THE UNIVERSITY

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GEOLOGICAL SURVEY

OF

KANSAS.

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VOL. II.

By ERASMUS HAWORTH
AND ASSISTANTS.

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Dr. F. H. Snow, Chancellor of the University of Kansas:

SIR—I have the honor of submitting to you herewith the following report on the stratigraphy and general geology of western Kansas, including the Upper Permiam, the Cretaceous, and the Tertiary. This will constitute volume II of the reports of the University Geological Survey of Kansas.

Yours most respectfully, ERASMUS HAWORTH.

DEPARTMENT OF PHYSICAL GEOLOGY AND MINERALOGY,
UNIVERSITY OF KANSAS, NOVEMBER, 1896.

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PREFACE.

Volume II of the University Geological Survey follows close upon the appearance of volume I. Those unacquainted with the work already done may wonder how such can be possible when so small an amount of funds has been used by the Survey. It may be stated, therefore, that material for this volume has been accumulating for years, so that it by no means represents the work of the past year only.

In the preparation of volume II the writer has been assisted by the following workers, each of whom volunteered his services, and consequently cost the state nothing but his actual expenses: Prof. C. S. Prosser, of Union College, Schenectady, N. Y., with his two assistants, Mr. J. W. Beede, of Topeka, and Mr. C. N. Gould, of Winfield; Mr. W. N. Logan, a graduate of the University, and now principal of public schools, Pleasanton; and Prof. S. W. Williston, professor of palaeontology in the University, and regularly a member of the Survey staff. The state has consequently been greatly benefited by their gratuitous contributions of service.

The drawings for the five etchings forming the figures in the text, and all the plates excepting the half-tone reproduction of photographs, were made, excepting figures 12 and 13, by Miss Harriet M. Huntsman, of Lawrence, the same artist who contributed so largely to volume I. Her work needs no comment. The engraving was all done by Blomgren Bros. & Co., of Chicago, whose work likewise speaks for itself. E. H.

UNIVERSITY OF KANSAS, NOVEMBER, 1896.

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ORGANIZATION AND OBJECTS.

In organizing a University Geological Survey of Kansas a full and complete geological survey of the state was contemplated. The work will necessarily have to be done with relative slowness, which may not prove to be a disadvantage. It is expected that it will be done by the members of the University faculty, their advanced students, and other individuals, citizens of the state or otherwise, who are willing to give their time and energies to the state a few months of the year in assisting to carry out investigations interesting and scientific in character, and valuable in many ways in their results, the compensation for which is to be an increase in the knowledge of nature, an opportunity to study geology in the field, a medium of publication by means of which they may have their labors brought before the world, and the consciousness of having added a mite to the "increase and dissemination of knowledge among men." Since the University has opened a graduate department in geology and paleontology it may not be a vain hope that the survey will help to build up these departments, and thereby produce a reactionary good in addition to those above named.

It is contemplated by the Board of Regents that the interested departments in the University will severally be responsible, not only for the work accomplished under the departments, but for the degree of energy and zeal with which it is prosecuted. Each will therefore be expected to issue reports from time to time on the work done, reports covering greater or lesser subjects, or natural divisions, of the great science of geology. At the outset it was agreed by all that the investigations in general stratigraphy, areal boundaries, and allied subjects should be taken up first, after which other divisions should follow in natural order.

The present volume, Volume II of the series, is prepared prin-

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cipally by the department of physical geology, although the department of paleontology has added a brief description of the paleontology of the Cretaceous and later formations of the state. It is a companion to Volume I and covers the western part of the state similarly to the way Volume I covered the east. It deals principally with the stratigraphic properties of the Cretaceous and younger formations, paying but little attention to the economic phases of the state.

A report is now in preparation by this department to the state board of irrigation on work done for them during the past two summers. A plan of cooperation was effected by means of which the department of physical geology of the University combined with the State Board of Irrigation in making investigations in the western part of the state. A large proportion of the data presented in this volume was gathered in that way. This portion of the report of the State Board of Irrigation is practically a report of the University.

Other volumes are in preparation. This department has two volumes more than half completed devoted entirely to economic subjects, which will cover the topics of lead and zinc ores, the mining and metallurgy of the same; coal; oil and gas; salt; and gypsum. The report on these subjects will constitute Volumes III and IV. The department of paleontology likewise is preparing a monograph on the vertebrate paleontology of the state which it is hoped will be published during the next two years. Likewise the department of chemistry is preparing a report on the mineral waters of the state which may be expected within a year or two.

For the present at least the octavo volume will be the style of publication adopted. Bulletins, the recent form of overflow publications so generally adopted in America, are unnecessary, because our University Quarterly, a regular publication, meets such requirements.

It should be remembered by the scientific reader that these reports are intended primarily for the masses of the citizens of Kansas, and that therefore an elementary character must be preserved, not however, it is hoped, at the expense of scientific accuracy. Divers elementary explanations must be given, and rudimentary

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principles, however well known to the scientist, must be elucidated, even to the frequent repetition of long used illustrations. But it is earnestly hoped this will not result in unnecessary repetitions, or in any other act which may give them a "padded" appearance.

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INTRODUCTION TO KANSAS GEOLOGY.

Kansas is a part of the great plain stretching from the Mississippi river on the east to the Rocky mountains on the west. It is approximately 200 by 400 miles in extent, and should be looked upon as a block in the great plain, constituting an essential part of it, but not specially different from other portions lying on either side of it. The elevation above sea level of the eastern end averages about 850 feet, with Bonita 1,075 feet, about the highest point, and Kansas City 750 feet at the Union depot the lowest. The north and south boundaries have approximately the same elevation, although the increase in hight is more rapid along the northern side from the Missouri river westward, while on the southern side the rapid increase in hight does not begin until farther west. The lowest part of the state is the Verdigris river valley where it crosses the southern line. At the Missouri Pacific depot in Coffeyville the elevation is 734 feet, 16 feet below the Union depot at Kansas City. The southern line crosses the great ridge west of Independence, the Flint Hills, which lifts the elevation to over 1700 feet, but it again declines westward toward the Arkansas river to an elevation of only 1066 feet at the Santa Fe depot in Arkansas City. From here to the southwest corner of the state the ascent is gradual, increasing slightly with the distance, so that for the western hundred miles across the whole of the state the eastern descent is from seven to twelve feet to the mile. The western boundary line varies slightly from north to south, but is between 3500 and 4000 feet above sea level.

The drainage of the state is therefore to the east. Here and there an irregularity of surface will deflect the stream southeast or south, as the Verdigris river and the Blue river, or northeast, as with the Republican river through a part of its course, and the lesser tributaries to the Missouri in the northeastern part of the

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state. The streams usually have a considerable current due to the great incline of the surface as a whole, which, from west to east, averages nearly eight feet to the mile for the whole state. Toward the east part of the state they have broad and level valleys filled in for from 20 to 60 feet with alluvial material, while in the far west some of them have scarcely reached base level.

The general physiographic conditions of the state are not as regular as is usually supposed. Although the surface is a great plain sloping eastward, its minuter topography is often varied and rugged; valleys 200 feet deep, bluffs and mounds with precipitous walls 300 feet high, overhanging rocky ledges, and remnants of cataracts and falls in numerous streams, giving a variety of scenery, are to be observed almost all over the eastern part the state, and to even a greater extent in some parts of the west. The physiography of a country is dependent upon its geologic structure, so that we may begin physiography by a study of structural geology.

The rocky portions of the earth accessible to the student of geology are confined to the surface of the sphere. Mountain chains are elevated, deep gorges and river channels are worn, and vast faults, or dislocations, are made in various places, whereby the rocky strata are exposed so that an accurate knowledge can be gained of the surface to considerable depth provided the field of observation is sufficiently extended. It is now generally understood that the oldest rocks of the globe are massive in form and crystalline in structure. It is probable they represent the oldest parts of the earth which is exposed to view anywhere upon its surface. It is likewise probable there was a time in the early history of the earth when the ocean waters entirely covered the whole surface of the sphere. Subsequent irregularities of the surface were produced by a contraction of the volume of the earth and portions of the ocean bottoms were lifted into dry land. No sooner was this accomplished than the ordinary agents of destruction and decay everywhere present in the atmosphere began acting upon these freshly exposed surfaces and resulted in wearing vast quantities of them away and carrying them back into the ocean by the drainage which resulted from the rainfall. In this way sedimentary material was produced which, added to the various forms of sedi-

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ment already existing in the ocean bottom produced layer upon layer of material over different parts of the ocean bottom which ultimately became changed into one kind or another of rock.

As the contraction of the diameter of the earth continued, and probably is in progress even at the present time, the irregularities in the surface were correspondingly intensified. The valleys in the ocean bottom were made lower and lower and the valleys between the dry land uplands were likewise made more intense, so that the difference in elevation betwen the land areas and the water areas was constantly increasing. But the destructive agencies of the atmosphere were likewise active upon all the dry land as fast as it appeared above the ocean water and constantly larger quantities of sediment were carried from the dry land back into the ocean. In this way the superficial portions of the globe were constantly being worked over and spread out over the ocean bottom in the form of relatively thin coverings of stratified rock in which layer upon layer of first one kind of material and then another was produced.

At the present time the greater portion of all of the dry land of the globe is covered with stratified rocks thus produced. The remaining part is covered with rocks resulting from one form or another of volcanic action or, in rare cases, possible of a portion of the original dry land materials is preserved.

The stratified rock, therefore, should be looked upon as relatively thin layers of sediments that have been accumulated and which have as great diversity of character as corresponds with the different conditions under which they were formed. Some of them are composed principally of grains of sand weakly or strongly cemented together, producing the different kinds of sandstone. Others are products of the finer sediments, the material which was carried in such large quantities into the ocean from the dry lands. These are usually designated by the one term shale, with explanatory terms prefixed as occasion may require, such as clay, or argillaceous shales, sandy, or arenaceous shales, bituminous, or carbonaceous shales, etc. A third kind of stratified rock which is everywhere present is produced by the accumulation of the shells of the various forms of marine invertebrates and is known by the general

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term of limestone. Here likewise various explanatory terms are employed to specify in greater detail the particular character of the limestone. In this way the whole of the stratified rocks of the earth may be classed under the three general heads of sandstone, shale, and limestone.

These various forms of material are interbedded with each other, sometimes in a very intricate manner, but usually in such forms that their relations to each other can be easily understood by those who are trained in field work in geology. The surface of the globe in any one particular place rarely exhibits more than one or two or possibly three of the various forms of rock just described, but by traveling some distance in any direction others are usually reached which overlie or underlie the ones first examined. The different strata in this way are brought to the surface so that they can be examined. Passing under each other in whatever direction is necessary for a particular place, the strata are found in positions somewhat similar to the position occupied by the shingles on a roof.

The time occupied in the formation of each of these stratified rocks has been very long, has included almost all the time generally understood as geologic history. For convenience and simplicity of expression it is desirable to refer to the various time epochs during which different rock strata were being formed, and correspondingly refer to the rocks produced during such time epoch.

In the history of the rise of the science of geology we find that different customs have been followed at different times and by different people, so that there has not been a perfect uniformity in the choosing of names for time periods or for rock formations. But as the science grows older this disparagement of usage will gradually grow less. In 1889 the United States Geological Survey[1] decided upon a certain series of names to be given to the great time periods, which in general correspond with the usages of standard text book makers, but which, in a few particulars, differ somewhat from that usually observed in other publications. They divided all geologic time into eleven periods and gave the following names and limitations:

"The first [the latest] period shall cover the time beginning

1 Tenth Annual Report Director U. S. Geological Survey, p. 65, Washington, 1890.

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with the first ice invasion and continuing until the present, or that which is commonly called the 'Quaternary.' This was called the Pleistocene."

"The second period shall include the time divisions sometimes called Pliocene and Miocene. Its earlier limitations shall be that indicated by paleontology, and its latter the first ice invasion of the Pleistocene; and its designation shall be the Neocene."

"The third period shall be the Eocene. * * * Its definition shall be that commonly accepted by paleontologists and geologists as determined by fossil remains."

"The fourth period shall be the Cretaceous. Its definition shall be that indicated by paleontology and usually accepted."

"The fifth period shall include the time divisions known as Jurassic and Triassic, and shall be designated as Jura-Trias. Its definition shall be by paleontology."

"The sixth period shall be Carboniferous, including the subdivision sometimes called Permian. Its definition shall be by paleontology.'

"The seventh period shall be the Devonian. Its definition shall be that indicated by paleontology and usually accepted."

"The eighth period shall include the time divisions sometimes styled Upper Silurian and Lower Silurian, and otherwise styled Silurian and Ordovician. Its definition shall be by paleontology, and its designation shall be Silurian."

"The ninth period shall be designated the Cambrian. The definitions of its upper limit shall be by paleontology. * * * Its lower delimitation shall be the time of deposition of the lowest rocks thus far known to yield a well defined fauna."

"The tenth period shall be the time of deposition of plastic rocks older than the Cambrian. * * * The term Algonquin was mentioned and agreed to as the designation of the period."

"The eleventh: The oldest time division shall cover the time of formation of the ancient crystalline rocks, and its designation shall be Archaean."

From what has already been said the reader will understand that it is impossible at any one place to find all the geologic horizons. There are different points in America from which one may

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start and travel over the exposed edges of the successive formations throughout a considerable portion of the entire column.

Of the above-mentioned geological column Kansas geology deals only with the Carboniferous and younger rocks, excepting as we may penetrate far below the surface of the earth by drill or imagination to consider those which lie beneath the surface. The portion of the column above the Devonian is well represented in our state.

The geologic structure of Kansas, when considered on a grand scale, is simple, but in detail often becomes complex and difficult. In the extreme southeast part of the state over an area not exceeding thirty square miles, dense limestones and interbedded chert rocks, with the residual products produced by their superficial decay, constitute all that is to be seen of the geologic formation. These limestones and cherts extend westward as far as prospecting with the drill has yet shown their presence or absence, constituting the floor upon which rest all the remaining parts of the rock formations of the state. Could we examine below this floor we would find that it in turn rests on other rocky layers and they on others, for a distance of about 2000 feet, at which place the drill would reach the solid granite or gneiss or shist below which no limestones or sandstones or shales could be found. But the limestone and flint beds above mentioned are the floor for the Kansas formations, and may well serve as a limit to our present investigations. In the eastern part of the state this floor universally dips to the west, the southwest or northwest, varying in places to a considerable extent, but being moderately uniform, and the superimposed strata one above the other follow this inclination. This westward dip of the strata and the eastward dip of the surface serve to bring the succeeding strata individually to the surface like the ends of shingles on the house roof. As we pass westward the surface rises from the horizon but rises doubly fast from the limestone and cherty floor, so that could we dig a trench from the eastern line of the state westward following the surface of the floor, it would rapidly become deeper, and in its walls would be exposed the successive layers of rock one above the other as they actually occur. But the westward sloping of the strata is not continued throughout the

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whole state. Scarcely has one-third the distance been passed until the order is reversed. The eastern part has been influenced by the great inland swell of the Mississippi valley, the Ozark hills, while the western part has been more mightily influenced by the great Rocky mountain uplift. Could we continue our trench westward to the western side of the state we might find that the limestone and cherty floor extended that far, but most probably long before that distance was reached it would pass into rocks of other character. Of this, however, we are in total ignorance, as no boring has yet been put down deep enough to throw any light on the subject; but the lines of stratification marked on the walls of our trench would change their direction and incline eastward instead of westward.

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PHYSIOGRAPHY OF WESTERN KANSAS.

BY ERASMUS HAWORTH.

In Volume I of these Reports a short description was given of the more important physiographic features of the eastern part of the state. A like description for the remainder of the state is now contemplated.

DRAINAGE.

The surface drainage over eastern Kansas throughout earlier geologic times was westward, as the great body of dry land lay to the east. At the close of Cretaceous time the continent was elevated sufficiently to destroy the great inland arm of the sea reaching northward from the then Gulf of Mexico and connecting probably with the Arctic ocean on the north. The whole of the area lying between the dry land on the east and the mountainous ridge on the west thus became a dry land area, and its surface was subject to the erosive agents of the atmosphere.

It was at this time that the direction of the drainage was reversed. The great mountainous area was lifted sufficiently to produce a water shed to the east. The drainage from this crossed the great plains and entered the Mississippi river or the Gulf. In fact, it was about this time that the Mississippi, in the true sense of the term, became a river. The greatest of these drainage channels at present carrying waters from the Rocky mountains is the Missouri, into which numerous tributaries enter, so that more than

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half of the great plains area drains into the Missouri. In the northeastern part of Wyoming, and in Montana, the drainage is to the northeast. South from this in Nebraska and Kansas the drainage at present is almost straight east, while still further south it becomes deviated more toward the southeast. The waters from this part of the plains area enter the Mississippi directly through the Canadian and other channels without entering the Missouri. Still further south the drainage is into the Gulf of Mexico, either through the Rio Grande, or through lesser streams which enter the Gulf at different places in Texas. Comparatively few of these different streams rise in the mountainous country. The Missouri river with its more important tributaries, the Big Horn, the Yellowstone, the Powder, on the north, rise in the mountains; as do also the Platte river and the Arkansas in the central area; and the Canadian, the Pecos, and the Rio Grande farther south. The whole plains area, however, is covered with drainage channels, the most of which originate east of the foothills of the mountains. The ordinary map of the United States will show that the different streams are about as abundant over the great plains as elsewhere through the United States.

Of the Kansas streams as they now exist only one rises in the Rocky mountains—the Arkansas. Of the upper branches of the Kansas river the Republican rises farthest west. Different branches of this stream originate on the plains about one hundred miles west of the western boundary of Kansas. The tributaries of the Smoky Hill likewise originate across the line in Colorado, but not so far away. South of the Arkansas river the Cimarron river exists, which takes its rise from near Raton in New Mexico. In fact this stream almost might be called a mountainous stream, as its headwaters are away up on the highlands of the mountains. Lying between the Arkansas and the Cimarron is a little stream called Bear creek, which originates fifty miles or more west of the Kansas line.

