Remains of bison and horse and other mammals have been found in it. It remains to be seen whether Cope's designation of the "Equus Beds" can be justified for so extensive a formation.

THE TERTIARY EROSION.

The greatest fact to which the Tertiary marl bears witness next to the one of the immensity of its own existence is that of the erosion immediately preceding its deposition. Assuming the grit to be Miocene, we may allude to this as the mid-Neocene erosion to distinguish it from the pre-Neocene erosion, which we have already described. The following diagrams give evidence of both periods of subaerial agencies. They are simply examples that might be multiplied almost indefinitely.

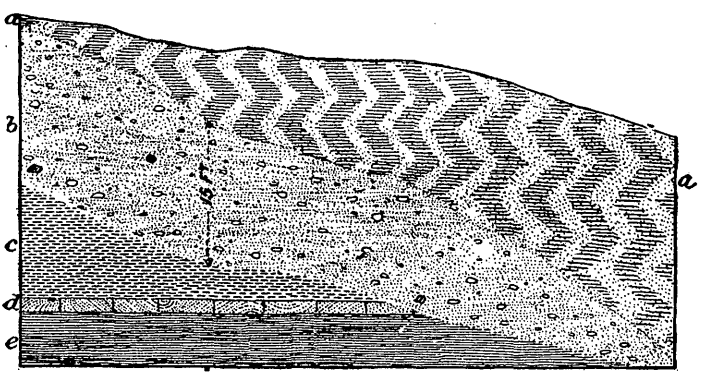


FIG. 11.—Section on Kiowa Creek, Comanche County, Kansas.

a, Tertiary marl; *b*, Tertiary grit; *c*, light drab and greenish shale; *d*, ledge of coarse yellowish sandstone; *e*, red iron ore.

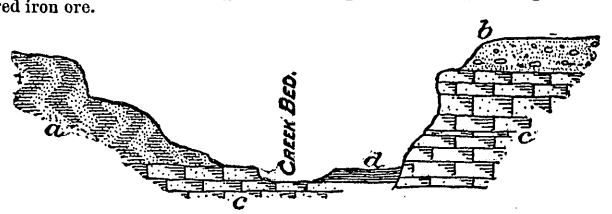


FIG. 12.—Section across Saw Log Creek, north of Dodge City.

a, Tertiary marl; *b*, Tertiary grit; *c*, Fort Benton limestone; *d*, alluvium.

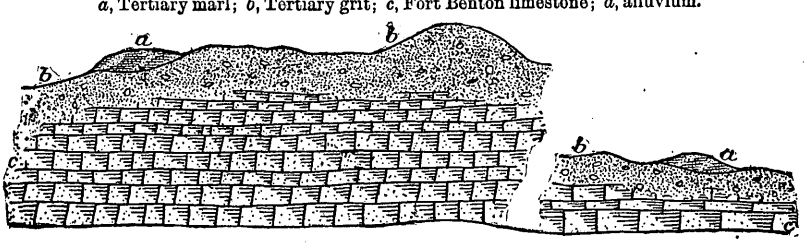


FIG. 13.—Section on south side of Saw Log Creek.

a, Tertiary marl; *b*, Tertiary grit; *c*, Fort Benton limestone.

For the sake of comparison I give the following from a "Report on the Geology of Norton County," made by me in 1884, to the Kansas Academy of Science. The locality of the section is in the Solomon Valley, south of Edmond, some distance east of the one hundredth meridian. The sections on Saw Log Creek are a little west of that meridian, but over one hundred miles south.

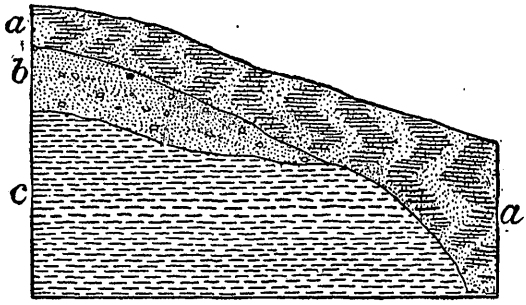


FIG. 14.—Section in Norton County, Kansas.
a, Tertiary marl; *b*, Tertiary grit; *c*, Cretaceous.

The following section of a bluff about 11 miles west of Dodge City shows in a striking manner the mid-Neocene erosion. The railway is on a terrace cut into the face of the bluff, and from the river up to this terrace the Tertiary grit is in place, and again it shows on the top of the next step; but the front of that step is formed of the Tertiary marl, which again appears back on the high prairie, thus showing an erosion-contour of the grit before deposition of the marl approximating to the form of the present valley. The line *s* in the diagram shows the position of the line of separation of the two forms of the marl already noted, the arenaceous character of the lower one being very marked (See p. 35, ante.)