At the present time many of these plains streams do not enter larger drainage channels. Having their rise in places where the inclination is relatively great, they frequently form channels from 20 to 50 feet deep, and prominent flood-plains, implying that they have a considerable age, but farther eastward simply spread out

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on the plains or into the sandhills. Bear creek, just mentioned, is a good example of this. In places its bluffs are 50 feet high and its flood plain valley is half a mile wide. Crossing the state line from Colorado into Kansas it reaches eastward to a point not more than eight or ten miles distant from the Arkansas river, where all traces of it gradually disappear. Not only this, but in times of freshets the water of Bear creek, instead of entering the Arkansas river as is so frequently represented on different maps, is spread out on the highlands area, none of which gets into the Arkansas excepting possibly an inconsiderable proportion which may work its way northward through the sandhills.

Other streams both north and south of the Arkansas have similar properties. The White Woman on the north is another good example. Rising a few miles west of the boundary of Kansas, it flows eastward for about seventy five miles. In places its channel is eroded to a depth of nearly 100 feet below the general level of the uplands, and a flood plain nearly a mile wide has been produced. In the vicinity of Scott City it gradually disappears, the bluffs and banks on either side gradually becoming less prominent, and finally no trace of the stream whatever can be found. In times of heavy rains large quantities of water are found in the stream which are emptied into a broad level basin near Scott City. The total number of such streams, big and little, has not been determined, but it is safe to say they would reach near a hundred were they all enumerated.

Drainage in Tertiary Time.

During early Tertiary time the drainage seems to have been similar to that of the present. It is probable the climatic conditions were very different then from those now existing over the great plains. The vast amount of material carried eastward from the mountains and deposited in the plains from the Gulf of Mexico northward into Canada implies a correspondingly greater precipitation. There are good reasons for believing the mountainous elevation occurred with relative slowness, but with considerable irregularity. The evidence of this on the great plains is confined principally to the character of the materials transported. In some places heavy coarse gravel

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beds were formed, the individual gravels in which frequently have a diameter as great as four or five inches, requiring a great velocity of water to transport them throughout the distance they have been carried. Above and below such gravel beds the material is frequently composed almost entirely of the finest sand, and clay, and silt, which strongly implies that the movement of the water at that time was not rapid, but rather that it was slow and sluggish.

As is shown later in an article on the physical properties of the Tertiary these heavy gravel beds and the beds of fine sand and clay alternate with each other showing conclusively that there have been recurrences of conditions, a rapid movement of the water being followed by a slow one, which in turn was followed by another period of greater velocities. It therefore seems that the terrestrial movements were such, either in the mountains or the eastern part of the plains area, that the velocities of the mountain streams were changing alternately from slow to rapid, and again from rapid to slow and sluggish. Evidence on this subject is reached outside of the great plains area, as has been shown by various authors in describing the drainage and general geologic conditions of the great west. It is well established that the main mountainous area had a gradual elevation rather than a rapid one; gradual upon the average but one irregular in character, with different periods of rapid elevation intervening between long periods of slow upraising, or possible entire cessation in upward movements.

It is somewhat difficult to decide the exact geologic date of the accumulation of the Tertiary materials in Kansas. From paleontologic evidence it would seem that the oldest Tertiary horizon in the state belongs to a later Miocene period. Similar evidence gathered from the paleontologic history of the great plains to the north in the Dakotas shows that Tertiary material began accumulating there considerably earlier, in the Oligocene, or possibly in the latter part of the Eocene. We have corroborative evidence of this in Kansas. The upper surface of the Cretaceous has been gradually eroded and subsequently covered with Tertiary material. It appears that after the elevation of the mountainous area sufficiently to produce dry land through the western part of the state, and probably over the whole plains area, a sufficient time elapsed before the deposition of

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Tertiary material began to admit of erosion of the Cretaceous surface almost as extensively as that which is now observed on the surface of the Tertiary. Streams of different sizes existed in many places cutting their channels sometimes wide and deep, elsewhere to a milder degree, leaving a corrugated Cretaceous surface to be covered later by Tertiary materials.

If we accept the view, which seems to be established for the Dakotas, of the former existence of a northern Tertiary lake, the Sioux lake of King[1], it might seem reasonable to suppose that likewise the greater part of the Tertiary materials in Kansas were accumulated at the bottom of fresh water lakes. It is almost certain, however, that at least a considerable part of this material was deposited in place by rivers rather than in the bottom of lakes, and that therefore the different drainage channels which have existed since the beginning of Tertiary time in Kansas have migrated back and forth across the great plains, depositing different kinds of material in the irregular form in which we now find them.

It would be interesting to study the life history of these different streams, and to determine whether or not they were originally at all similar to the various streams crossing Kansas from the west at the present time. With the evidence already alluded to regarding the probable condition of drainage in the earlier Tertiary there is no special reason for not believing that the migration of the different streams has been sufficient in the aggregate to accomplish the main part of the results as we now see them. Should this be the case it is probable some of the erosion in the Cretaceous has taken place very recently. In fact, different ones of the lesser tributaries at the present time are cutting their channels into the Cretaceous throughout a part of their course and having their valleys filled in with Tertiary material from the adjacent bluffs in other places. It seems quite possible that some, at least, of the erosion of the Cretaceous may have occurred during Pleistocene and recent times.

Character of the Materials Eroded.

The character of the materials in western Kansas into which the different drainage channels have been eroded differs greatly in

1 Clarence King, U. S. Geological Exploration of the Fortieth Parallel, Vol. I., p. 451. Washington, 1878.

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different parts of the state. Throughout the western part over the areas covered with the Tertiary erosion could be produced very rapidly were the precipitation sufficient. Much more than half of the Tertiary material is in the form of loose beds of silt, or clays, or sand, or gravel, materials which would yield most readily to the corrasive action of running water.

Elsewhere the Cretaceous rocks are exposed to the surface, or have been so exposed. These in general would resist corrasion more vigorously than the Tertiary materials. In places, it is true, they are composed principally of shales which would yield quite readily. But elsewhere the limestone beds are so frequently interspersed with the shale that a relatively strong resistance to all forms of erosion would occur. It is quite probable that such formations have had a strong influence in producing the particular physiography of the country wherever they are exposed to the surface.

Eastward from the Benton and Niobrara exposures we find the Dakota covering the surface. In most places the materials of the Dakota are quite easily worn away. Consisting as they do of sandstone and shales, with the sandstone weakly cemented together, they offer but little resistance to the vigorous action of running water. In a few horizons the cementing material of the sands seems to be sufficiently strong to produce a tolerably strong sandstone, and therefore a material which will resist decay. It is a noticeable fact that the character of the river channels vary from place to place through their course, depending to a great extent upon the character of the material through which the channel is worn.

The residual materials found here and there through the drainage area corresponds in character quite closely with the materials into which the channel has been produced. Through the Tertiary area the most common residual products are sand and gravel. It is by no means unusual to find a small stream, or an arroyo, of only a few miles in length, in the Tertiary area which has carried away the clay and finer silt and has left behind as a complete mantle for its flood plain the sand which constitutes a portion of the original materials. Such sand washes are seen particularly in the southern part of the state through Meade and Clark counties, where the inclination of the surface to the south is so great that the streams

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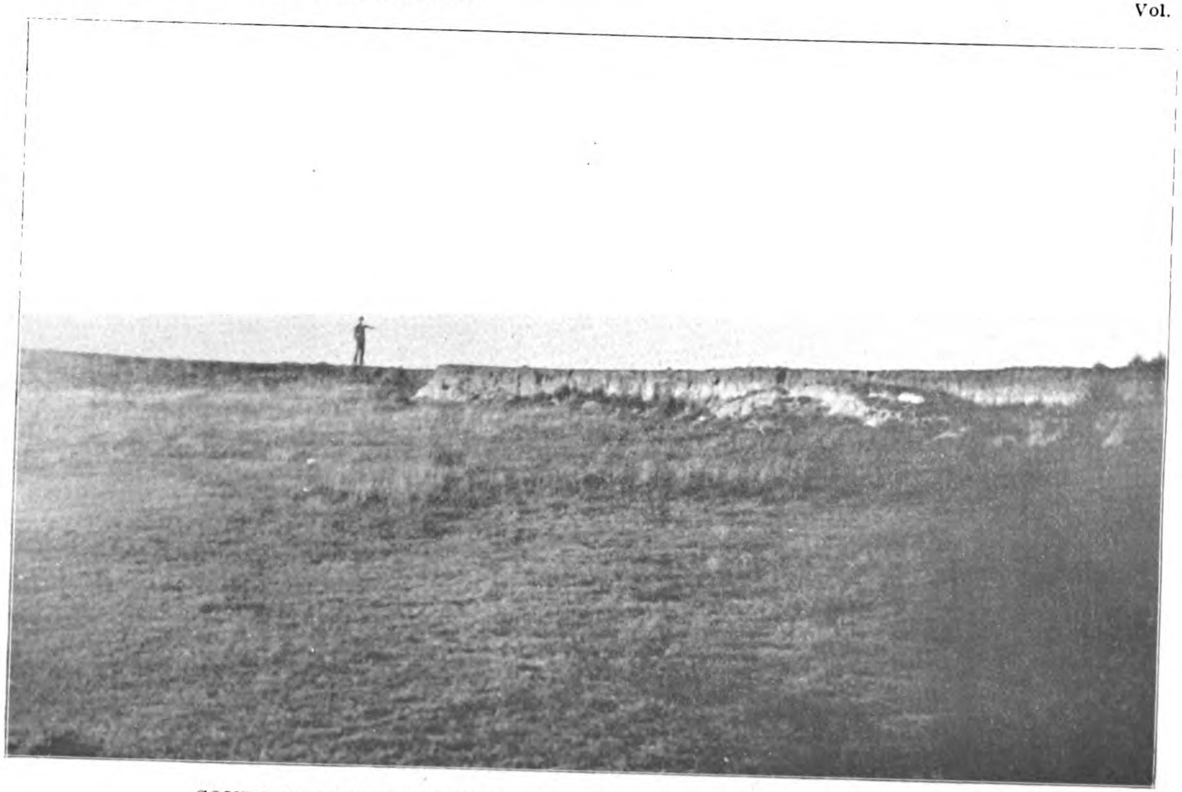

SOURCE OF AN ARROYO IN THE TERTIARY OF MEADE COUNTY.
(Photographed by Haworth, 1896.)

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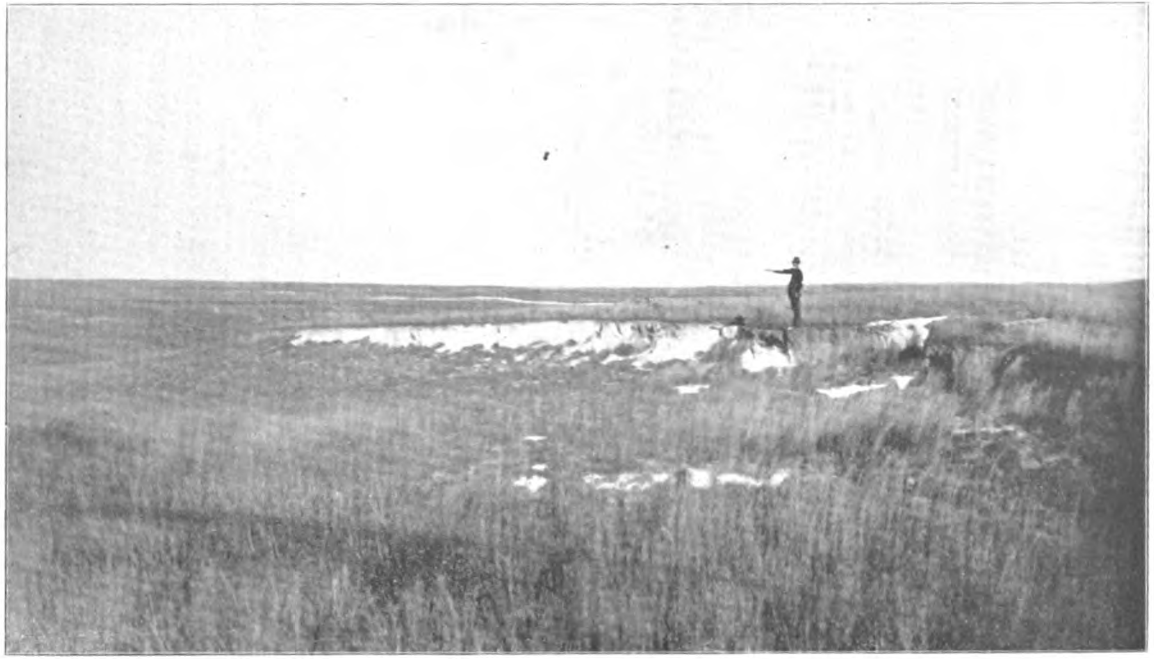

SIDE WALL OF AN ARROYO IN THE TERTIARY OF MEADE COUNTY.
(Photographed by Haworth, 1896.)

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have a correspondingly high velocity. Scarcely a creek can be found in this part of the state as much as five miles long, which rises in the main uplands of the Tertiary plains, that has not produced a channel from a quarter to a half mile in width in the lower part of its course, with the greater part of the channel floor entirely covered by these residual sands, sometimes to a depth of 10 or 20 feet. The evidence regarding the origin of the sands in such a case is so apparent that little doubt can be entertained regarding it. On the higher uplands away from the drainage channels sand dune areas often are found miles in extent, the accumulation of the sands of which probably being of this same nature. Likewise gravel beds are frequently produced in the valleys of the arroyos and larger streams—beds composed of the residual materials left behind after the clays and finer sands have been carried away by the water of the streams. In many such cases it is easily seen that the gravels have been moved but a short distance from their previous home in the Tertiary formations.

Streams cutting their channels into the Niobrara and Benton limestones and shales leave but little residual materials in their course. The character of the limestones and shales is such that the erosive processes consume almost everything that is worn loose. Occasionally limestone boulders of various sizes are produced which are left behind along the valleys of the streams, but they are by no means common.

Eastward in the Dakota areas we have a condition similar to that in the Tertiary. The weathering action of the atmosphere and the abrasive action of running water have produced a large amount of loose Dakota sands, which are blown here and there over the valleys and flood plains of the different streams. In places on the high uplands where it appears the Dakota sandstone previously existed, it seems that it is largely crumbled to a loose sand which is scattered over the general surface, and blown by the winds into sand dunes and sandhills similar to those in the far west.

Methods of Erosion.

Some of the present peculiar features of the erosive channels in the western part of the state are undoubtedly quite recent in origin.

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The climatic conditions are such that precipitation is greatly limited, and the ground is usually so thoroughly desiccated that but little moisture is found near the surface. The general shape, or appearance, of the immediate source of the various arroyos are in many respects different from any heretofore observed in other parts of the state. However, they are most nearly approached in the eastern part by the little ravines the immediate source of which is on a hillside where a relatively thin mass of limestone protects a heavy bed of shale. Under such conditions, even in a humid climate, the peculiar shape of the arroyos is similar to the commonly occurring forms in the western part of the state.

The main peculiarities referred to consist in the great width of the channel at its immediate source, and in the unusual abruptness of its banks. It is by no means rare to find an arroyo carrying a width of a hundred feet or more to its immediate source, so that the very uppermost part of it will simply be the upper somewhat rounded end of a plat a hundred feet wide. The banks on either side of such arroyos frequently are so abrupt that one can with difficulty ride across them. Plate I is made from a photograph representing the peculiar shape of such a bluff-line along an arroyo in Meade county, while plate II likewise represents the side of an arroyo in Meade county. This peculiar shape prevails everywhere in the west, not a single instance having been found of the ordinary V-shaped ravine so common in humid climates where soft materials are eroded.

The upper tributaries of the drainage channels in the west rarely have water in them more than a few weeks in the year. Therefore they evidently have not been eroded by the ordinary corrasive action of running water. This is further indicated by the fact that in nearly all cases the mat of grass covers the entire floor of the arroyo, the same as it does on the plains above. Such a covering of grass could not exist did erosion occur in the bottom of the arroyos at the present time.

The question may then well be asked: How were such channels formed? It has appeared to the writer that probably we have here an origin of drainage channels differing from that ordinarily produced elsewhere. It is certain that large quantities of material

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have been removed and carried downward by some process, so that ultimately they were carried away by the waters down stream where the currents are of some consequence. The vertical walls of the arroyos already alluded to seem to stand as indicators of the process nature has employed. May it not be that the principal part of erosion in the uppermost part of the arroyos has been accomplished largely by a slow creeping of the underground clays and soils immediately under the sod covered surface of the arroyo itself? During the rainy season the subsurface materials are saturated to a higher degree than on the main uplands. The inclination of the surface in such places is relatively great, frequently as much as thirty or forty feet to the mile. The sod of the buffalo grass on the surface is not broken through by what little water may flow during the rainy season, and consequently it will hold itself together and will not pass downward with any appreciable velocity. But immediately under the roots of the grass where the soil and the clay are kept moist during a considerable part of the year conditions are favorable for a rapid creeping of the materials in this particular part of the arroyo. Such a creeping would allow the mantle of sod gradually to settle downward, a settling extending itself finally to the outermost limits of the arroyo. The result would be that this blanket of sod would have an almost vertical movement and the steep and precipitous walls of the arroyo, frequently measuring from 3 to 6 or more feet in hight, would be a natural result.

If this explanation is correct, it is readily understood why the various arroyos should uniformly have so great a width at their source. The creeping process could be extended over the width of a hundred feet as readily as over five, and therefore the abruptness of the walls which is noted on the sides would also be produced at the immediate source, exactly as is shown in the plates already referred to.

Another feature of the Tertiary plains in the west which has attracted considerable attention is the frequent sinkholes, or swales, or lagoons, sometimes filled with water. The various topographic sheets issued by the United States Geological Survey have the greater number of these pools marked in blue lines, implying that

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they contain water intermittantly. It has now been five years or more since any of them have held water for any continuous time. During July and August of 1895 they were nearly filled from the north side of the state to the south. But the water soon sank away, or was evaporated, so that they were entirely dry for perhaps eleven months out of the year.

In some parts of the state there seems to be no relation between these swales of various size and shape and the drainage channels. In other places there is an undoubted relation. Frequently an arroyo has been found heading toward a row of such swales. When we come to ask the question regarding the source of the swales we find it hard to answer. Different views have been expressed by different individuals. The one which the writer deems most probable is that they are located in places where the Tertiary materials were not quite as solid and firm as elsewhere, consequently, by the natural settling process, a difference in the surface was produced. As soon as such a depression was formed the rain waters from the higher grounds around would drain into it, and consequently a greater movement of water immediately under it would take place. This accumulation of water would dissolve and carry away by downward percolation a greater amount of matter than would be dissolved elsewhere. It is reasonable to suppose that in the deposition of the Tertiary sands and clays a somewhat heterogeneous character would be produced and that here and there would be streaks where the material would not be quite so firm as the average, and would consequently settle more irregularly. In this way would be formed a string of little swales which would become deeper and more pronounced as the solvent action was continued. An arroyo is only one step further. The continuous dissolving of the material under the swales would draw them nearer together and ultimately the barriers between them would be broken down and the arroya would result.

Such a relation between the swales and arroyos is frequently noticeable in southwestern Meade county, perhaps more so than anywhere else in the state. It is frequently noticed that immediately above one of the upper branches of an arroyo a chain of swales is found reaching backward for a distance varying from a

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hundred yards to as much as half a mile. In such a case the relation is so apparent that it can not be doubted. The character of the walls of these swales is similar to that of the arroyos already described. A pond no more than thirty feet in diameter, with a buffalo-grass sod covering the whole of its bottom, frequently has a vertical wall from 6 to 12 or 18 inches high. At other times the wall is more rounded, but such a vertical condition is sufficient to recall the similarity between their character and that of the arroyos. If the explanation of the origin of the vertical arroyo walls is correct, this would be additional evidence in favor of the solvent action of the water in the swales being one of the causes in their production. The buffalo grass would be held in place on the surface of the bottom of the swale and of the arroyo, and as the material was dissolved from below the whole of the sod mantle would settle downward in a manner similar to the mantle of buffalo grass in the arroyos.

The swales are most abundant on the high uplands where the Tertiary materials are the heaviest. Usually there seems to be no relation between their respective positions, but not always so.

INDIVIDUAL STREAMS.

We will now give a short discussion of the individual streams of western Kansas:

The Cimarron River.

The Cimarron river rises near Raton, N. M., and flows eastward through southern Colorado and the southwest part of Kansas, ultimately emptying into the Arkansas river. In Kansas it has water in it throughout the greater part of the year in most of its course. It usually has a rise during the summer season at about the same time the Arkansas rises from melting snows. A considerable portion of the water in the river during the dry parts of the year is obtained from seeps and springs fed by the general underground water of the Tertiary areas.

The valley of the Cimarron where it enters Kansas on the west is not very pretentious. The bluffs on either side of the stream are rounded rather than abrupt, and rise to a hight of from 100 to 150 feet. The valley itself will average perhaps no more than a

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mile in width throughout Morton, Stevens, and Grant counties. Farther east it widens somewhat, so that in southwestern Meade county it is nearly two miles wide. The general character of the bluffs likewise changes, becoming more abrupt. This is probably due to the greater hardening of the "mortar beds" near the surface throughout the greater part of Seward county. At Arkalon and a few miles above and below the bluffs are exceptionally abrupt and the valley is entirely cut down into the broad, flat Tertiary plains. The "mortar bed" rocks are prominent along the bluffs near the summit, producing a very picturesque appearance. Perhaps no river valley in the state, or in the world, as for that matter, is more nearly a channel cut downwards with almost vertical walls into a broad flat plain. The "mortar beds" near the surface serve as a protection which prevents the bluff-lines from assuming the customary rounded form of erosion.

The Little Cimarron river is a tributary to the Cimarron river, rising a short distance across the state line in Colorado. Throughout Morton and Grant counties its course is almost parallel with that of the Cimarron river. It rarely has water in it during any considerable portion of the year, and is entirely unaffected by melting snows in the mountainous regions. It has a wider valley than the Cimarron does throughout the part of its course where the two are parallel. In Grant county its valley will average about two miles wide, while in Morton county it is but little less. The bluff lines along this tributary correspond very well with the bluff lines along the Cimarron in Morton and Grant counties, but possess none of the abruptness so prominent along the Cimarron river in Seward and Meade counties.

Bear Creek.

The general characteristics of this little stream have already been given. Its peculiarities consist in the deep channel it possesses in the western part of its course, and the absence of any channel whatever in the northern part of Grant county. It is an excellent example of the short streams so common in western Kansas which have a well defined channel and valley through their upper course but which reach eastward to a plain of less inclination through which they have no channel whatever.

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During times of heavy rains in eastern Colorado and western Kansas Bear creek carries a large volume of water, which it pours out upon the high plains of northern Grant county, and into the sandhills along the south side of the Arkansas river. In order to give the reader a fair idea of the character of this little stream during such freshets, and of its disposition of the water it carries, quotation will be made from a letter received from Judge W. E. Hutchinson, descriptive of the time of high water in July 1895.[1]

"During the night of the 19th of July 1895 the water raised in "Bear creek about the line between Grant and Stanton counties "and proceeded slowly towards the end of the channel in the edge "of the sandhills near the Arkansas river south of Hartland. The "amount of water was such as could be retained within the channel "of the stream and not more than has often been seen in the chan-"nel of this creek once every two or three years. By the morning "of the 21st of July the water had almost subsided, but it was re-"inforced by the heavy rains in Colorado, and commenced to rise "again on the 21st of July and continued to run until the 25th of "July. From the places where it broke out from the channel, most "particularly which were near the Grant and Stanton county line, "the water flowed in northeasterly and southeasterly directions out "upon the highlands. The average depth in the bed of the stream "was about 6 or 7 feet; that on the highlands would average "about 12 inches. It spread out on each side of the stream one "and one half to three miles, carrying with it drift of all kinds that "passed down the channel, particularly grass, weeds, sage brush, etc. "It seemed to run over the highlands as if in a newly made channel. "The overflow in a southeasterly direction near Shockeyville, Grant "county, continued as in a channel in which the current was very "apparent for eight or ten miles, spreading out on either side of the "well defined and recognized center, or channel. The velocity in "these channels out on the highlands was nearly equal to that in the "main channel for a distance,—it was at least on an average from "a mile and a half to two miles an hour; the velocity of the water in "the main channel was probably three miles an hour. Bear creek

1 This letter was written for a preliminary Report to the State Board of Irrigation, and will appear in their final Report.

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"has a well defined channel from the state line to the sunk well at the "south side of the sandhills, seven miles south of Hartland. This "well, which is simply a depression in the sandhills, and in coarse "sand, was never known to have been dry until about two years "ago. The level of the water, however, in this depression is usually "about 6 feet below the bottom of the channel at that place. "From the sunk well on through the sandhills is a winding channel "which one would scarcely think was intended for a channel of a "stream until he should see water coursing through it, as we did this "summer. The water ran past the sunk well, the usual terminus of "the stream in times of ordinary floods, clear through the sandhills "to the last ridge of them next to the Arkansas river, through which "ridge there seems to be no opening whatever for its escape. It "spread out east and west in irregular shapes, as it could find "openings between the ridges of the hills, for probably a mile and a "half or two miles wide, and it is safe to say was in some places "15 to 20 feet deep, as is now made very apparent by the "marks washed out and the drifts left on the sides of the hills. Not "a drop of the water escaped into the Arkansas, and after the 25th "of July when the flow down the channel ceased, the water stood "and remained in the channel and elsewhere in the sandhills, the "same as it did in the basins and lagoons on the uplands. It was not "long, however, in drying up in the main channel of the stream. "Out on the uplands, especially in basins, the water stood for several "weeks. In the sandhills there is water standing now (Dec. 27th "1895) in some places. Eleven years ago there was a similar over-"flow of Bear creek which spread over the uplands, we are told by "the cattlemen who were then in the country, and ran past the sunk "well into and nearly through the sandhills as at this time."

The Arkansas River.

This stream rises in the mountainous areas of Colorado, flows eastward through a portion of Kansas, and finally reaches the Mississippi. It crosses the western line of Kansas at Coolidge near the middle of the Hamilton county line, or about seventy two or seventy three miles north of the south line of the state. Here it flows east southeast to Hartland, thirty five miles within the state, at which place it bends considerably to the north to the east

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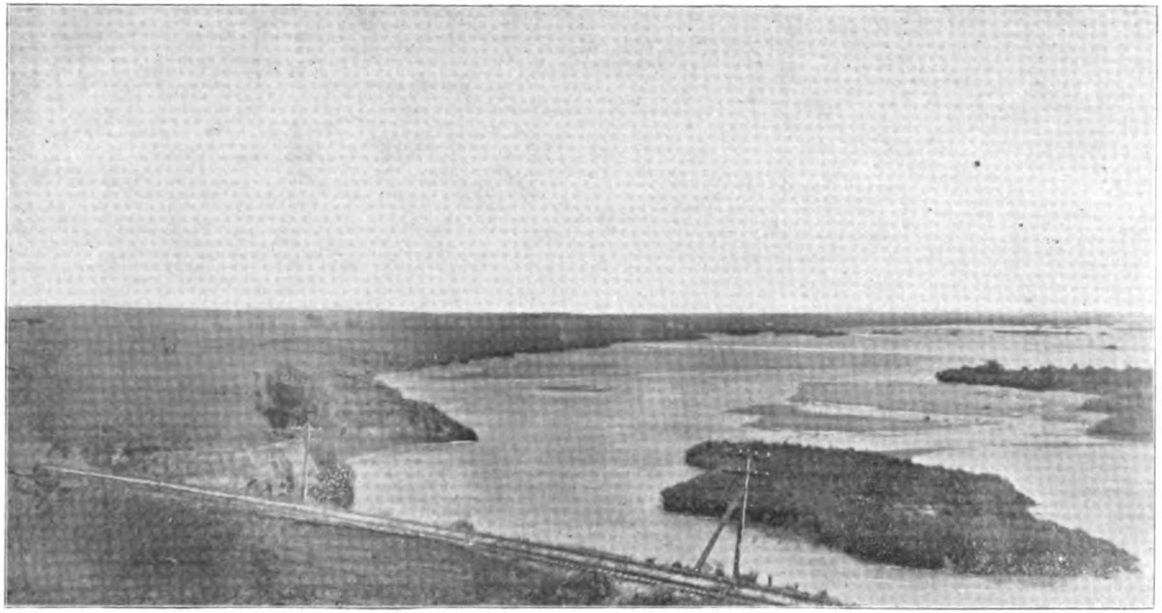

ALONG THE ARKANSAS RIVER, NEAR DODGE CITY.
(Photographed by Haworth, 1896.)

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TERTIARY "MORTAR-BEDS" BLUFF NEAR DODGE CITY.
(Photographed by Haworth, 1895.)

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line of Kearney county, twenty miles away. From here it travels east southeast about eighty miles to near the eastern line of Ford county. At this point it is within forty five miles of the south line of the state. Here it bends decidedly to the north and travels in a northeasterly course to Great Bend, about forty miles east and forty miles north. Making a bold curve at Great Bend it bears to the southeast and finally more to the south, passing out of the state at Arkansas City about one hundred and twenty five miles west of the southeast corner of the state.

Throughout its course from Coolidge to the eastern side of Ford county the river has a valley or flood plain which will average about three miles in width. See plate III. The valley is limited on the north by a tolerably abrupt bluff line, which is very pronounced throughout this whole distance, excepting for a few miles in the vicinity of Garden City. From Coolidge to near Hartland the north bluff is composed of Benton limestones and shales. Below Hartland it is composed of Tertiary materials. The "mortar beds" are so pronounced throughout the greater part of this distance that they offer a strong resistance to erosion, and result in the production of unusually abrupt bluffs. See plate IV. Frequently the "mortar beds" are most prominent near the top of the bluffs, but it is not unusual to find them well cemented throughout almost the entire hight of the bluff. In such cases they do not constitute the whole of the bluff, but two or three or four strata of coarse sand or gravel exist with clay partings between varying from 5 to 20 feet in thickness. The coarse sand and gravel is almost invariably cemented by calcium carbonate so that a tolerably firm rock mass is produced which resists decay and helps to produce the abrupt character of the bluffs.

In the vicinity of Garden City there seems to be an old drainage channel entering from the north, a channel which is popularly believed to connect with the White Woman area in the vicinity of Scott City. As this part of the country north of the Dodge sheet area has not yet been covered by the U. S. G. S. topographic survey we are in doubt regarding the exact conditions of elevation. It can be seen, however, by riding across the country that there is at least an approach to an old valley, and in certain parts of the distance it

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looks as though little doubt could be entertained regarding the former existence of an old channel from the north into the Arkansas near Garden City.

From the eastern part of Ford county to the vicinity of Larned but few if any bluff lines are noticeable on the north side of the river. Here the Dakota sandstone caps a hill of sufficient prominence to be noticed in the landscape which has received the name of Pawnee Rock, in commemoration of an important historical event in connection with the Pawnee Indians said to have occurred at this place. From Larned to beyond Great Bend the Dakota sandstone and the Benton which overlies the Dakota form considerable bluffs some distance back from the river. As the river bears to the east and finally to the southeast near Great Bend, the width of the valley between the river and the Cretaceous bluffs greatly increases. For some distance below Great Bend to the vicinity of Wichita, and in fact throughout the remainder of the state, there is but little demarcation of the river valley or flood plain, the whole area being one great expanse of level country on both sides of the river, scarcely relieved by any upland areas of noticeable prominence.

On the south side of the river from Coolidge to Great Bend the conditions in the main are quite different from those on the north. A row of sandhills limits the river valley on this side throughout the entire distance. The actual elevation of the sandhills and the plains beyond is as great upon the average as the high uplands to the north of the river. In fact, the sandhills themselves are usually a little higher than the plains to the south of them, as though in some way they had been elevated above the surrounding country. The width of the sandhills is variable, in some places being no more than three or four miles, while elsewhere they stretch away to the south fifteen or twenty miles. Such an unusual southern extension occurs in the southern part of Finney and the northwestern part of Haskell counties where the sandhills reach almost to the Cimarron river. Again in the eastern part of Haskell county another long southern extension may be noticed, which extends from ten to twelve miles south of the river. Beyond the eastern limit of Ford county the sandhills become less prominent, but are very noticeable all the way from near Bucklin to almost opposite Great Bend,

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where they gradually disappear, or become less pronounced in elevation above the surrounding country. From Great Bend to Wichita, and from Wichita to Arkansas City, the whole area on the right bank of the river is covered with an exceedingly sandy silt which here and there is blown into a series of sand dunes somewhat approaching in character the sandhills further to the west, but no where equaling them in magnitude.

The Arkansas river valley has been much deeper at one time than it is at the present. The filling in process has been in operation for a sufficient length of time to fill the channel of the stream to a level with its flood plain, and doubtless raised the general level of the flood plain very appreciably. So few wells have been sunk in the valley entirely through the river sands that we are almost entirely uninformed regarding the character of this earlier river channel. At Coolidge the artesian wells which have been drilled showed that the river valley was probably less than 50 feet in depth. Great effort was made to obtain an accurate record of one of the wells, but no such record could be found. It is currently reported by the citizens of Coolidge that the stratified material is generally found in the valley at that place at a depth not exceeding 35 to 50 feet. Eastward from Coolidge and Syracuse no information is obtainable on the subject until Garden City is reached. At this place in the summer of 1888 a deep well was bored nearly half a mile northwest of town to a depth of 1000 feet or more. No resident of the place could be found who had kept an accurate log of the well. By an examination of the old files of the "Garden City Sentinel," however, it was learned that that paper published on April 18, 1888, a log of the well to a depth of 550 feet, as follows:

Soil	12	feet.
Quicksand	299	"
Black slate	150	"
Sandstone	5	"
White slate	10	"
Black sand	5	"
Soapstone	69	"
	550	feet.

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From this it would appear that the river sands were reached at the surprising depth of 311 feet. It is difficult to understand how such a great depth could exist here with so shallow a covering of sand in the valley at Coolidge less than seventy five miles above.

Below Garden City no further evidence is available until Great Bend is reached. Some years ago a deep well was put down three or four miles to the northeast of town, but still within the river valley, in search for fuel. No absolutely accurate log of this well was kept, but it is tolerably certain the river sands at this place are no more than 80 or 90 feet thick. As the well was located some distance back from the present river channel it is quite possible they were shallower there than in the deepest part of the river valley. From Great Bend eastward nothing more is obtainable until the salt wells of Sterling, Nickerson, and Hutchinson are reached. The logs of various wells in these localities have been examined, not one of which showed a thickness of sand more than 100 feet, and the greater portion of them showed the sand to be from 70 to 90 feet in thickness. At the present time a deep well is in process of construction at Wichita. Samples of material from it have been preserved in glass bottles and are open for examination. They have been partially studied and seem to show that the stratified material was reached at the depth of about 150 feet.

Taking all these facts into consideration, it makes it seem exceedingly doubtful about the river channel ever having been as much as 300 feet deeper than it is now in the vicinity of Garden City, although one cannot positively dispute this record. We have ample evidence, however, for stating that the river valley at one time was from 50 to 100 feet deeper than it now is, and that at the present time a filling-in process is in operation.

Within the last fifteen years a very noticeable filling in of the river channel has occurred. The various bridges which are built across the river at different places when constructed from eight to twelve years ago were usually built high enough so that a man on horseback could easily ride under them while sitting erect. At every bridge along the river the sands have accumulated until the most of them are not more than from 3 to 6 feet above the top of

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the sands. Such an accumulation of sand is in no way due to the presence of the bridge, as the sand level under the bridge is the same as that both above and below.

Throughout the greater part of its course in western Kansas it seems that the recent filling in process has been principally on the south side. A typical illustration may be taken from the river at Ingalls. The bridge there was built in 1886, twelve hundred feet long. At that time the main current of the stream was just to the south of the present (1896) south end of the bridge. Southernly winds and the river currents during times of overflow have filled in the bottom to the south of the bridge so that the bottom land has been carried far to the north. Several hundred feet of the south end of the bridge have been taken up, and the area occupied by the main river channel in 1886 is now a cultivated field.

The river valley throughout its entire course has marks of many old channels in it similar to the conditions so frequently noticeable elsewhere after a river has reached its base level. The stream has shifted from bluff to bluff along its channel many times, during which time it has been gradually building its flood plain higher.