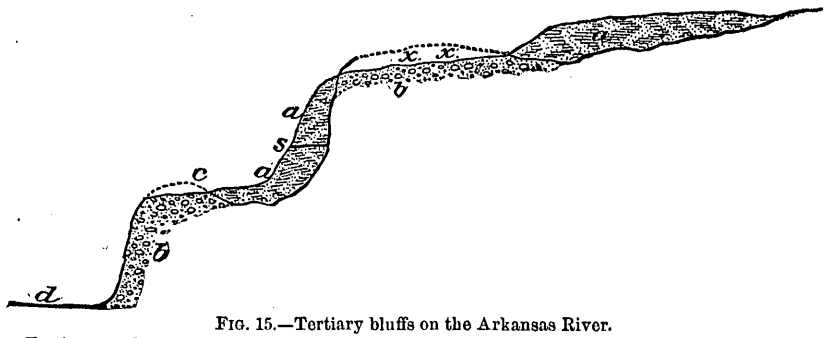


FIG. 15.—Tertiary bluffs on the Arkansas River.
a, Tertiary marl; *b*, Tertiary grit; *c*, railway terrace; *d*, river level; *s*, line of separation of the two forms of marl; *x x*, gravel of the conglomerate.

That the pre-Neocene erosion cut the valley of the Arkansas nearly to its present form is seen in the fact that small side ravines and other lateral valleys show the erosion of the Cretaceous rocks, with hollows partially filled with the Tertiary deposits. The following diagrams represent actual sections as seen from the main valley a few miles below Kendall.

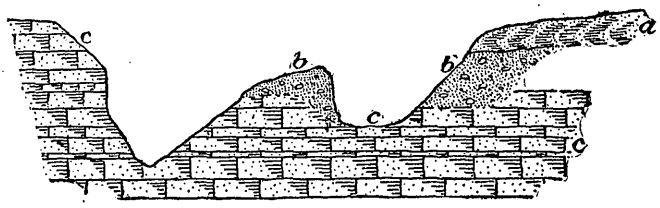


FIG. 16.—Section in Hamilton County.
a, Tertiary marl; *b*, Tertiary grit; *c*, Cretaceous limestone.

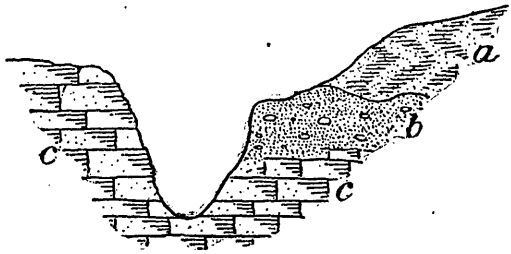


FIG. 17.—Section in Hamilton County.
a, Tertiary marl; *b*, Tertiary grit: *c*, Cretaceous limestone.

QUATERNARY.

The Quaternary deposits recognized in the reconnaissance are five in number. In ascending order they are: The Gumbo, The Earlier Gravel, The Loess, The Later Gravel, and the Alluvium.

THE GUMBO.

I take this name from a tough, solid, dark colored clay, which is so named in northeastern Kansas by the farmers, who dislike to find it near the surface. In my explorations I found it of a lavender color where weathered, but under the surface of a blackish brown. It is sticky and tough, but when dry breaks with a cuboidal fracture like hardpan. I found it in the Arkansas Valley forming the bottoms of pools, where the surrounding alluvium is almost pure sand. It occurs apparently beneath the gravel forming a good road-bed in Kingman County. In Clarke County I saw a few exposures of it in the faces of bluffs. The view at Red Bluff near the line of Clarke and Comanche Counties shows its occurrence overlying the Tertiary marl, and represents characteristic weathering of the red rock.