Throughout a portion of its course the Arkansas river seems to flow on the summit of a ridge. The general elevation of the country at Coolidge is perhaps a little lower than the surface either north or south. In the absence of topographic surveys, however, one is liable to err in his estimates. The elevation of no point south of Coolidge has yet been determined, while to the north we must go to the Missouri Pacific railway in Greeley county twenty five miles away. The elevation of Horace, a point fifteen miles farther east than Coolidge, is 3643 feet, while that of Coolidge is only 3341 feet, making Coolidge, or the Arkansas river valley, about 300 feet below these uplands. The bluffs at Coolidge are no more than 100 feet high, and probably less, making the general elevation of the uplands at Horace nearly 200 feet above those just north of the river. At Garden City the elevation in the river valley is 2827 feet, while thirty five miles to the north Scott City is 2771 feet above sea level, showing the decline of the surface eastward along the Missouri Pacific railway is more rapid than that along the Arkansas. The old river valley at Garden City is therefore higher than the main uplands

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at Scott City. As we move east this difference is still more noticeable. The elevation of the river valley at Dodge City is about 2440 feet, while the high bluffs to the north are 2600 feet high. Immediately north, at Ness City, the elevation is only a little more than 2200 feet, making the river valley at Dodge City more than 200 feet above the Walnut valley at Ness City, fifty miles to the north. The elevation of the Buckner a little west of Jetmore is about 2300, showing the decline from Dodge to Ness is gradual. It would therefore seem that the Arkansas river from Garden City to Dodge at least is occupying much higher ground than that which lies to the north. South of the river, however, the general elevation is about the same, or a little greater, than the river until the central part of Haskell and the southern part of Gray and Ford counties is reached, from which line the surface drops rapidly towards the southeast. Below Dodge City there is not so much difference in elevation between the river and the adjacent country.

These conditions can be tolerably well determined by an examination of the ordinary map of the state. It will be seen that from Coolidge to near Garden City the general drainage of the country is towards the Arkansas river from both sides, although but few of these lesser tributaries actually enter the river, as the most of them simply spread out in the broad valleys. Below Garden City almost no drainage from the south enters the river, while from the north the upper tributaries of the Sawlog and the Buckner rise within a few miles of the bluffs of the Arkansas. By an examination of the country itself one will be surprised to find that many of these lesser arroyas have their source within less than a mile of the brink of the bluffs on the north side of the river from Dodge City towards Garden City. Below the bend in eastern Ford county the drainage again becomes more natural, and the Arkansas has tributaries entering it from both sides, showing that it no longer flows along a ridge.

One of the most noticeable features in connection with the Arkansas river is the great and unusual bend it makes in passing from eastern Ford county so far to the north to Great Bend, and back so far to the south. By an examination of the geologic map it will be seen that in eastern Ford county the Dakota is exposed at the

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surface, and that a strip of it extends eastward from this place continuously to below Great Bend. The country to the south of Great Bend in Edwards, Pratt, Stafford and Reno counties is covered with a sandy accumulation strongly resembling the general river sands. It would seem that when the river reached the Dakota formation, a formation so easily corraded, it immediately began acting upon it with great vigor. As the general inclination of the strata of the Dakota is to the northeast it follows that a given geologic horizon is considerably higher in eastern Ford county than the same one in southern Barton county at or near Great Bend. The evidence is so striking that it would seem the cause of the river's great bend to the north is the existence of the easily corraded Dakota sandstone. We may therefore believe that at an earlier period in the history of the river it passed eastward from Ford county across the north of Kiowa, Pratt and Kingman counties, probably passing out of the state not far from its present location.

If this explanation is correct, one can not help inquiring why the river did not break through the uplands in the vicinity of McPherson county and ultimately join the Cottonwood river through Marion and Chase counties. To answer this clearly we only have to look at the general geologic character of the southern part of the Permian in Butler and Cowley counties to find an adequate reason. The great Flint-Hills area described in Volume I of these Reports has its surface rising to points considerably higher than the main uplands of Sumner and Sedgwick counties. Evidently these high elevations in the early Tertiary times deflected the river southward and prevented it from crossing the Flint-Hills region when the drainage was first changed to an easterly direction by the elevation of the mountainous area. The same Flint-Hills area has continuously remained higher than the uplands in Sumner, Sedgwick and adjoining counties. Therefore, with the river once flowing out of the state near where it now does it would be impossible for it to pass eastward across the Flint-Hills so long as the elevations remain as they now are. In the course of its corrasion when it finally reached the Dakota sandstone the cutting away of the Dakota material would be a natural consequence, and the great bend in the river would thus be produced.

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Along the western part of its course the stream is held in place by the relatively firm Benton limestones and shales from Coolidge to near Garden City, so that the migration of the stream northward down the gentle inclination of the bedding plains of the Benton is an exceedingly slow process, and therefore not very prominent. Likewise the unusually strong cementation of the "mortar beds" in Finney, Gray, and Ford counties on the north side of the river have served as a check to the northern migration of the stream in this part of the country. What has likewise helped in this matter is a relatively high ridge of the Benton extending westward from Jetmore up the Buckner and the Sawlog, so that we have a ridge of Benton limestone which strongly resists decay, which has probably served to assist in preventing the river from migrating northward in Gray and Ford counties. But when the eastern limit of Ford county is reached no further obstruction was placed to the northward migration of the river. The upper channel being held in place from Coolidge to Dodge City, and the lower channel being held in place in the vicinity of Arkansas City and Winfield, and no restraints being placed upon the river throughout the interval it would follow in the process of its corrasive actions the path of least resistance, and would therefore migrate northward with the gentle inclination of the bedding plains of the Dakota sandstone. This northward migration probably continued until the condition of base level was reached and the filling in processes began, after which the stream was unable to corrade the Dakota bluffs from Larned to beyond Great Bend, and consequently its northward migration has ceased.

Pawnee Creek.

The Pawnee is a small stream draining the country north and northeast of Dodge City, and south of the Walnut. It enters the Arkansas river at Larned. It has an unusually large number of tributaries which cover an area of fifty or sixty townships to the north of Dodge City. Its upper branches rise in the Tertiary, but they soon cut their channels through the Tertiary to the Benton limestones and shales. In this way they drain the Tertiary ground water and are supplied with running water almost the entire year.

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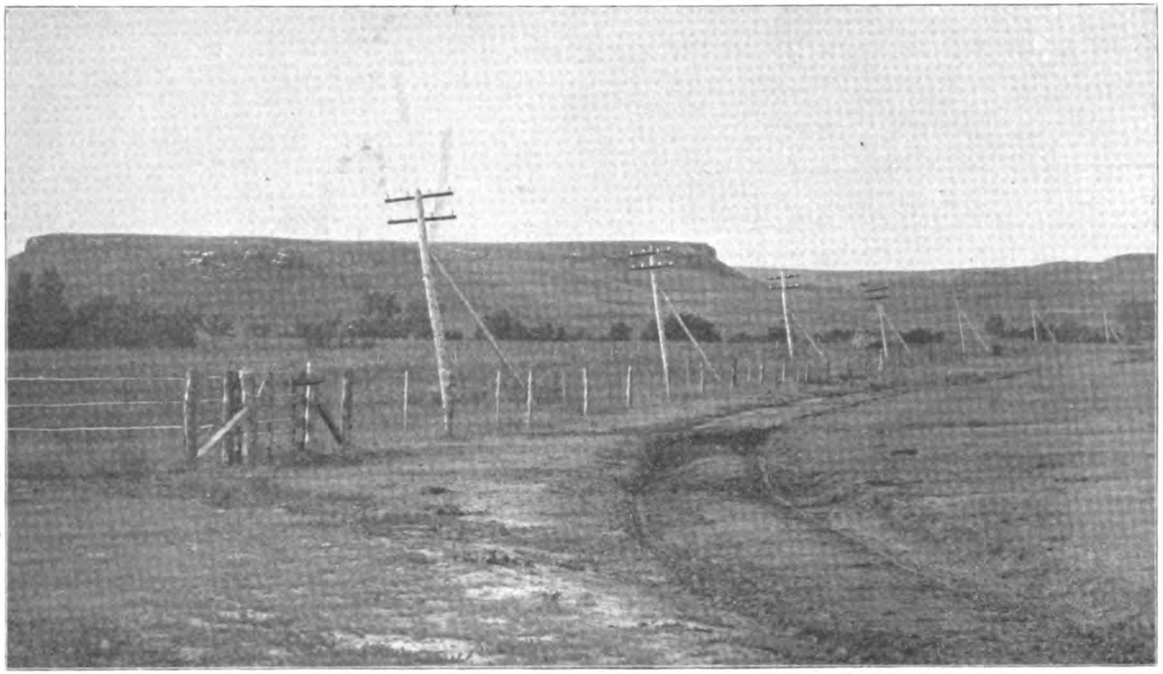

DAKOTA SANDSTONE BLUFFS ALONG UNION PACIFIC RAILROAD, SIX MILES WEST OF BROOKVILLE.
(Photographed by Haworth, 1895.)

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The Pawnee in this respect is much more fortunate than many larger streams.

Another peculiarity of this stream is that its uppermost tributaries on the south drain the country to within a mile or two of the Arkansas river, as already explained when discussing the Arkansas. The larger tributaries, the Sawlog, the Buckner, and Pawnee fork itself, have worn channels from 50 to 100 feet deep, and in most places have valleys which are from half a mile to a mile in width. The Buckner is particularly noted throughout the upper portion of its course above Jetmore. It has very abrupt bluffs on either side, capped with unusually firm "mortar beds" material of the Tertiary formation. In this respect it simulates in general appearance the larger streams.

Farther east, beyond the junction of the Pawnee fork and the Buckner in Pawnee county, the bluffs are less abrupt and the valleys less distinct from the uplands. In this respect it corresponds to the valley of the Arkansas as already described. The country occupied by Pawnee and Edwards counties is a broad, almost level sandy plain with only a gentle inclination to the east, while farther west along the headwaters of the Pawnee the inclination is sufficient to cause decided erosion.

The White Woman.

The White Woman is a stream which rises in Colorado twenty miles or more beyond the state line and flows eastward to Scott City, at which place it entirely disappears, not emptying into any other stream. Throughout its course in Greeley county and the western part of Wichita county it has a decided channel, often with bluffs from 40 to 75 feet high, and a valley from a quarter of a mile to nearly a mile in width. The general inclination of the surface of the country towards the east is fully ten feet to the mile, and probably more. As Scott county is approached, however, the inclination of the surface declines until the vicinity of Scott City is reached, at which place it is almost entirely level. There seems to be a ridge, a sort of underground Cretaceous swell, to the east of Scott City, which has probably affected the action of this stream. At any rate its bluffs and banks disappear, and it empties its

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water in times of flood into a broad flat area called the Basin. This basin in reality in dry times seems to be only a broad flat part of the country with no special boundaries that one would notice, excepting when it is covered with water.

There are a few smaller streams lying between the White Woman and the Arkansas, most of which are locally known as Sand creek. They occupy the uplands in the north of Kearney and Hamilton counties, one of which rises across in Greeley county. They are similar to the White Woman in that they have no connection with other streams, but simply pour their water in times of flood out upon the broad plains of northern Finney and northeastern Kearney counties.

Walnut Creek.

Walnut creek is a stream rising in Lane county near Dighton and flowing east through Ness and Rush counties and entering the Arkansas river three or four miles below Great Bend. It drains a strip of country about twenty five miles wide through nearly all this distance. It rises in the Tertiary area of Lane county, but soon reaches the Niobrara chalk beds in Ness county, into which it and its tributaries cut deep channels. Farther down in Rush county it passes over the Benton, and finally reaches the Dakota in Barton.

One of the most remarkable features of the Walnut is its surprisingly wide valley. Throughout all its course from the eastern part of Ness county it has a valley that will average nearly as wide as that of the Arkansas. The bluff lines on either side are exceedingly varied, depending upon the character of the material into which the valley is cut. Eastward in the Dakota area the bluff lines are rounded and relatively mild. In fact, the valleys of the Walnut and Arkansas coalesce several miles above Great Bend, so that throughout at least ten or more miles of its course the Walnut has no bluff lines, but simply follows its little channel through the general valley to its confluence with the larger stream. In Rush county and eastern Ness county where the Benton material is exposed along the bluffs the valley is limited by the relatively high and abrupt bluffs. Frequently they will reach the hight of from 75 to 100 feet in the western part of Ness county and the eastern

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part of Lane county. Where the various tributaries of the Walnut have cut their channels in the Niobrara chalk the valleys are narrower and the bluff lines very abrupt, often almost precipitous, producing thereby a picturesqueness scarcely surpassed by any one of the streams in western Kansas.

Smoky Hill River.

The Smoky Hill river is one of the principal tributaries producing the Kansas river. By its junction with the Republican at Junction City the Kansas is formed.

The Smoky Hill rises in Colorado only a short distance beyond the western Kansas line. From the west side of the state to as far east as Salina it has a great many lesser tributaries, none of which are of particular importance. At Salina the Saline river enters from the north, and at Solomon the Solomon river likewise enters from the north. Each of these will be considered separately. Through the western part of the course of the Smoky Hill its lesser tributaries rise in the Tertiary formation. The larger ones, however, and the main channel itself, have cut through the Tertiary to the Cretaceous, so that the main part of the Smoky Hill flows on a cretaceous floor continuously from the western part of the state to Salina, from which place it rests on a Permian floor throughout the remainder of its course to Junction City.

This series of geologic strata through which it has cut its channel gives a variety of conditions regarding the water content of the stream. Invariably where a stream rises in the Tertiary and has just cut its channel to the Cretaceous floor below, or almost to the Cretaceous floor, it is supplied with seeps and springs so that it carries never failing water. The upper tributaries of the Smoky Hill therefore in most cases have water in them throughout the entire year. They are fed by seeps and sometimes by springs which never fail. Such geographic terms as Russell Springs and Sharon Springs imply the presence of springs of considerable importance. But farther east where the channel is worn a considerable distance into the Cretaceous, a formation which produces no water whatever of any consequence, the evaporative forces of the air and sun's rays generally have evaporated all the water in such streams. We have

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the anomalous condition, therefore, particularly along the Smoky Hill river and its tributaries, of a stream which is well supplied with living water in the upper part of its course having little water in it farther below, they being entirely dry throughout a considerable part of the year, but still farther down being rarely without water. East of Russell county a new condition is met with, the presence of the Dakota sandstone. The tributaries in this area likewise are moderately well supplied with springs and consequently pour considerable water into the Smoky Hill river, so that throughout its lower course it is rarely if ever dry.

The channel of the Smoky is perhaps the deepest of that of any stream in the state. Through a large part of its course in Gove, Trego and Ellis counties the main uplands on either side are from 300 to 400 feet above the valley of the stream itself. The bluff lines are generally not as abrupt as those already described for the Cimarron river in the vicinity of Arkalon, or those for some other streams, but have been somewhat more eroded and have the rounded form so common in old age. The great depth of the channel, however, has caused all the lateral tributaries likewise to cut deep channels, so that the country on either side of the river for from two to four miles back is so hilly that it is difficult to travel in directions parallel with the stream.

Farther west, in places where the main part of the bluffs is composed of Tertiary materials they are correspondingly less rugged and the channel to the west gradually becomes shallower. In Gove and Trego counties and the western part of Ellis county the rocks through which the channel is cut are the Niobrara chalk beds. These have yielded to erosion apparently with great ease, but being relatively uniform throughout the general character of the hills and hillocks produced is different from that commonly observed where hard and soft materials are in alternating strata.

The valley, or flood plain of the Smoky Hill river is not very wide throughout the greater part of its course. But few places west of Ellsworth can be found where the flood plain is more than a mile in width, while in many localities it is narrower. Neither is the river valley extensively filled with fluviatile debris, as has been seen to be the case in the Arkansas river valley. In most places

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over the flood plains of the Smoky one can dig in the river sand only a few feet, rarely over 20, until the solid Cretaceous floor is reached. The river channel itself in many places exposes the Cretaceous. These conditions show that the river has scarcely yet reached its base level. Probably in a considerable part of its course it is still deepening its channel. From the vicinity of Salina eastward, the condition of base level has doubtless been reached for some time. The unusually wide valley at Salina and the relatively wide valley from Salina eastward imply a much longer period for widening the channel than has existed farther to the west.

The particular direction of the river in places is of great interest. Nothing of special importance is noticed in this connection above Ellsworth. But from Ellsworth to Salina the course of the stream is quite remarkable. At Kanopolis a great ox-bow form reaches to the south a distance of three miles, while just east of Kanopolis a similar ox-bow carries the river to the north. Such ox-bow forms are repeated to the eastern side of Ellsworth county. As best one can judge from examining them on the map these forms are in every way similar to the ox-bow forms produced by a stream meandering across its flood plain after it has reached base level.

The cause of such forms has not yet been determined. Possibly they are due to the shape having been assumed in earlier times when the elevation of the western part of the great plains area was so limited that the stream had a sluggish movement and meandered as though it had reached base level. Possibly it is due to the peculiar variation of the hardness of the formations through which the channel is cut, and its consequent variable ability to resist decay.

From the eastern line of Ellsworth county the river bears still further to the south until a point near Lindsborg is reached where, with a bold curve, it passes to the northeast and north by way of Salina. From the Ellsworth county line eastward the valley gradually becomes wider. At Marquette it is about two miles wide, at Lindsborg it is nearly four miles wide, at Bridgeport it is approximately six miles wide, while still further down in the vicinity of Mentor and Salina it is eight or nine miles wide. The peculiarity of direction from Kanopolis to Lindsborg may possibly be due to the extraordinary thickness and hardness of the Dakota sandstone

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immediately east of Kanopolis for a distance of twelve or fifteen miles. The general conditions of the country imply that for some reason the sandstone was less resistant to erosion southward than in the vicinity of Terra Cotta, and that consequently the river worked its way eastward where the resistance was less marked. Reaching the vicinity of Lindsborg we find Dakota sandstone immediately east of the direction of the river. As the whole of the Dakota is swept away from the broad valley between Lindsborg and Salina, it is impossible to conjecture what the character of it was. Possibly here it was less resistant than farther to the east. This explanation is assuming unusual variations in a mass of sandstone covering the country from twenty to thirty miles. Still it is possible. Aside from this possibility at the present time no observations have been made which throw any light on the question of the peculiar direction of the Smoky Hill river between Ellsworth and Salina.

Later in this report is a discussion by Mr. Beede of the old river channel now occupied by the McPherson Equus beds. In that connection will be found a discussion of the probability of the Smoky Hill river formerly having flowed southward from near Lindsborg connecting with the Arkansas rather than to have flowed northward and ultimately become a part of the Kansas river. It is there shown that great obstacles are encountered on such a supposition, but that the true explanation of the existence of the Equus beds has not yet been discovered.