The contact of the Gumbo and the Tertiary marl suggests intermediate erosion of the marl. More extensive exploration of Quaternary

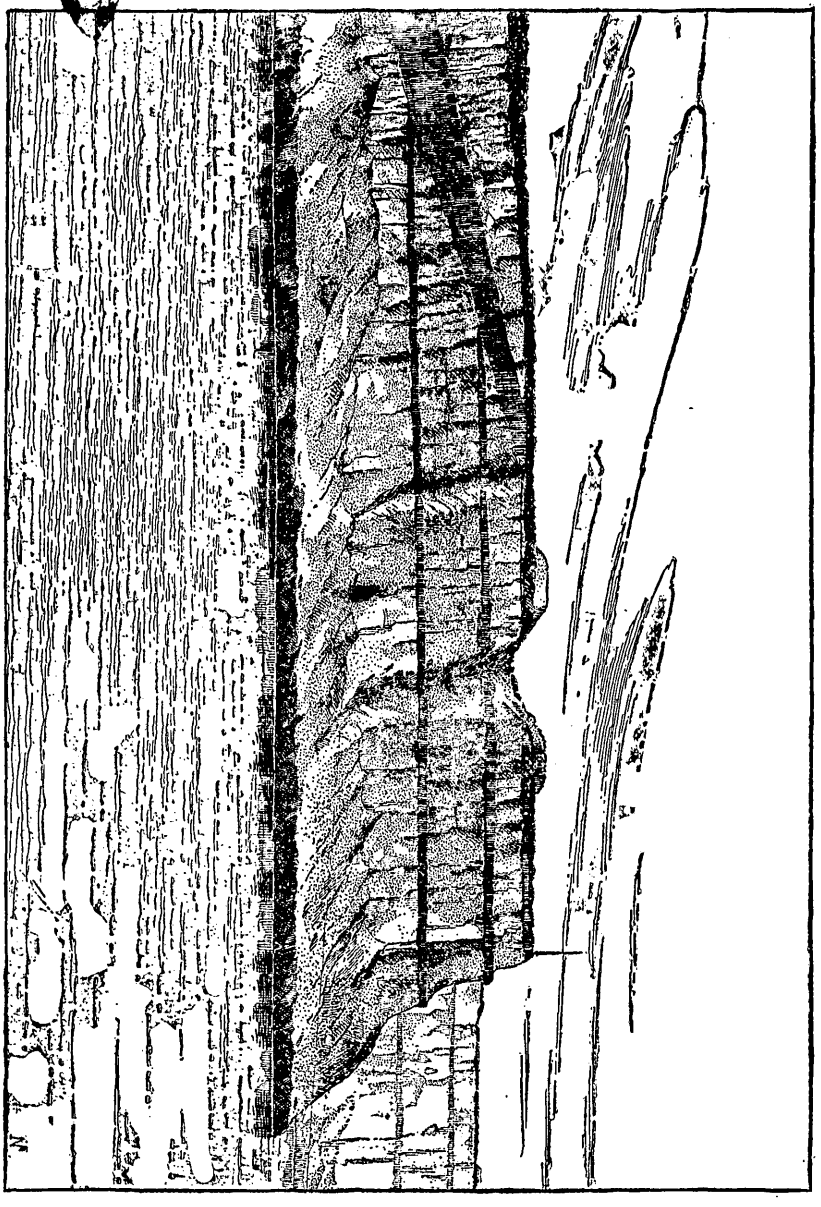


FIG. 18.—Red Bluff on Bluff Creek.

formations will be required before such erosion can be positively affirmed.

THE EARLIER GRAVEL.

An immense deposit of gravel lies under and around the town of Wellington, in Sumner County. It has been partially described in the Kansas City Review by J. P. West, and was by him referred to the

Champlain period. It has yielded fine teeth and jaws of *Elephas*, and also a fine skull and horns of *Bos latifrons*, which are now in the possession of Mr. John H. Wolfe, of Wellington. Water-worn fragments of petrified wood are found in it, and on the line of the railway to Honnewell, where the gravel is of finer material, it has yielded fragments of a large *Unio* and well preserved specimens of *Sphærium sulcatum*. These fossils perhaps sufficiently determine the horizon of this deposit.

The gravel is composed of well worn pebbles, not very large but making the deposit in places notably coarse. The pebbles are mostly quartz and quartzite with feldspar and other igneous rocks, and an admixture of Permian cherts and limestone, granite being rare. Some of the mounds are quarried and the material is passed through sieves to obtain building sand. Besides the branch road to Honnewell, the Southern Kansas Railway also cuts the gravel, and the Atchison, Topeka and Santa Fé branch on the west side of the city gives a fine section of it. It is therefore possible to study the deposit pretty fully. It lies in eroded hollows of the saliferous strata, which can be traced over parts of the town site by the wells. Those which are in the gravel give good water; those in shale are strongly impregnated with gypsum. The relation of the gravel to the loess is distinctly shown, and is well illustrated in Fig. 19. The cross bedding in places is remarkable, evincing the presence of powerful and changing currents.

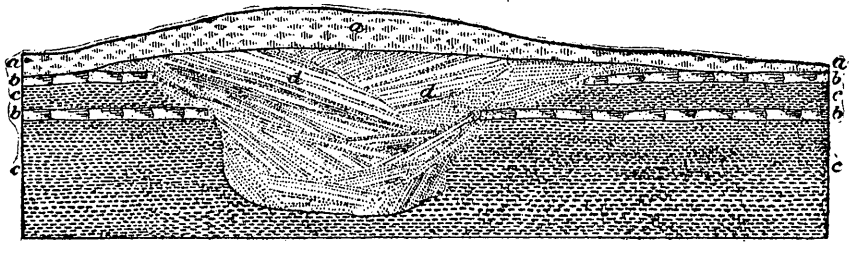


FIG. 19.—Section at cutting on Santa Fé Railway, Wellington, Kansas.
a, Loess; *b*, hard limy ledges; *c*, dark-colored shales; *d*, gravel.

Similar deposits of gravel are found occasionally to the west line of Barber County. Between Harper and Medicine Lodge they occupy large areas. They form the tops of the high prairie at Attica and east of that place for miles. They show depths of from five to twenty-five feet. The materials are the same as at Wellington, except the local material, which is in the western localities a reddish clayey extract of the red rock (Trias), which gives a sort of tenacity to the gravel and colors it distinctively. West of Attica the mounds are at lower levels. Medicine Lodge is on a mound which lies over a low spur of the red rock between Elm Creek and Medicine River. The railway cutting shows the contact of the gravel and the rock. Good specimens of teeth of *Elephas* have been taken from the gravel here and at Attica; fragments of large bones, shells, and fragments of the matrix containing them from the shell bed in Fig. 5 are also frequent in these gravels. North-

west and west of Medicine Lodge there are frequent mounds of gravel apparently synchronous with those already described, and northeasterly towards Kingman they cover large areas. The lower parts of the mounds are colored with the red rock, but the surfaces of the mounds are light colored, showing preponderance of quartz and buff feldspar pebbles. In western Barber County, and increasing west and northwest, there are other mounds of gravel not synchronous in their formation with those already described. I have designated them "the later gravel." I refer to them here because in western Barber County they are distingushable from the gravel mounds under consideration only by careful exploration and not always with certainty then. The reason of this will appear further on.

Difficulties in arriving at precise results with regard to the Quaternary gravels lie in the fact of their immense area of distribution and in the large size of single deposits, combined with their position at the tops of the prairie. Currents of considerable force were required to move the material. It seems difficult in many cases to consider them river currents; more difficult still to consider them lake currents. A littoral current in the Irish Sea is, however, depositing just such gravel now. Further study is required.

The fragments of petrified wood in the gravel being mostly waterworn, they appear to be of greater age as petrifactions than the deposit of the gravel. At least one silicified log seems, however, to be of wood of the gravel period. The log is of the color of the red rock.

THE LOESS.

The loess of the Missouri Valley is found as far up the Kaw Valley as the east line of Dickinson County. It extends up the Neosho to its source, but nowhere in northern Kansas does it appear to have passed much if any beyond the ninety-seventh meridian. At Wichita, however, it is strongly developed, and the water-shed between the Arkansas and the Walnut is mostly crowned by a heavy deposit of it. (See Fig. 1.) In the lower part of the Neosho Valley the loess is frequently much darker (orange brown) than in the Kaw, taking its color from the iron of various local deposits. But in the Arkansas Valley it becomes darker still, of a rich maroon. Farther west on the Minnesquah and the Medicine it becomes redder still. It is stained through and through, like the red rock, from which it is derived. In these valleys it attains its most westerly extension in Kansas. The comparative proximity of the Tertiary marl makes it easy to compare it with the loess. As compared with the later gravel, we have noticed that at Wellington the loess overlies the gravel; I infer a similar condition at Medicine Lodge, but I did not find the loess in any of the places (e. g., Attica), where the gravel is at relatively high levels. The bluffs of loess on the Medicine River show a characteristic that seems to have been inherited from the red clays of the Jura-Trias, i. e., they are more abrupt

in their contour than the Kaw River bluffs. The dry material has a cuboidal fracture, and the bluffs have a more precipitous appearance.