From Salina to Junction City the direction of the Smoky Hill is apparently normal. The valley from Salina to Solomon is from three to four miles wide. Beyond Salina the bluffs are relatively unimportant to below Abilene, from which point they begin to appear on either side of the stream, and are quite prominent downward to Junction City. The probable cause of the absence of pronounced bluff lines from Salina to below Abilene is the particular character of the material into which the channel is cut. Here we have the last remnants of the Permian exposed to the surface at the eastern part of the lowermost portions of the Dakota, a kind of material which is relatively soft and comparatively uniform throughout, so that the conditions are most favorable for the rapid erosion

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and the gradual wearing away of the bluff lines until they are unimportant.

The river from Salina downward has an unusually larger number of bends as it meanders from side to side of the flood plain. The curves are such that in many places typical ox-bow forms are produced, and frequently more angular curves than those are noticeable. As these curves are confined to the flood plain area it is probable they have been produced since the river has reached base level through this part of its course.

The most striking feature in connection with the Smoky Hill is its extraordinary deep channel and the narrowness of its valley. Compared with the Arkansas, the Saline, the Solomon, or the Republican, the narrowness of its valley is most remarkable. By an examination of the U. S. topographic sheets it will be seen that other streams, such as the Saline and the Solomon, which are much smaller, have valleys nearly twice as wide. The extraordinary depth of the channel which, as before stated, is between 300 and 400 feet, implies an elevation of the land throughout the upper part of its course. It is probably true that the high uplands on each side of the Smoky Hill river are as high as any other parts of the state. Aside from the character of this stream there has not yet been observed any indications of such an uplifting. If in the earlier history of the stream it should chance to have been located on the summit of a ridge trending east and west, the general explanation of its somewhat anomalous characters could be explained.

Saline River.

The Saline rises in the southwestern part of Thomas county, or possibly across the line in Sherman county, and flows almost straight east to its junction with the Smoky Hill river near Salina. Its general direction is nearly straight east, its mouth being not more than twenty miles south of its source, while were a straight line drawn from the mouth to the source, the stream would no where miss this line more than ten miles. Its source is in the Tertiary material. For some distance along its uppermost course it is dry almost all the year, as its channel is not deep enough to be within reach of the Tertiary underground water. In Sheridan and Trego

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and part of Ellis county, however, its channel is deep enough to reach the Tertiary waters, and it is constantly supplied with seeps and springs, so that never failing water occurs throughout almost all the remainder of its course.

The valley of the Saline in the western part of the state is narrow, practically amounting to nothing. Eastward in Ellis county the valley widens to a mile or more, while below it gradually widens to from two to four miles.

The bluff lines of the Saline are almost inconspicuous at its immediate source. But a short distance is passed, however, until the channel has reached a depth of from 20 to 40 feet, a depth which gradually increases eastward until the Cretaceous formations are reached in Ellis and Russell counties, where the bluffs frequently are 100 feet or more in hight. Below these localities the bluffs maintain their great hight. In the vicinity of Salina the Dakota hills some distance back from the stream rise nearly 200 feet from the level of the water in the Saline.

There are no features of this stream which are in any way different from the ordinary. It is remarkably straight in its course, has worn a valley through the lower part of its length commensurate with the valleys of other streams in the state, and has a depth of channel about the same as those of other streams in this part of the state.

Solomon River.

This river rises in the northwestern part of the state in Sherman and Thomas counties. From here to Downs in Osborne county there are two forks, the north and the south. These two branches rise within less than ten miles of each other, but separate in Graham and Rooks counties to a distance of about twenty five miles. In the upper part of their course each stream is very like the Saline river, so much so indeed that little can be said of one which is not applicable to the other. As they pass eastward their channels gradually become deeper and their valleys wider. At Stockton in Rooks county the valley of the South fork is about a mile wide, while at Marvin, immediately north, in Phillips county, the North fork has a valley of about the same width. In this area the high upland

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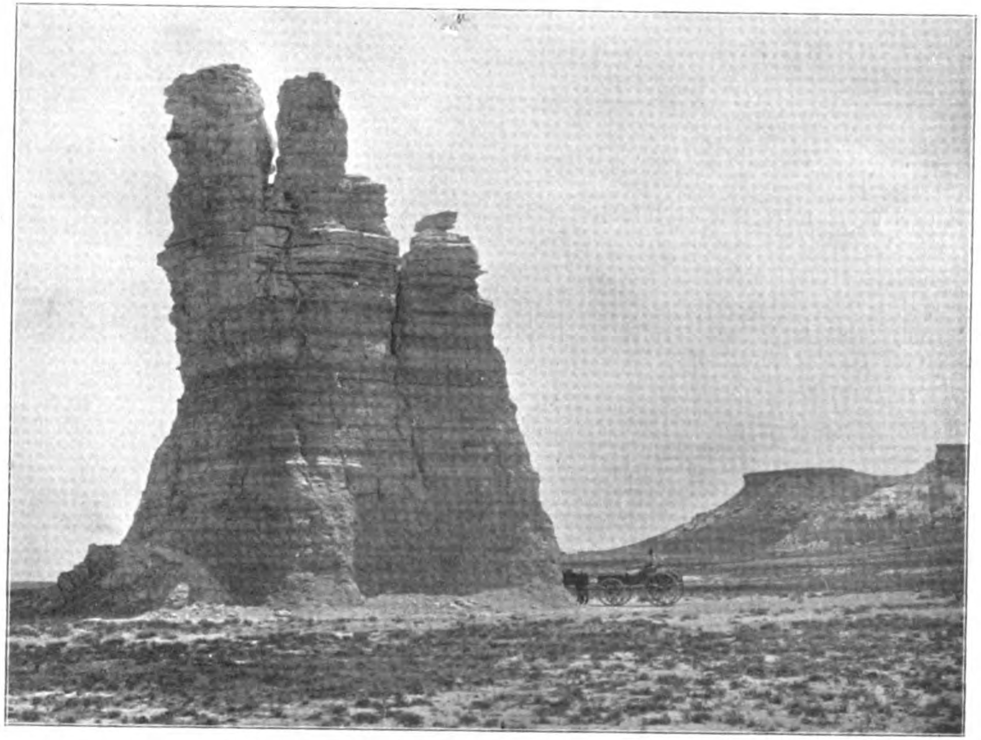

CASTLE ROCK, NIOBRARA CHALK, TREGO COUNTY.
(Photographed by Williston, 1894.)

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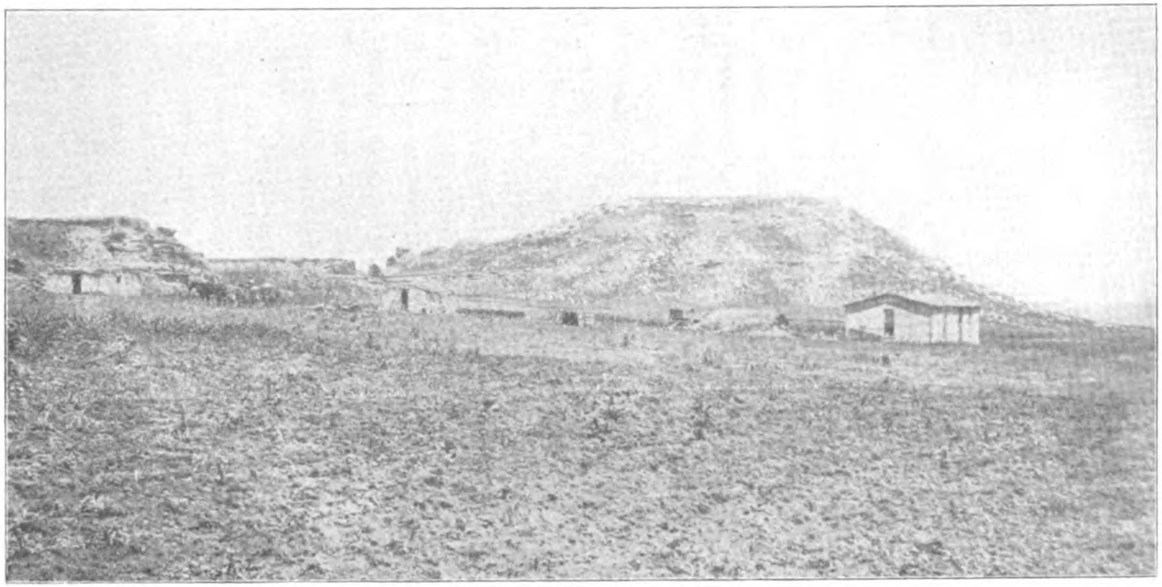

LONE BUTTE, BUTTE CREEK, LOGAN COUNTY.
(Photographed by Williston.)

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between the two streams is nearly 300 feet above the valley of either stream. Farther east the relative hight of the bluffs perhaps decreases a little, while the width of the valley correspondingly increases. From their junction at Downs to the mouth of the Solomon the valley will average more than two miles wide, reaching more than three miles in different places. This stream has nothing remarkable about it, every feature as thus far observed conforming to the general characteristics of the western Kansas streams.

Republican River.

This stream rises in Colorado opposite the northwest corner of Kansas. It flows to the northeast across Cheyenne county, passing into Nebraska on the north, through which state it travels for about two hundred miles. It again passes back into Kansas at the northwest corner of Republic county and flows in a southeasterly direction to its junction with the Smoky Hill at Junction City, about eighty five miles away. We therefore have but little of the stream in Kansas excepting this one space of eighty five miles. The upper tributaries which are formed in Cheyenne county are small and of but little interest. They lie wholly within the Tertiary formations, but have cut channels near to the base of the Tertiary, so that the most of them are supplied with living water. East from Cheyenne county a number of tributaries pass from Kansas to the northeast, entering the Republican. These tributaries are in most respects similar to the upper tributaries of the different streams in western Kansas. The Tertiary formations in the northwestern part of the state seem to be so thin that the different streams have cut their channels almost to the base of the Tertiary, so that they draw upon the underground Tertiary water. In this way the Republican through the greater part of its course is unusually well supplied with water, but few places being known from Cheyenne county to Junction City where water is not available in greater or less quantity throughout the year.

From Republic county to Geary the stream has a wide valley or flood plain with prominent bluffs on either side. The valley will average more than two miles wide through this distance and the bluffs are from 100 to 150 feet in height.

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IN GENERAL.

The different drainage channels of western Kansas have many similarities. If we except the period of Tertiary time during which the Tertiary materials were being carried from the mountainous areas, we are forced to the conclusion that none of the streams of western Kansas show marked indications of variation of level. No stream has been studied which seems to bear evidence of a former condition of base level having been reached and a subsequent elevation to the west, causing it to deepen its channel and form a new flood plain. This fact would imply a condition of stability in this part of the great plains area dating from the close of the Tertiary period.

In addition to the streams already described a number of smaller ones of considerable local interest occur. A few of them have peculiarly shaped valleys of erosion which are different in some respects from any features connected with those described, in that wide, short valleys of the "fry-pan" form are produced. The best developed instance of this kind is in the Blood creek valley near Great Bend, locally known as Cheyenne Bottoms. Mr. Benj. L. Miller, one of the assistants on this survey, has written a tolerably complete description of this valley[1], from which the following quotation is made:

"Even to the ordinary observer, these bottoms are of great in-"terest. They consist of an area of land about six miles in width "and eight in length, and include over thirty thousand acres. Over "this large scope of country there is scarcely to be found an eleva-"tion or depression of more than five or six feet. Even where such "do occur the slopes are so gradual that they are not noticeable to "the eye. While the basin is inclined slightly towards the east, the "inclination is very gentle, as is shown by the fact that on the gov-"ernment topographic survey sheets, with 20-foot contour intervals, "no contour crosses any portion of the basin.

"Surrounding and enclosing this whole area is a line of hills the "slopes of which are quite steep on all sides except the east. In

1 Benj. L. Miller, The Cheyenne Bottoms, a paper read before the Kansas Academy of Sciences, December 1896.

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"this enclosing wall there are but four breaks—three, at the north "and northwest, caused by entering streams, the fourth, at the "southeast, a partial outlet, the elevation of the base of which is "considerably less than that of the adjoining parts of the enclosing "wall, but greater than the general level of the basin. Hence it "does not prevent the flooding of the entire bottoms with water to "the depth of several feet in the rainy season. Nearly every spring "this basin is converted into a large lake by the drainage water of "the surrounding country being poured into it. A poor variety of "salt grass is the main vegetation which grows in the basin, which "furnishes a small amount of pasturage.

"By reference to the map, figure 1, it will be seen, that on all but "the east side the walls are composed of the Dakota formation, with

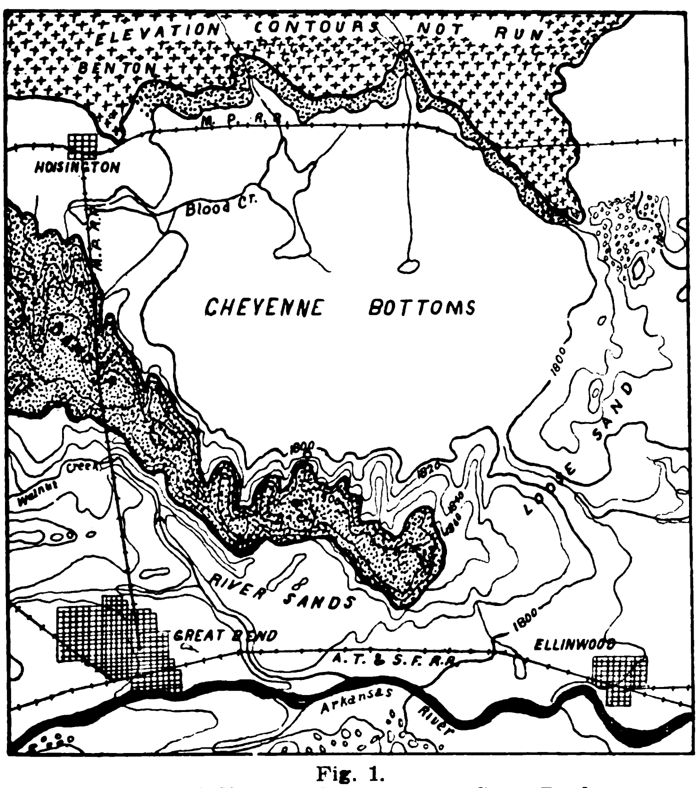

Fig. 1.
A map of Cheyenne Bottoms, near Great Bend.
By Benj. L. Miller.

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"an irregular capping of Benton limestone on the north and west "sides. The east wall seems to be entirely sand. Wells sunk on "this ridge go through continuous sand until they strike the Dakota "sandstone at some distance below the surface level of the basin. "At the northeast corner of the bottoms there are several sandhills "similar in form to those on the south side of the Arkansas river.

"In the region of this basin we find the upper part of the Dakota "formation, consisting of a layer of sandstone underlain by a thick "stratum of soft shales. Owing to the presence of considerable "quantities of salt and gypsum in these shales, Mr. W. N. Logan has "named them Saliferous Shales. He estimated their thickness at "about 30 feet.

"In past time the two streams, Blood creek and Deception "creek, which are the only streams of importance entering the "basin, probably flowed about as they do now. We suppose at one "time their channels were cut into the Benton and the Dakota sand- "stone. These materials resisting erosion quite well necessarily "made the deepening of their channels and the widening of their "valleys slow processes. But finally, having cut through these "harder strata to the softer stratum of saliferous shales beneath, "the processes of erosion were greatly increased, and it was there- "fore a comparatively short time until the streams had cut their "channels entirely through this stratum of shales to the harder layer "of sandstone beneath. They now began to widen their valleys, or "their valley; for the two streams probably united in one when this "shale was first encountered. This widening was likewise rapid, "so that a wide valley was soon formed. Had the sandstone over- "lying this shale bed been very hard we should doubtless have had "falls produced of about 30 feet in hight, which would have slowly "retreated up stream. There are good reasons for believing that "the point where the stream first encountered the shale bed was "considerably farther east than the present limits of the basin. "Evidence of this is furnished by the fact that river sands cover "the surface for some distance in this direction. Thus the valley has "been extending up stream as well as widening on either side. The "upper courses of the two streams mentioned have not even yet

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"reached the soft, saliferous shales, and consequently have narrow "valleys.

"But while this was going on, the Arkansas river was slowly "working its way northward by wearing away the soft Dakota sand-"stones and shales along its northern bank. As the course of the "river to this point was northeast and the course of the creek to "the southeast, their valleys finally met. A long, wedge-shaped "ridge remains, which separates the upper courses of their valleys.

"The breaking down of so much sandstone necessarily left be-"hind great quantities of sand. In the great quantity of sand lying "to the south of this wedge-shaped mass of land and in frequent "southerly winds, we have the conditions requisite for producing the "present basin. The sand blown by the wind across the mouth of "this valley formed a drift back of the point of this wedge between "the valleys. The drift gradually increased in length and hight "until it became a barrier entirely across the valley of the small "creek and formed a great basin. The drifting of snow often pro-"duces similar results, though on a smaller scale. Could the stream "have had considerable water flowing in it continually, it might have "been able to keep its channel clear; but probably there was not "water enough or current strong enough to carry away the sand "that drifted into the channel.

"Nearly all the wells that have been sunk in this basin produce "very strongly mineralized water, much of it so strong that cattle "will not drink it. The water is commonly spoken of as salty, "but no analysis of the water has yet been made. The mineralized "condition of the water is doubtless due to two causes, the evapora-"tion of so much water over the surface and the leaving behind of "mineral constituents in the wearing away of the saliferous shales."

THE UPLANDS.

The general physiographic features of the uplands of Kansas have already been hinted at while discussing the different streams. Throughout the greater part of the whole western half of the state there is an approach to a level peneplain condition covering the whole of the territory. This is particularly true over the Tertiary areas of the west. The dip of the strata of the Cretaceous lime-

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stones and shales and sandstones is east, approximating an angle the same as the inclination of the surface. In a north and south line there is perhaps a general inclination of the strata to the northeast, but the north dip is so slight that it is scarcely perceptible in most places. We therefore have the most favorable conditions for the production of broad level plains by the general weathering of the uplands. In most cases the valleys are simply channels cut into this great peneplain.