I have seen no fossils certainly referable to the loess of this district, but at Kiowa I was shown the humerus of a mastodon, which, from the stain and from its friability, I judged came from the red bluff formation. At Manhattan, in the Kaw Valley, the loess has yielded *Elephas*—teeth and tusks—at a depth of thirty-five feet.

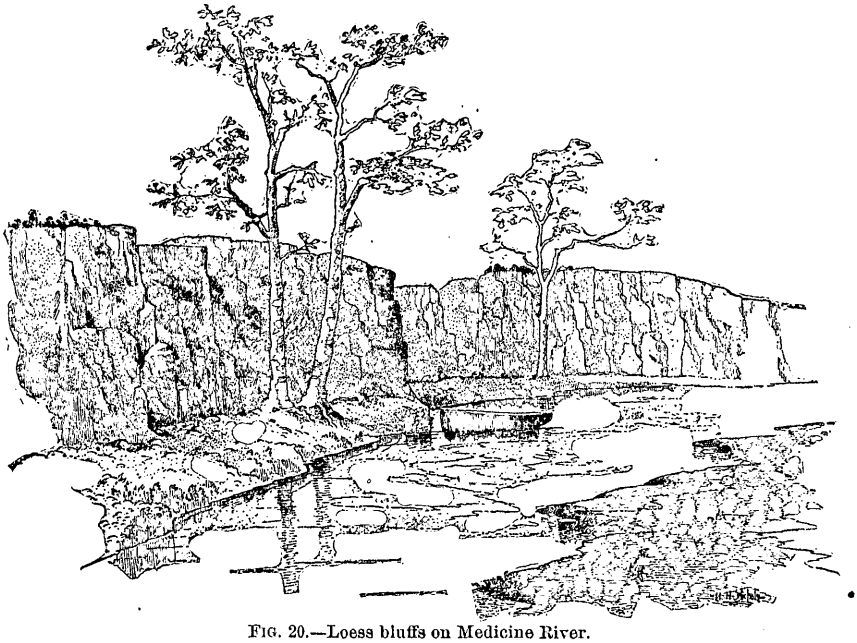


FIG. 20.—Loess bluffs on Medicine River.

THE LATER GRAVEL.

A very conspicuous feature of the Arkansas Valley from Dodge City to the mountains is found in the frequent mounds of gravel. They stand out as rounded bluffs from the high lands that bound the main valley. Our specific description is from the occurrences within the state of Kansas.

Approaching one of these mounds, we find that very rarely does the gravel reach the bottom. There is frequently a well defined line, below which but few pebbles are found, and above which the gravel is plentiful. Again, there are mounds where the gravel does not reach the top. The top in such case is formed of the Tertiary marl. The pebbles, of which this gravel is largely composed, are of igneous rocks, hornblende, greenstone, granite (rare), quartz, quartzite, diorite, chalcedony and feldspar. The feldspar is mostly dark red, and it is so conspicuous by quantity as to give a ruddy tint to the whole surface of the mound. This ruddy tint can be distinguished at long distances in the sunlight. The pebbles vary from the size of a hand downwards.

I have elsewhere referred to the fact that pebbles of the same kind are scattered over the tops and at the bases of bluffs of the Tertiary conglomerate, and that such bluffs have the same ruddy tint. The fact is that the gravel mounds are simply the disintegrated conglomerate bluffs of the Tertiary grit. The bluffs and mounds are the two extremes of a series of great interest, every intervening term being found in the valley. We may state them thus:—

1. A beetling, craggy rock of conglomerate with a few loose pebbles.
2. A craggy ledge of conglomerate with a considerable talus of pebbles and sandy soil.
3. A flat ledge of conglomerate just showing above a sloping talus of gravel and a surface sprinkled with pebbles.
4. A rounded gravel mound.

The inner side of a mound (No. 4) sometimes shows its base of conglomerate not all gone but connecting it with a conglomerate ledge farther back.

The discovery of this series shows that these mounds are not, per se, transported gravels like the earlier gravels already described. As gravel, they are in situ and were produced by agencies at present in operation. Some of the mounds are thinly sprinkled with vegetation. Some have their structure almost hidden by a vegetable humus. There must be such mounds entirely buried by both alluvial and eolian deposits of sand, for traces of such are revealed by recent floods. The formation of such mounds, then, has been going on ever since the Tertiary conglomerate arose from the waters in which it was deposited, but the mounds which are now conspicuous I regard as of recent origin, synchronous with deposits which are called alluvial. Like alluvium, they are forming now and have been since the last upheaval from lake or sea. Hence the designation The Later Gravel. Many mounds in Comanche and Barber Counties belong to this later gravel, and possibly some in Kingman. They may be looked for wherever a fragment of Tertiary conglomerate is left. These more eastern mounds are of paler hue, like the conglomerate of which they are formed. The pebbles of quartz are more numerous and the feldspar is decidedly paler.

THE ALLUVIUM.

The alluvium of the region covered by this reconnaissance includes a class of deposits important because of their extent. The valleys of many of the streams are broad and comparatively shallow, giving large areas of both past and present flood plains.

A conspicuous feature of most of the river and creek bottoms is their arenaceous character. The immense beds of sand in the valleys of the Chikaskia, the Medicine, the Cimarron and the Arkansas are merely larger examples of what is shown in the bottoms of Elm Creek, Crooked Creek, Kiowa Creek, and numberless others whose beds in the dry season swallow up their streams entirely. The sources of this sand

are not far to seek. In the Jura-Trias region the decomposing red rock yields some sand. But the main source of all is the wearing away of the two Tertiary formations, both of which are rich in arenaceous material. So abundantly do they yield it that the quantity of sand in the eastern part of the region may be taken as evidence of their former existence in localities where they are not now observed. Where they do exist the ravines below their outcrop are mere sand beds.

Another characteristic of the arenaceous deposits is that they are sometimes found in places where they can not strictly be called alluvial. No river ever ran there. They have been formed in situ from the breaking up of the Tertiary marl by atmospheric agencies. Wind, rain and carbonic acid have broken and leached out the calcareous and argillaceous parts where the slope has not been sufficient to carry away the sand to any great extent, and the wind has helped to arrange the material as hills or low dunes both before and after the growth of vegetation. I regard the extensive sandy region east, southeast, and southwest of Coldwater as having been formed by agencies of this kind. It is an occasional feature of this region that at the base of a hill is a talus of the later gravel, and sometimes the sand all blown away leaves exposed a gravel mound or even a ledge of the Tertiary grit. These features are found in Barber, Ford and Hamilton counties, and probably to a much larger extent than our reconnaissance showed.

The sand dunes of the Arkansas Valley merit distinct notice. The entire river bottom is more or less arenaceous, but in places there is below a few feet of sand, or, at the surface, when the sand is blown or washed away, a deposit of stiff clay or gumbo. At Wichita this clay has been pierced for wells, and sand is found again at a considerable depth below. Farther up the broad valley, a little elevated above the level of the stream, is simply a sand bed, carpeted with the grasses of the region. From Cimarron west into Colorado, on the south side of the river and in places coming down to the edge of the channel, is a vast range of sand hills. Opposite Syracuse they attain a height of fifty feet, bare, glaring sand dunes, changing with the changing wind. Often, however, they are covered with some vegetation, and are assuming a more stable character. The tops of a large part of the range are from one hundred and fifty to two hundred feet above the river, and the range attains a breadth of six to eight miles. The sand brought down the river from Colorado is large in quantity, and its eolian distribution when the water is low is certainly extensive; but we can not regard the sand hills referred to as owing all their substance to the sands transported from the west. Their apparent height is not their real height as sand hills. They are buttressed against the sides of the valley, and passing through them southward we emerge, without diminution of altitude, on the prairie, whose level is formed by the Tertiary marl. On the river front of the dunes we occasionally find the red mounds of the later gravel, and pools within the hills have a bottom of gumbo. It appears certain, then, that much of the material of the dunes is of

strictly local origin, increased by the amount that the ever flowing stream may bring from the west. The sands absorb much of the rainfall, and what should be water courses are mere sand beds. Bear Creek in wet weather is a series of pools, but it never reaches the river as a surface stream. Two of the pools are what are known as "sunk wells;" one of them is said to show no bottom at two hundred and forty feet, and the other is over one hundred and fifty feet in depth. It is certain that alluvial deposits are very deep in the Arkansas Valley. It is possible that the depth of these sunk wells represents the depth to which side ravines and, approximately, the main valley were excavated by Eocene or mid-Neocene erosion.

The Arkansas Valley has also an argillaceous alluvium. This is found in places as much as 50 feet above the present level of the river. At Hartland and below Cimarron ledges of rock approach the river from both sides. These are probably the remains of barriers which existed before the river was reduced to its present base level, and above which alluvium may have been deposited in exceptional quantity, but the period of the excavation of the short gorges between the barriers is unknown.