There are irregularities in the uplands, however, which are due to the geologic structure and which produce very prominent features in the landscape. Near the eastern limit of the Dakota sandstone we have escarpments facing the east reaching more or less all the way from the north line of the state to the Arkansas river. Such escarpments are produced by the Dakota shales and probably the underlying Permian shales wearing away and the strongly cemented brown Dakota sandstone serving as a protection to the upper surface. In this way a somewhat mountainous appearance is frequently produced, especially where various streams cut their way through the hard sandstone into the softer materials below. Plates V. and VI. represent two such scenes along the Union Pacific railway a few miles west of Brookville, and also Plate XXIV. at Top of Soldier Cap mound. Here the hard Dakota sandstone only a few feet thick has served as a protection to the upper part of the bluffs. The weathering agents have gradually removed the softer sandstone and shales from beneath leaving the harder material above and producing a precipitous escarpment, as shown.

The hight of such escarpments is therefore dependent upon the thickness of the softer material which underlies the protecting sandstone. If this should be 100 or 200 feet thick the escarpments usually have a corresponding hight. As the sandstone is traced towards the Arkansas river it is found that the hight of the escarpment gradually declines, until at Pawnee rock it is less than 30 feet, while at the north boundary of the state the hills are from 200 to 250 feet above the surrounding plains.

West of the Dakota sandstone area a prominent row of hills is found trending northeast and southwest, passing over the area covered by the Benton limestone. This range of hills has been

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called the Blue hills, in allusion to the bluish haze the atmosphere frequently presents when looking at the hills from a distance. These hills are composed principally of the Benton shales, the Blue Hill shales, with a protecting cap of Fort Hays limestone in places. It is a prominent feature of the landscape and can be seen from the east for a distance of from 20 to 40 miles. West of this still is another escarpment likewise trending northeast and southwest, produced by the eastern limits of the Niobrara chalk formations. It passes southwest from Jewell county, reaching almost to the Arkansas river, gradually growing less prominent in the southern direction on account of the thickness of the Niobrara formation correspondingly decreasing. Frequently along these escarpments outstanding mounds or columns are left after erosion has removed all surrounding materials. Plate VII., Castle Rock, is a good illustration of this. It is situated on the north side of the Hackberry, near its mouth in Gove county. Plate VIII. represents such a mound in the process of formation.

Beyond the Niobrara limits north of the Arkansas river the Tertiary formations are reached. The general character of the uplands throughout the whole of the Tertiary area is that of a broad level plain excepting where it has been cut into by a drainage channel. One of the peculiar features of this part of the state is, that no matter where one may be standing or in what direction one may be looking, it seems as though one is surrounded by higher ground on all sides. This is a feature of the landscape in all prairie countries where the surface is so nearly level. The general eastward inclination of from five to fifteen feet to the mile which obtains throughout the whole of this western country is nowhere noticeable.

South of the Arkansas river the character of the uplands is materially different from that to the north. The broad plains area south of Great Bend is almost level, few streams having cut their channels exceeding 50 to 75 feet deep. One can travel by train across this area on the Santa Fe or the Rock Island, and can hardly notice any variation in the grades until Barber county is reached. From this locality westward the surface is very rugged, due to the great southern inclination. In the vicinity of Medicine Lodge

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we have a series of conditions similar to that just described for the Dakota sandstone area, excepting that the protecting rock here is gypsum rather than sandstone, the so-called "Mansard beds" south of Medicine river being exceedingly picturesque. See Plates XIII., XIV., XV., XVII., XVIII., XXI., and XXII. Such hills rise to an altitude of more than 500 feet above the valley of the river, and frequently to the altitude of 300 feet above the surrounding valleys. The broad layers of gypsum from 5 to 15 feet thick which occur on the tops of the hills have a regular stratified position and extend for many miles east and west. The general feature of the country is therefore similar to that of the Kearney hills west of Salina, in the Dakota sandstone area. Passing westward still from Barber county the general features of the country in Comanche and Clark counties are similar. The surface of the country drops southeastward in some places at the rate of 30 feet to the mile, producing a large number of drainage channels which have been worn out to an unusual depth resulting in the production of an exceedingly varied topography for the whole surface. See Plate IX. This rugged area covers nearly all the south half of Barber, Comanche, Clark, and Meade counties, beyond which both to the north and west high level plains are again encountered. The general surface of the country south of the Arkansas river and west of Meade county is that of one high upland area smooth as a graded land except here and there a drainage channel has been cut down into the plain like a ditch in a meadow, and presents a monotonous appearance of which the eye soon tires.

This can not be said of the far west north of the Arkansas river. The geologic formations being so different is the cause for the different results. From the time the Smoky Hill river has entered the state it has cut its channel through the Tertiary and into the Cretaceous formations. Its various tributaries, which are numerous, likewise have done the same, many of which have relatively broad valleys. The result is that a varied and pleasing topography is produced which consists of the flat topped upland areas and the broad valleys from 50 to 200 feet below producing a general scenic condition in many places similar to that of the Kearney hills already referred to. See Plate X.

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Taken as a whole the western part of Kansas is much more varied in its scenery than one would think from its position in the great plains area. The diversities of elevation are not great, rarely exceeding 300 feet and averaging perhaps less than 200 feet. But when one is near any of the drainage streams one almost invariably finds a varied and pleasing landscape which in many respects is rarely surpassed in America.

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THE UPPER PERMIAN

AND

THE LOWER CRETACEOUS,

BY

CHARLES S. PROSSER.

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THE UPPER PERMIAN.

THE UPPER LIMIT IN EASTERN CENTRAL KANSAS.

INTRODUCTION.

In central Kansas, particularly in Dickinson, Saline, McPherson and Marion counties the line of separation between the Permian and Cretaceous systems has been drawn quite differently on the various geological maps of Kansas. The greatest variations are found in the wide valley of the Smoky Hill river from the mouth of Solomon river to above Lindsborg; and the high divide between the Smoky Hill river and the branches of the Arkansas and the Cottonwood rivers which extends across the northern part of McPherson and Marion counties and north into the southern part of Dickinson and Saline counties.

REVIEW OF FORMER MAPS.

Professor Mudge in 1878 published a "Map showing the superficial strata of Kansas"[1] on which the base of the Cretaceous is represented as crossing the Smoky Hill river valley near the mouth of the Solomon river, thence extending southerly along the Dickinson-Saline county line; next turning easterly and crossing the southern part of Dickinson county and extending two thirds of the distance across the central part of Morris county; finally turning southwesterly across the southwesterly part of Morris, diagonally across Marion and the southeastern corner of McPherson county.

On the "Geological Map of Kansas" by Professor St. John in 1883[2] the Cretaceous is represented as crossing the Smoky Hill river near Bridgeport, about fifteen miles south of Salina, (all of the river valley and Saline and Dickinson counties to the east be-

1 First Biennial Report State Board Agriculture of Kansas, p. 47.
2 Third Biennial Report State Board Agriculture of Kansas, opposite p. 575.

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ing represented as belonging in the "Upper Coal Measures"), then extending easterly across southern Saline and Dickinson counties into the southwestern part of Morris, when it turns southwesterly across the northwestern part of Marion and the southeastern and southern part of McPherson.

The line just described on St. John's map was followed practically by Doctor Williston on his geological map of Kansas published in 1892.

The "Geological and Topographical Map of Kansas" by Professor Hay in 1893[1] represented the base of the Cretaceous system in these counties more accurately than it had been given on the former maps. The top of the river bluffs from northwest of Abilene to the vicinity of Salina were shown as the base of the Cretaceous, then the line ran considerably to the west of the river across the wide valley of the central part of Saline county, bending easterly around the Smoky Hill buttes, crossing the Smoky Hill river near Marquette, then following the bluffs south and east of the river until opposite the city of Salina. The divide between the Smoky Hill river and Gypsum creek, in the eastern part of Saline county, was given as Dakota; the line turning easterly at the southeast corner of Saline county and crossing the extreme southern part of Dickinson county and the southwest corner of Morris county where it made a loop turning westerly across the northern part of Marion county to the northeast corner of McPherson which it crossed diagonally in a southwesterly direction.

Finally in 1896 Professor Haworth published "A Reconnaissance Geologic Map of Kansas"[2] on which so far as the geology of the Smoky Hill valley is concerned, there is an approximate return to the geological map of Mudge. The Dakota is represented as covering all of Saline county, except a very small area on the central part of the Saline-Dickinson county line. The base of the Dakota is shown as crossing the Smoky Hill river at the mouth of the Solomon river, when it runs southeast about one third of the distance across Dickinson county, then turns southwest and runs across the Saline-Dickinson county line, turning southeast across the south-

1 Eighth Biennial Report State Board of Agriculture.
2 The University Geological Surv. of Kansas, Vol. 1, Pl. XXXI.

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western part of Dickinson county to about the middle of the Dickinson-Marion county line, when it turns southwest with a somewhat irregular line crossing the northwestern part of Marion county and southeastern part of McPherson county.

MAP OF PROSSER AND BEEDE.

It was planned to accurately trace the line of separation between the Permian and Cretaceous systems over all the area under consideration; but it became necessary to bring the field work to a close before this had been accomplished. However, the work as far as it was finished showed conclusively that the broad valley of the Smoky Hill river in the central part of Saline county is underlain by the Permian which extends even farther up the river valley than represented to do by Hay; that the upper part of the divide in the eastern part of Saline county between the Smoky Hill river and Gypsum creek is composed of Cretaceous rocks; and finally that on the high divide between the headwaters of the Cottonwood and the southern branches of the Smoky Hill and northern branches of the Arkansas, the Dakota does not enter the southern part of Dickinson county, but only extends about six miles into Marion county to a point about two miles southwest of Durham village in Durham Park township.

Over a part of Saline county at or near the base of the Cretaceous, as represented in that county, is an iron-brown sandstone that contains, in places, abundant fossils. This zone has recently been named "the Mentor beds" by Professor Cragin and referred to the Comanche series.[1] The nonfossiliferous bluish-gray, greenish, and reddish shales overlying the fossiliferous Marion formation of the Permian, which are well represented west of the Smoky Hill river in the central part of Saline county, have been mapped in the Permian. For these shales, which may be regarded as constituting a formation, Professor Cragin has proposed the name Wellington shales[2] and mentioned their occurrence in Saline county along "the foot of the bluffs of Spring creek from Salina to a point in the southwest vicinity of Bavaria."[3]

1 F. W. Cragin, American Geologist, Vol. XVI, Sept. 1895, 162-166.
2 F. W. Cragin, Colorado College Studies, Vol. VI, pp. 3, 16-18.
3 Ibid., p. 17.

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On the northern bank of the Saline river in the northern part of Saline county the Dakota (including the Mentor beds) forms the upper part of the river bluffs. Five miles north of the city of Salina, in the western part of Cambria township, the base of the Dakota is between 90 and 100 feet above the level of the Saline river, or approximately 1300 feet above sea level. On the Salina sheet of the U. S. topographic map the 1300 foot line has been taken as the approximate line of division between the Permian and Cretaceous systems for that part of the sheet north of the Saline river. From the south side of the Saline river to the ridge southeast of Brookville the line on the map is only an approximation; but from that point along the ridge south of Bavaria, east of Soldier Cap mound, near Falun and around the northern, eastern, and southern flanks of the Smoky Hill buttes the line was traced with some care. To the south and east of Smoky Hill river in the northern part of McPherson county, on the western side of the divide between the Smoky Hill river and Gypsum creek, the line was traced by Mr. Beede. In Saline county the writer traced the line down the western and up the eastern sides of the divide between the Smoky Hill river and Gypsum creek into the northeastern part of McPherson county, in Delmore and Battle Hill townships. The line around the divide between the Smoky Hill, Cottonwood and Arkansas rivers in the northeastern part of McPherson and northwestern corner of Marion county was mostly traced by Mr. Beede, as well as the line in the western part of Marion county and the northern part of Harvey between the Permian and Tertiary or Quarternary sand. Mr. Beede also traced the greater part of the boundary of the deposit of sand in Marion, Harvey, Reno, and McPherson counties.

THE UPPER PERMIAN FORMATIONS.

MARION.

The upper fossiliferous strata of the Permian consist of thin buff limestones, shales and marls, containing in places beds of gypsum and salt. These strata have been described by the writer under the name Marion formation[1] for which Professor Cragin,

1 Chas. S. Prosser, Journal Geology, vol. III, November 1895, p. 786.

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later proposed the name Geuda salt measures,[1] but which, however, he subsequently withdrew in favor of the prior name of Marion.[2] This is the highest formation of the Kansas Permian in which fossils have yet been found, and paleontologically the upper limit of the formation may be considered as defined by the disappearance of fossils. Only in the lower part of the formation have any Brachiopods been found, and then simply the one species, *Derbya multistriata* (M. & H.) Pros.,[3] the majority of the species being rather small Lamellibranchs characteristic of the Permian. The most abundant species are:

Pleurophorus subcuneatus M. & H.
Pseudomonotis Hawni M. & H.
Myalina permiana (Swallow) M. & H.
Bakevellia parva M. & H.

all of which are typical Permian species. From this formation the author has identified the following species:

1. *Pleurophorus subcuneatus* M. & H.
2. *Pleurophorus subcostatus* M. & W.
3. *Bakevellia parva* M. & H.
4. *Yoldia subscitula* M. & H.
5. *Macrochilina* cf. *angulifera* White.
6. *Nautilus eccentricus* M. & H.
7. *Schizodus curtus* M. & W.
8. *Schizodus ovatus* M. & H.
9. *Dentalium Meekianum* Geinitz (?).
10. *Aviculopecten occidentalis* (Sheem.) Meek.
11. *Myalina permiana* (Swal.) M. & H.
12. *Pseudomonotis Hawni* M. & H.
13. *Pseudomonotis Hawni* M. & H. var. *ovata* M. & H.
14. *Pseudomonotis* cf. *variabilis* Swal.
15. *Nuculana bellistriata* Stevens var. *attenuata* Meek.
16. *Derbya multistriata* M. & H. Pros. (?).
17. *Septopora biserialis* (Swal.) Waagen (?).
18. *Edmondia Calhouni* M. & H.

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1 F. W. Cragin, Colorado College Studies, vol. VI, March, 1896, pp, 3, 9.
2 American Geologist, vol. XVIII, August, 1896, p. 131.
3 Professor Cragin reports Athyris subtilita in the Marion in southern Kansas (see Colorado College Studies, vol. VI, p. 13).

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19. *Nucula* cf. *Beyrichi* v. Schauroth ; also cf. *N. parva* McChesney.
20. Small *Gastropod* cf. *Aclis Swalloviana* (Geinitz) Meek.

From the buff limestones and shales in a small quarry on the south bank of the Smoky Hill river, south of Abilene and not much below a conglomerate exposed along Turkey creek which was first described by Meek and Hayden in 1859[1], the writer collected the following species:[2]

1. *Pleurophorus subcuneatus* M. & H. .... a
2. *Bakevellia parva* M. &. H. .... e
3. *Edmondia Calhouni* M. & H. (?) c
4. *Yoldia subscitula* M. & H. .... u
5. *Schizodus curtus* M. & W. (?) .... u
6. *Nucula* cf. *Beyrichi* v. Schauroth ; also cf. *N. parva*, McChesney .... a
7. *Ariculopecten* (?) sp. } Very imperfectly preserved .... u
8. *Septopora* (?) sp. } Very imperfectly preserved .... u
9. Small *Gastropod* cf. *Aclis Swalloviana* (Geinitz) Meek ...... r

The bluffs on the southern bank of the Smoky Hill river from Abilene to Salina are comparatively low with but few outcrops. On the east bank of Gypsum creek at its mouth twelve miles west of Turkey creek, or eleven miles west of the fossiliferous limestone in the quarry south of Abilene, is the Merrill gypsum quarry and mill. The section of the bank of the creek bluff at the Merrill quarry is as follows:

Section of the Merrill Gypsum Quarry.

No.		Feet.
6.	Soil.	
5.	Yellowish and bluish shales alternating with thin layers of gypsum	14 —26
4.	Thin layer of fibrous gypsum 1 or 2 inches.	—12
3.	Massive snowy gypsum the principal quarry stratum.	5 —12
2.	Mainly shales	3½— 7
1.	Gypsum to level of Gypsum creek	3½— 3½

1 Proceedings Academy Natural Science, Philadelphia, Vol. IX, p. 16, No. 9.
2 See Journal Geology, Vol. III, p. 788.

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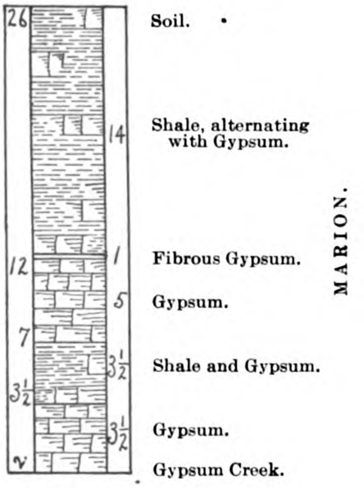

Fig. 2.

Merrill Quarry Section, five miles East of Salina.

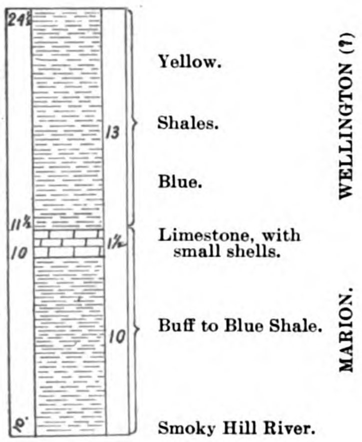

Fig. 3.

Section of Bacott Quarry, South of Salina.

Plate XI gives a clear idea of the exposure of rocks at the above quarry. Mr. Beede's foot rests on top of the massive stratum of gypsum—No. 3 of the section—only part of which is shown in the picture. Above this are the 14 feet of alternating layers of shales and gypsum—No. 5—capped by the soil. The rock dips slightly to the north and east while several small rolls are shown along the side of the bluff. Doctor Grimsley in describing the gypsum deposits of Kansas has correctly referred the gypsum of central Kansas to the Marion formation[1].