The alluvial deposits of the Medicine and tributary valleys claim a passing notice. I have referred to those of an arenaceous character. There are others decidedly argillaceous. These are red. They are finer grained than the red loess of the valley. The loess is finer grained than the red rock clay of which it is mainly formed. It would be interesting to examine these three forms with respect to the physical and chemical conditions of their materials and their relation to the fertility of the soil. The red rock soils—both sedentary and transported—are fertile.

CONCLUSION.

THE GENERAL RESULTS.

Among the results of this reconnaissance has been the distinct recognition of various formations in the region explored. It is not to be expected that a hurried reconnaissance should enable the geologist to delineate the formation boundaries of a considerable area with much exactness; and accordingly the boundaries indicated on the accompanying map are to be regarded as provisional, excepting in the immediate vicinity of the route traversed. The determination of the great easterly and southerly extension of the two Tertiary formations is an addition to American geology; the discrimination of the two Quaternary gravel deposits is believed to be new; and the tracing of both gravel beds to their sources in the Tertiary conglomerates is of local and general value as a means of ascertaining the origin of certain superficial deposits.

The Source of the Tertiary Conglomerates.—One of the most interesting problems suggested by the reconnaissance relates to the origin of the materials, particularly the coarse gravels, composing the Tertiary

formations. It has, indeed, already been inferred by geologists familiar with the region that the materials of the Tertiary conglomerates were originally derived from the Rocky Mountains; but investigations of the reconnaissance confirmed by more recent explorations have placed the inferences on a firmer basis than ever before. There is a series of mounds of gravel and of conglomeratic deposits along the western margin of the Great Plains in Colorado, well exhibited from north of Denver to below Pueblo; these deposits are apparently the westward continuation of the Tertiary grit of Kansas, and their materials are so similar to those of the deltas and alluvial fans built by the mountain streams at the mouths of their cañons as to prove identity of source. It is true that in the Tertiary grit of Kansas, the physical condition of the materials and the proportion of the various elements are different from those found in the gravel mounds, conglomerates and alluvial fans at the immediate base of the mountains; the materials are universally finer and better rounded, and there is a predominance of quartz and other obdurate minerals; but the differences in the coarseness and in the mineralogic character of the materials observed between the ninety-eighth meridian and the Colorado boundary are even greater than those occurring between the Colorado boundary and the Rockies.

It is probable that the Wichita Mountains of Indian Territory, which are composed of igneous rocks, have contributed material for the Tertiary formations of Kansas; but the character of the pebbles and the direction of the mountains with respect to slopes alike indicate that this source was unimportant.

The manner of transportation of pebbles so coarse as those found in the Tertiary conglomerate in southwestern Kansas over the four hundred miles intervening between the localities described above and their original source, remains a problem. The Tertiary deposits were laid down in lakes or inland seas in which the currents could have been of but limited strength—probably too limited to permit of transportation of such coarse materials. It may be suggested that the period of deposition of the Tertiary grit of western Kansas and eastern Colorado witnessed the progressive elevation of the Rocky Mountains either by steady uplift like the coast of Sweden, or by a succession of sudden upheavals like the Andes, and that during this period the shore of the lake with its attendant shingle and littoral debris and the mouths of the mountain-fed affluents from which the debris was derived, were progressively shifted farther and farther to the eastward, and that the coarser and finer phases of the Tertiary conglomerates throughout the whole area thus represent successive littoral deposits.

The Question of Tertiary Shores.—A second problem suggested by the reconnaissance relates to the eastern shores of the water bodies in which the Tertiary deposits were laid down. Little progress has been made in the solution of this problem. No unmistakably Tertiary deposits were found as far eastward as the ninety-seventh meri-

dian either in situ or in the form of residuary sands and gravels, and there is nothing in the topography or in the behavior of the rivers to suggest that the formations ever extended much farther eastward. It is significant, however, that the course of the Arkansas River is suddenly changed above Wichita, and that a prominent ridge—the Flint Hills—which attains an elevation of sixteen hundred feet and which might have formed a barrier for the Tertiary sea, occurs just eastward. It is possible that evidence of the coincidence of the old shore with this ridge may ultimately be found, but such evidence has not thus far been brought to light.