Three miles west of Gypsum creek and seven miles east of Salina, on the southwest quarter of section 7, Solomon township, is a small excavation known as Benfield quarry. The locality is 100 feet above the Gypsum creek level, though probably not stratigraphically as much as that above the gypsum, on account of the easterly dip. In the bottom of the quarry is a stratum of massive limestone, hard and quite durable, containing fragments of a few shells, probably *Nuculas*. Above this are about 10 feet of thin, buff to yellowish shales, mostly soft, though some of the layers are hard and

1 G. P. Grimsley, American Geologist, Vol. XVIII, October 1896, p. 237.

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distinctly laminated. Part of the shales are covered with dendritic markings which are common on many of the Upper Permian shales.

About five miles west of the Benfield quarry, and perhaps a little lower, Professor Cragin reports an abandoned quarry, the upper stratum of which is a 10 inch "bastard limestone" that was used in the early settlement of Salina for walling wells, etc. Upon this limestone stratum it is reported that reptilian footprints were noticed some years since[1], though there seems to be no well authenticated record of the correctness of this determination.

On the east side of East Dry creek, in the southern part of section 21, Greeley township, three miles southeast of Salina is a small quarry, at the bottom of which, now nearly covered, are thin brownish yellow limestones with blackish specks, which contain fossils that are the typical small Lamellibranchs of the Marion, and the following species were obtained:

1. *Myalina perattenuata* M. & H. .... r
2: *Pleurophorus subcuneatus* M. & H c
3. *Bakevellia parva* M. & H. .... r
4. Small Lamellibranch ; somewhat like *Pleurophorus*, possibly *Edmondia* or *Schizodus*. .... a

In that vicinity a number of loose pieces of the Marion or a very similar limestone were noticed containing specimens of *Bakevellia parva* M. & H. Above the limestone are creamy to buff colored shales with reticulated or dendritic markings, 6 feet thick, covered by 3 feet of soil.

Three miles south and two miles east of Salina, on the eastern bank of the Smoky Hill river, on the southwest quarter of section 29, Greeley township, is the Bacott quarry, in which a stratum of limestone 1½ feet thick has been worked to quite an extent for common building stone. The exposures along the bank of the river show slight rolls, the rocks being folded into gentle anticlines and synclines. In one place there is quite a sharp dip to the south amounting to 8 feet in a short distance, when the dip turns to west of north.

1 F. W. Cragin, Colorado College Studies, Vol. VI, p. 13.

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Section of Bacott Quarry.

No.		Feet.
5.	Soil.	
4.	Yellowish shales on top containing a layer of flint 1 inch thick. Blue shales in lower part...........	13 —24½
3.	Massive limestone of quarry containing small fragments of shells..............................	1½—11½
2.	Drab hard limestones containing abundant specimens of *Myalina perattenuata* M. & H. 1 inch thick.	—10
1.	Buff and bluish shales to the level of the Smoky Hill river	10 —10

From this quarry the following species were collected:

1. *Myalina perattenuata* M. & H......................... aa
2. *Myalina permiana* (Swallow) M. & H.................. u
3. *Pleurophorus subcuneatus* M. & H...................... c
4. *Bakevellia parva* M. & H............................. u
5. Small Lamellibranch same as in the quarry on section 21, Greeley township.................................... c

According to Prof. A. W. Jones of Salina—to whom the writer is indebted for many favors—at about the level of the river is a stratum of gypsum about 10 feet below the base of the limestone—No. 3 of the above section. A shaft sent to the depth of 25 feet is reported to have penetrated principally gypsum. Professor Cragin has briefly described this locality, noting the layer with abundant *Myalinas*, which he called *M. permiana*, and named the gypsum stratum the Greeley gypsum[1]. The writer agrees with Professor Cragin in regarding the fossiliferous limestones in this quarry as near the top of the Marion formation.

No other outcrops of the Marion were studied in the valley of the Smoky Hill river, and these limestones according to Professor Jones do not extend much farther up the river valley.[2] the southeastern part of Saline county and southwestern portion of Dickinson below the base of the Cretaceous are variously colored argillaceous shales which have been referred to the Wellington. Farther

1 F. W. Cragin, Colorado College Studies, Vol. VI, p. 10.

2 Ibid., p. 10, where Prof. Jones is the authority for the statement "that the most southerly appearance of these limestones and shales on the Smoky is about four and a half miles south of Salina."

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south in the western part of Marion county on the head waters of the Cottonwood river occur the buff, thin limestones of the Marion formation, containing specimens of *Bakevellia parva* M. & H. with a few other fossils typical of the upper rocks of this formation. They were noticed especially in Lehigh and West Branch townships, and west of these limestones is the deposit of sand of varying thickness, the eastern border of which crosses the western tier of townships in Marion county.

The fauna and lithologic characters of the Marion formation in Marion and Butler counties were described by the author in his paper defining this formation, to which the reader interested in the details is referred.[1] Farther south in Cowley county it was found that, in general, the distinctive features of the formation as noted in the eastern central part of the state remain constant. The base of the formation is well shown along the bluffs of the Walnut river in the western part of the county. Capping the bluffs along both sides of the river in the vicinity of Winfield are numerous exposures of a rough, heavy limestone which frequently contains large iron-stained concretions in which are a few fossils, as *Productus semi reticulatus* (Martin) de Koninck, and these concretions are termed in that locality "sand bricks[2]." This is the same limestone that is prominently exposed in the vicinity of the cities of Marion and Burns in Marion county regarded by the writer as the top beds of the Chase formation. On account of its conspicuous occurrence in the vicinity of the city of Marion, the writer first called it the "Marion concretionary limestone."[3] Although the name was never intended in any sense as a formation name, objection has been made to its use because it is not included in the Marion formation, consequently, in order to avoid confusion, it is considered better to withdraw the former name, and on account of the characteristic exposures in the vicinity of Winfield to substitute the term *Winfield concretionary limestone*. Again objection is made to the use of a name for a bed, zone or any subdivision of a formation differing from the name used for that formation. In respect to this criticism it is only

1 Chas. S. Prosser, Journal Geology, Vol. III, p. 786.
2 On the authority of Mr. C. N. Gould.
3 Journal of Geology, Vol. III, pp. 772, 797.

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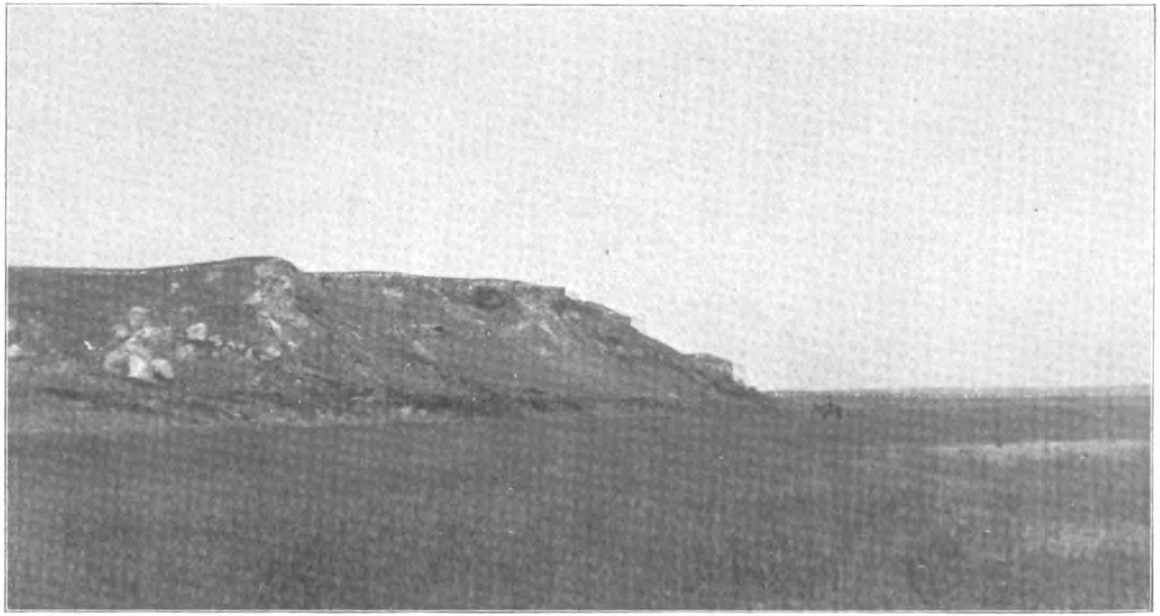

BASIN SANDSTONE RESTING ON RED-BEDS, ON SAND CREEK, NEAR CASH CITY, CLARK COUNTY.
(Photographed by Haworth, 1896.)

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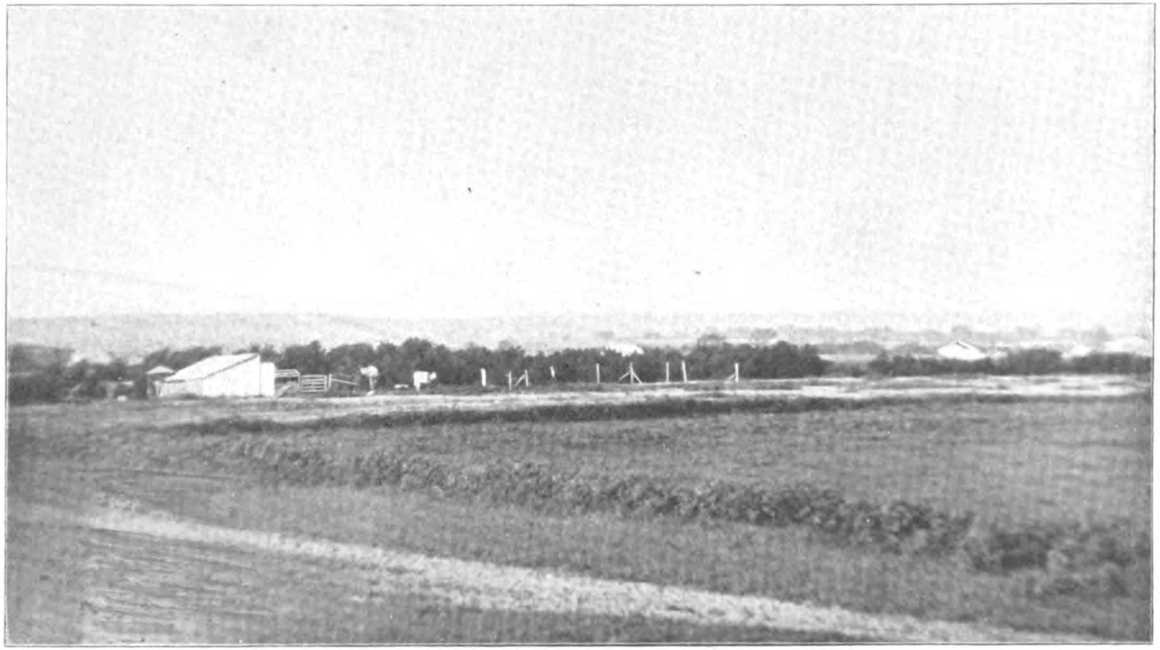

DISTANT TERTIARY HILLS, NORTON.
(Photographed by Haworth, 1896.)

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necessary to say that such usage is well established in geological classification and is of decided assistance in referring briefly to certain local characters, or minor divisions of a formation to which it would be undesirable to give the rank of a formation. The classic state in American stratigraphic geology affords numerous illustrations of this usage as, for example, the *Moscow* and *Ludlowville* shales of the Hamilton formation, and the *Cashaqua* and *Gardeau* shales of the Portage formation. This custom seems to be sufficiently sanctioned by its use in such standard works as Dana's Manual and Geikies' Text-Book of Geology.

Five miles north of Winfield, in the southwest corner of Fair View township at the head of a small arroyo is an excellent exposure of this prominent Winfield limestone, in which the concretions are numerous and exactly the same in character as in this stratum farther north in Marion county. This limestone forms a marked escarpment along the side of the bluff west of the Walnut river at Winfield where it has a thickness of 13 feet. It caps the high points to the east of the river at Winfield, as, for example, on the Asylum reservoir and College hills, where the ledge is some 80 feet higher than in the escarpment of the river, indicating a dip of about forty feet per mile to the west across the valley of the Walnut river at Winfield. The line of division between the Chase and Marion formations in the western part of Cowley county, follows the Walnut river valley for the greater part of the distance across the county. Apparently this same limestone is quarried on the eastern bank of the Walnut river east of Arkansas City, though at this locality above the 11 feet of massive limestone are shaly layers containing abundant fossils, but no concretions were seen.

On the eastern side of the Arkansas river and canal, two and one half miles northwest of Arkansas City, is a buff soft limestone, 15 feet thick, covered by 7 feet of yellowish shales. In the limestone beds is a cellular layer containing specimens of *Bakevellia parva*, M. & H.—typical thin-bedded Marion limestone.

About Geuda Springs, seven and one half miles northwest of Arkansas City, are outcrops of yellowish shales and coarse, cellular rock, some of it brownish-red to iron color—due probably to the

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presence of iron. No fossils were found in the rocks at this vicinity, nor west of that town in the Marion. At this locality are mineral springs, while along the valley of Salt Creek above and below the springs is an incrustation of salt. The porous rocks in this part of the Marion formation have been shown by other writers to contain the thick beds of rock salt of southern and central Kansas[1]. This has been recently very clearly stated by Professor Haworth as follows: "Well records have been obtained from many different parts of the salt region which, when drawn to scale and compared, show very conclusively that the salt beds lie above the heavy limestone beds, and below a bed of blue shale which in turn is below the 'Red-beds.' As the blue shales so well developed in Sumner county and adjacent territory underlie the 'Red-beds,' and as the latter are admitted to be the first above the Permian, it follows that the blue shales are Permian. But as the salt beds are below the blue shales, which approximate 300 feet in thickness, they are well within the Permian[2]." For these salt and gypsum bearing rocks, evidently a portion of the salt bearing beds being in the vicinity of Geuda Springs, Professor Cragin proposed the name "Geuda salt-measures," which, later he withdrew in favor of the prior name Marion formation, as already stated.

In the Anthony well, in Harper county, 404 feet of rocks have been referred to the "salt beds[3]," though in the well section it would probably be a difficult matter to determine the exact line of division between the Marion and Chase formations. Professor Cragin has estimated that "the thickness of the outcrops probably varies from 300 to 400 feet" and has concluded that the dip "in southern Kansas is southward and westward."[4]

No attempt was made to trace the line of division between the Marion and Wellington formations across Sumner county which if accurately done would be an undertaking of some difficulty on account of the level nature of the county and the gradual transition from the lower to the higher formation.

1 Robert Hay, Seventh Biennial Report Kansas State Board of Agriculture, 1891, pt. II, p. 83. Eighth ibid., pt. II, p. 105. F. W. Cragin, Colorado College Studies, Vol. VI, 1896, p. 9.

2 University Geological Survey of Kansas, Vol. I, 1896, p. 191.

3 Ibid., Pt. XXI.

4 F. W. Cragin, Colorado College Studies, Vol. VI, p. 15.

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WELLINGTON.

It will be, perhaps, a somewhat difficult matter to draw a line of separation sufficiently sharp for the purposes of areal geology between the Marion formation and the overlying gray, reddish and greenish argillaceous shales. However, the two negative characters, absence of fossils together with the general absence of limestones, may serve as a means of identifying the formation. It is probable that careful search will eventually reveal a few fossils, the number probably always remaining small, in some part of these shales. On the lithologic side, though the formation contains some calcareous layers and a larger amount of red shales, perhaps Professor Cragin's characterization of these rocks as "essentially a thick body of blue-gray and slate-colored shales"[1] will serve as a satisfactory description of the formation. Professor Cragin has proposed the name *Wellington* shales[2] for the above formation, upon which is located the city of Wellington, the county seat of Sumner county. In Saline county there are probably 200 feet of the Wellington shales,[3] but in the southern part of the state they attain a thickness of more than twice that amount. The greatest reported thickness of these shales is in the well section at Caldwell in the southwestern part of Sumner county, which according to Professor Cragin is 445 feet;[4] while in the Anthony well in Harper county, twenty five miles northwest of Caldwell, a mass of blue shales, referred to the Wellington by Professor Cragin, has a thickness of 395 feet.[5] The author first studied the upper part of this Kansas Permian in Marion county where these shales are much thinner, and in the description of that part of the state included them in the Marion formation.[6] However after studying them as exposed in their typical region in Sumner county, the writer is inclined to follow Professor Cragin and assign to them the rank of a formation.

In Saline county the base of the Cretaceous, which is the Kiowa shales, Mentor beds, or Dakota sandstone, rests on the Wellington

1 F. W. Cragin, Colorado College Studies, Vol. VI, p. 17.

2 Ibid., Vol. VI, pp. 3 and 16.

3 Professor Cragin gives 255 feet for the Wellington beneath Ellsworth, in the first county west of Saline (ibid., Vol. VI, p. 16).

4 Ibid., Vol. VI, p. 16.

5 University Geological Survey of Kansas, Vol. I, pl. XXI. F. W. Cragin, Colorado College Studies, Vol. VI, p. 17.

6 Journal Geology, Vol. III, p. 786 and 797.

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whose upper surface is apparently irregular indicating a period of elevation during which its surface underwent extensive erosion before the deposition of the Cretaceous. This is well shown by various sections in Saline county, a few of which will now be described.

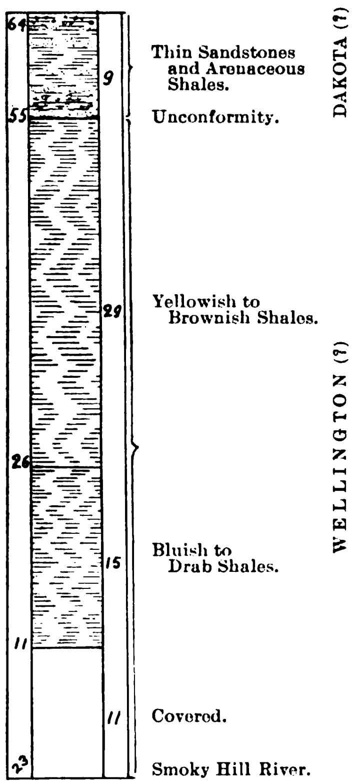

Fig. 4.

Section at Smoky Hill Mill, one mile Southeast of Salina.