The Tripartite Erosion.—The most striking facts developed by the investigation of the Great Plains are connected with the three periods of erosion. The profound depths of the Grand Cañon of the Colorado give a visible exhibition of erosion, that from the direct evidence of the senses affects the imagination of even the illiterate. But on the plains it is only after painstaking observation, during a long time and over extended area, that the great fact of the erosion is made out. But when it is made out, and the mind grasps it, it is as striking a fact as the Colorado chasm. Here is an area whose dimensions are not less than the whole State of Colorado, which has been cut first into great valleys—from the Platte to the Canadian—and its general level lowered several hundred feet after the close of the Cretaceous period. Next it was submerged, and a deposit, the Tertiary grit, laid over it to a depth

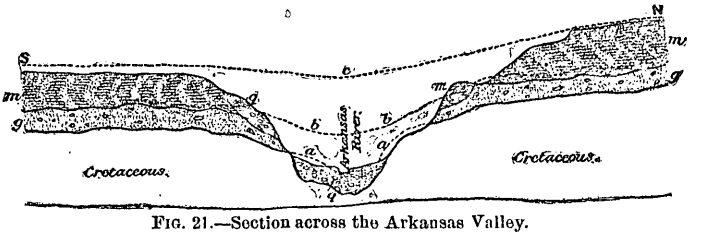


FIG. 21.—Section across the Arkansas Valley.

m, Tertiary marl; *g*, Tertiary grit; *c*, contour at commencement of post-Tertiary erosion; *q*, Quaternary deposits; *a*, assumed contour at close of pre-Neocene erosion; *b*, assumed contour at commencement of mid-Neocene erosion.

of probably fifty feet. Then after emergence so uniform that the new waterways followed the old, it was again eroded, the grit almost entirely disappearing in the valleys, and being certainly much thinned elsewhere. Another submergence spread over all the area a deposit which on the highest points is yet two hundred feet thick, and must have been thicker in the valleys. And this has again been eroded, generally along the old lines, and cut down to and below the depth of the first cutting into the Cretaceous rocks. The mean total erosion for the whole region can not be less than three hundred feet, as it must much exceed that in the valleys.

The generalized section in Fig. 21 shows the observed facts of the Arkansas Valley, commencing with the close of the pre-Neocene erosion. The broken line *a* shows an approximation to the eroded surface of the Cretaceous strata at the commencement of the deposition of the grit. The line *b* represents the completion of the grit. The line *c* may be taken

as the probable level at the post-Tertiary emergence of the marl. At present there are no data for estimating the original height of the Cretaceous strata. Sections like this, differing only in detail, can be constructed for the Smoky Hill River, the Saline, the Solomon, the Prairie Dog, and the Sappa, and, in smaller areas, the valley of the Cimarron. The Tertiary grit forms in parts of Seward county the bed of that stream.

The average dip of the strata in the region of Carboniferous formations is to the west; the dip of the higher Cretaceous rocks in the Arkansas Valley is certainly towards the east. Both northerly and southerly local dips have been noticed. It has not been easy to decide how to represent the observed facts, but in the sections forming Pl. II the dip is believed to be approximately correct.

These varied phenomena of the plains, then, are all the results of this complex application of the force called erosion. Its manifestation is on every hand. It has carved the weird forms and the deep cañons of the Gypsum Hills. It has cut out the broad valleys of the great rivers and the narrow ravines of the torrents. It has spread out vast sheets of sand and piled up mounds of gravel which it has brought from higher regions, and it is, day by day and year by year, still degrading the solid rock and sapping away the solid body of the high prairies of the west.

ECONOMIC GEOLOGY.

It is not possible to give proper discussion here to the facts of economic value in this region, mainly because they could not have the investigation their importance warranted. They have been incidentally touched in preceding pages, and here I will note only that observations on the water-holding capacity of the Tertiary grit have been published by me in a bulletin of the State Board of Agriculture, and, being extensively copied in the newspapers, have been useful to the settlers of the Southwest. Similar observations were also made by Professor St. John. It is interesting to note that recent examinations in northern Kansas have revealed traces of the Tertiary formations east of the ninety-seventh meridian.

The gypsum deposits are being practically utilized in the manufacture of stucco and plaster-of-Paris, and some beds yield marble and alabaster that may take a place in ornamental architecture. Some of the red beds at Kingman are yielding a fine quality of mineral paint. The Cretaceous formations are in places yielding building stones that are of great value to the increasing population of southwestern Kansas.

The salt rock on the confines of the Permian and Triassic formations is of great thickness and is being extensively utilized at Hutchinson and elsewhere. At Kingman it has been reached by a shaft which has already passed through 24 feet of solid salt in four layers, and thicker veins are expected at a somewhat greater depth than that now reached (700 feet).

INDEX.