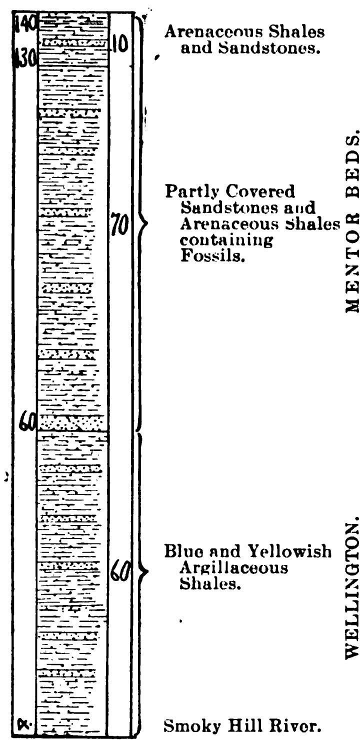

Fig. 5.

Section three and one-half miles East of Mentor.

Section of the Bluff east of the Smoky Hill River, at the Upper Smoky Hill Mill, one mile southeast of Salina.

No.		Feet.
4.	Capping the small buttes is a coarse-grained, massive brownish-gray sandstone, containing dark brownish-red concretions. Thin sandstones and arenaceous shales, partly brownish-gray in color. At base a massive sandstone that rests directly on	9—64

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	the shales, but apparently unconformably. Base of the Cretaceous, probably *Dakota.*	
3.	Yellowish to brownish and buff soft argillaceous shales.	29—55
2.	Bluish to drab shales that weather to a buff color —thin and somewhat laminated.	15—26
1.	Covered. A little farther up the river the blue shales show to the water level.	11—11
	Level of the Smoky Hill river.[1]	

No fossils were found in the rocks composing the above section, although careful search was made for them. Nos. 1, 2 and 3 have been referred provisionally to the Wellington, simply on account of the absence of fossils and their lithologic characters. Two miles farther up the river is the Bacott quarry with the Marion fossils, and on the hill two and one half miles southeast of the river bluff section, in section 21 Greeley township, buff limestones with *Bakevellias* were found at an elevation near that of the shales in No. 3 of the section. It seems probable that the small anticlinal fold noted in the Bacott quarry has brought up the top of the Marion at that locality, so that lower rocks are exposed than in the section at the mill.

Six miles south of Salina and the Upper Mill section on the Smoky Hill river is the small village of Mentor in Walnut township. A section east of Mentor was measured from the river level past the Berwick school house to the top of the ridge two and a quarter miles east of the river. This is the typical locality of the "Mentor beds" of Professor Cragin which will be discussed later.

The Mentor Section.

No.		Feet.
3.	Mostly covered; but apparently a brownish sandstone similar to that below.	10—140
2.	Iron brown sandstone exposed at intervals along the roadside and in the field. Three quarters of a mile east of Berwick school house. Partly covered. In layers are abundant fossils. Apparently the base of the *Mentor.*	70—130

1 Prof. Robt. Hay called this hill Dakota with Permo-Carboniferous shales at the base (Transactions Kansas Academy Science, Vol. IX, 1885, p. 112).

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1. Yellowish and bluish argillaceous shales, with some red streaks. *Wellington.* 60—60

Level of Smoky Hill river.

Two miles directly south of the four corners, one mile east of the Berwick school house, is a most interesting exposure of the Permian and Cretaceous line of contact. The rocks show along the highway at the southwest corner of section 27 Walnut township, and in the field in the southeast corner of section 28. The section is as follows:

3. Brownish, iron stained sandstone containing *Mentor* fossils.
2. Slightly pinkish shell limestone 1 foot thick, containing abundant specimens of *Ostrea. Kiowa.*
1. Yellowish argillaceous shales immediately below the limestone. Similar blue, yellowish and slightly reddish shales continue from 150 to 160 feet to the level of the Smoky Hill river. *Wellington.*

It will be noticed on comparing the two sections just given, that in the Mentor, the base of the Mentor beds is approximately 60 feet above the river level; while in the second section, only two miles south, the base of the Kiowa is from 150 to 160 feet above the river level, or from 90 to 100 feet higher than in the Mentor section. The uncertainty as to the exact base of the Mentor beds in the Mentor section may reduce this difference somewhat, still there will be a decided discrepancy between them which is not explained by folding or dip. The floor upon which the Cretaceous was deposited was evidently a decidedly uneven one.

On the western side of the Smoky Hill river these shales are developed to a greater thickness than on the eastern. Professor Cragin has identified them as belonging to the Wellington, stating that they occur at intervals in the foot of the bluffs of Spring creek from Salina to a point in the southwest vicinity of Bavaria.[1] The Wellington shales were noted at a number of exposures from Bavaria to the vicinity of the summit of the ridge three miles south, but only a number of short sections were found. One mile southwest of Bavaria on the Spring Creek bluff are yellowish shales similar to those of No. 3 in the Upper Mill section southeast of Salina.

1 F. W. Cragin, Colorado College Studies, Vol. VI, p. 17.

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About one and one fourth miles southwest of the above locality is another fairly good exposure on the banks of a small pond, in the southern part of section 4 Washington township. This shows some 15 feet of argillaceous, unfossiliferous shales, the lower and greater portion of which are thin, yellowish and bluish, and above these are some harder and thicker layers capped by 2 feet of red shales.

Near the summit of the ridge three miles south and one half mile west of Bavaria, in the southwest corner of section 10, Washington township, Mentor fossils were found in the brown iron colored rock on top of the yellowish Wellington shales. The base of the Mentor at this locality is from 160 to 170 feet above the Smoky Hill river level, nine and one half miles directly east. One mile south of the locality just described, four miles west of Smolan and eleven and three fourths miles west of the Berwick school house Mentor beds, on the roadside at the northwest corner of section 22 Washington township, is an excellent exposure of the brownish-red very fossiliferous Mentor beds. A little below are yellowish, argillaceous shales, which according to Mr. Beede are shown for some 50 feet in the well in the draw just south. This exposure is fully 150 feet above the Smoky Hill river, 10 miles directly east. Professor Udden concluded that the Dakota in Saline county dipped 8 fet per mile to the east.[1] A dip at this rate to the east would carry the outcrop of the Mentor beds four miles west of Smolan, down to only 66 feet above the river level on the hill east of Berwick schoolhouse. It will be remembered that in the section of that hill the approximate base of the Mentor beds is given as 60 feet.

Six miles south of the above locality, at Falun, are two buttes capped by brownish-red sandstone containing fragments of parallel and netted veined leaves, apparently Dakota species. Below, from wells and exposures by the roadside are bluish and yellowish shales, some of which are rather coarse and contain gypsum of the Wellington. The base of the Cretaceous on these buttes is about 1370 feet A. T., or approximately the same as at the Mentor locality six miles north. The Wellington shales are quite well shown around the

1 American Geologist, Vol. VII, June 1891, p. 344.

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northern end of the Smoky Hill Buttes where their top is about 1360 feet A. T.

Professor Udden has indicated a Pleistocene deposit that covers the central part of McPherson county and extends north along the valley of the Smoky Hill river to the vicinity of Salina. This deposit contains bones of *Myalonyx Leidyi* Lindahl, *Equers Major* De Kay and some fresh water shells.[1]

The streams and arroyos of the adjoining corners of Saline, Dickinson, Marion and McPherson counties revealed numerous exposures of bluish, yellowish and slightly reddish shales which were generally regarded as belonging in the Wellington. These are apparently the same as the shales noted by Doctor Sharpe as extending from the middle of Marion county to north of Smoky Hill river, though I do not agree with the statement that they are "principally red in color."[2]

The vein of the *Dakota sandstone on top of Twin Hill*, Plate XII, represents one of the Twin Hills in Delmore township, capped by massive Dakota sandstone. The slope of the hill is covered with large blocks of the sandstone which have fallen from a former larger cap of the sandstone than the one that now remains on top of the hill.

In Sumner county, in the southern tier of counties these shales attain their greatest known thickness and cover the greater part of that county. On account of the very level nature of this county there are no exposures of any considerable thickness, though small outcrops along the streams and in the steeper parts of the low hills are not of infrequent occurrence. Slate creek, which flows diagonally across the county from the northwest corner to near the southeast portion, affords many small exposures of these shales. The prevailing colors of these shales are yellowish to bluish and grayish tints with greenish and reddish bands of some thickness. There are also occasional thin layers of limestone not unlike some of the thin limestones in the upper Marion. They may be distinguished, however, from the underlying Marion by the general absence of limestones, being composed principally of argillaceous shales; and

1 American Geologist, Vol. VII, June, 1891, pp. 340-345. See especially the map on p. 340.

2 University Geological Survey of Kansas, 1895, Vol. I, p. 191.

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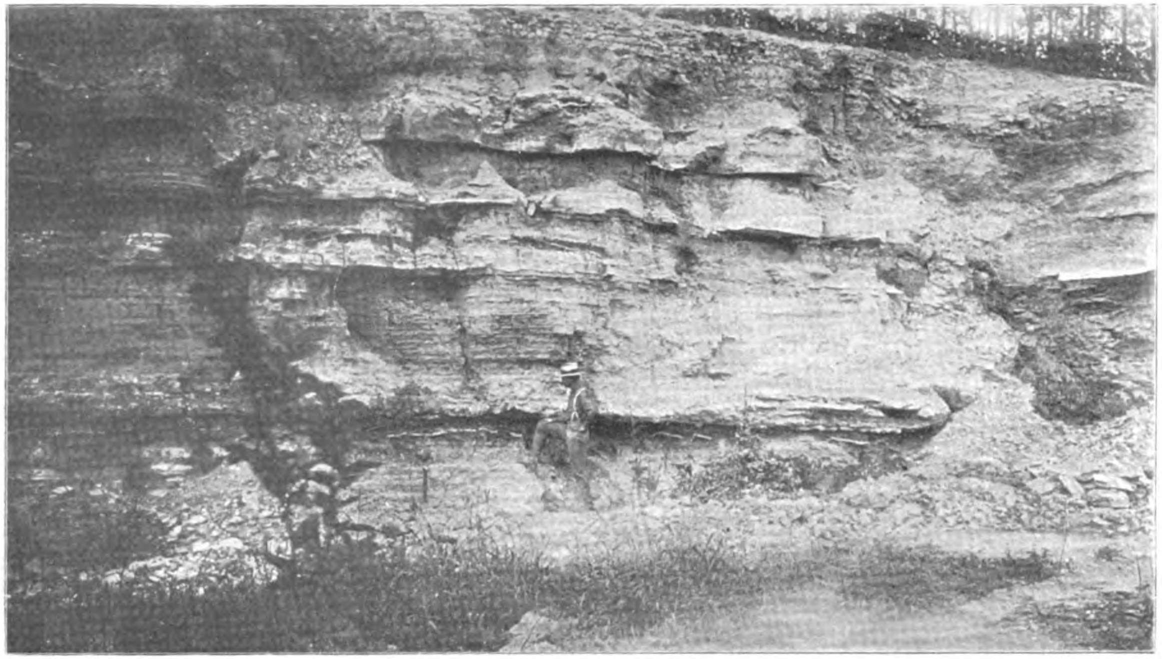

MERRILL GYPSUM QUARRY, ON GYPSUM CREEK, MARION FORMATION, SALINE COUNTY.
(Photographed by Prosser, 1896.)

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DAKOTA SANDSTONE ON TOP OF TWIN HILL, McPHERSON COUNTY.
(Photographed by Prosser, 1896.)

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from the overlying Marion by their general grayish or bluish color which is in strong contrast with the prevailing red color of that formation.

Professor Hay in his paper on the "Geology of Kansas Salt" noted the occurrence of "between one and two hundred feet of gray shales, with an occasional limestone stratum[1]." However, as already stated, Professor Cragin is the first one to accurately describe the lithologic characters of these rocks and to propose an appropriate formation name for them.

By the roadside on the Oxford-Wellington road four miles east of Wellington are yellowish thin limestones that alternate with yellowish shales, the lithologic character of these rocks differing but slightly from that of some of the Marion. Toward the top of the ridge are greenish argillaceous shales, and with them are layers of yellowish shales in which are layers of small, somewhat flattened concretions. The concentric structure of some of these concretions is nicely shown. Professor Hay has described these layers as similar "to a pan of biscuits" and states that they will "separate into several thin concentric domes as would the layers of half an onion[2]." He apparently failed to recognize their concretionary character.

From the above locality along the road toward Wellington are occasional outcrops of yellowish and bluish, soft argillaceous shales, with an occasional layer of harder material an inch or so in thickness. Similar shales show in a branch of Slate creek just east of the city, and along the side of the hill to the west of Slate creek and the city. The blue shales are especially well shown in a small creek on the upland west of Slate creek and 75 feet above it, along the Southern Kansas railroad.

In the vicinity of Wellington is an extensive deposit of gravel and sand which was referred to the Champlain period by J. P. West,[3]

1 Robert Hay, Seventh Biennial Report Kansas State Board of Agriculture, Pt. II, p. 87, Topeka. See also Fig. I "Generalized section from Geuda Springs to Kingman" on p. 86, and Fig. III, "Generalized section across Kansas" on both of which the "gray shales" are represented between the "Salt measures" and the "red beds."

2 Robt. Hay, Bulletin U. S. Geological Survey, No. 57, pp. 19, 20, Washington, 1890. See Fig. 2, on p. 20.

3 Ibid., pp. 39, 40. See Fig. 19, p. 40, which gives a section of the Santa Fe railway cut at Wellington. See Judge West's article in Kansas City Review of Science and Industry, February 1895. This stratified deposit of sand and gravel was also referred to the Champlain by Professor Cragin who mentioned the occurrence of Mastodon Elephas and Bos latifrons in it (Bulletin Washburn College Laboratory Natural History, April 1895, p. 85, Topeka).

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and which Professor Cope calls "the Pleistocene sands."[1] This identification is not simply conjecture, for from an abandoned sand quarry to the west of the city vertebrate fossils have been obtained which Professor Cope identified as *Elephas primigenius* and *Bos crampianus* Cope[2]. From the sand quarry on the eastern side of Wellington, Professor Cope identified a posterior molar of *Elephas primigenius.*

On the creek a short distance west of Mayfield is bluish sandy shale in places, while the soil is decidedly red, probably colored by leaching from the Red-Beds to the northwest. On a small branch of Beaver creek, one mile north and three miles east of Milan (northwest quarter section 14, Ryan township) is an exposure of a few feet of the Wellington shales.

Section three miles east of Milan.

No.		Feet.
4.	Soil.	
3.	Greenish argillaceous shales	2 —5½
2.	Maroon argillaceous shales	2 —3½
1.	Blue argillaceous shales to the creek level.	1½—1½

The shales of the lower part are thicker, light gray in color and contain small quantities of Malachite.

On the road one fourth mile west of Beaver creek are red somewhat sandy shales, similar to those seen on the ridge east of the creek. Along Shore creek to the west of Milan are reddish, rather sandy deposits regarded as in the lower part of the well known Red-Beds, the lower part of which Professor Cragin has called the Harper sandstone. This opinion agrees with an early one held by Professor Cragin; for in 1885 he said that west of Wellington he first saw "the red sandstone of the Dakota [as he then called the Red-beds] at Milan. It also appears at certain points in the Chikaskia river[3]." Mr. Adams also spoke of Argonia in the Chikaskia river as the eastern limit of the Red-Beds.[4] From this locality westward toward

1 Proceedings Academy Natural Science, Philadelphia, Pt. I, January-April 1894, pp. 67, 68.

2 Loc. cit., p. 68 and Journal Academy Natural Science, Philadelphia, Vol. IX, pt. 4, 1895, pp. 453, 456.

3 F. W. Cragin, Bulletin Washburn College Laboratory Natural History, Vol. 1, April 1895, p. 86, Topeka.

4 University Geological Survey, Kansas, Vol. I, p. 29.

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Argonia and the Chikaskia there are not infrequent outcrops of the red rocks, though a large part of the country in the broad valley of the Chikaskia river and its branches is covered by beds of loose sand so that the underlying rocks are concealed. This loose sand forms dunes along the banks of the streams, and is probably an alluvial formation as suggested by Professor Hay[1].

The red sandy rocks mentioned above are referred by the writer to the overlying Red-Beds, consequently their appearance marks the close and upper limit of the Wellington formation. This line was determined at several localities by Mr. C. N. Gould and the writer, but circumstances prevented tracing it accurately across the country. From the above data an approximate line of division between the Wellington Red-Beds has been indicated as crossing Sumner, Kingman and Reno counties.

THE CIMARRON SERIES OR THE RED-BEDS.

HISTORICAL REVIEW.

Succeeding the Wellington formation is a great mass of rocks composed essentially of soft, friable, sandstones and argillaceous shales. The prevailing color is red and this series of rocks has generally been called the Red-Beds. The name refers of course to the prevailing color similar to that of the rocks of northern Texas and Oklahoma which are also known by the general name of Red-Beds.

In Kansas in the upper part of the series are thin layers of gypsum, and at one horizon is a deposit from 25 to 50 feet in thickness of massive gypsum. Thin layers of gray to greenish gray sandstone also occur occasionally, but are neither of sufficient thickness nor frequency to affect the general descriptive term of Red-Beds.

1 The Professor said "on the west line of Sumner Co. the Carboniferous (in which he includes the Wellington) * * * disappears under the extensive sands of the Chikaskia, whose broad valley is a mere depression in the high prairie. This concealmeant by alluvial deposits is very extensive both south and north" (ibid., p. 20); also see p. 43 where he speaks of the "immense beds of sand in the valleys of the Chikaskia, the Medicine," etc. As shown on his "Geologic Map of Southwestern Kansas" quite a large area in the western part of Sumner county and eastern part of Harper county to the south of the Chikaskia river is mapped as covered by Pleistocene sand.

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On the Atchison, Topeka & Santa Fe railway running from Winfield to Medicine Lodge this series is first seen in the vicinity of Mayfield and Milan. So far as determined, the base of the Red-Beds rests conformably on the Wellington formation. The line of separation has been traced to some extent and indicated on the geological map as crossing irregularly the western part of Sumner, eastern Kingman, western Sedgwick and eastern Reno counties, to the valley of the Arkansas river. The top of the series is determined on the west and north by either the base of the Comanche series or the Tertiary where the Comanche is wanting. The series has a thickness of perhaps 1200 feet, determined partly from well sections and partly from surface exposures.

In correlating this mass of rocks investigators have referred them to several systems and a brief review of such correlation may be of interest.

On the geological map of Kansas published by Professor Mudge in 1878,[1] the greater part of the area south of the Arkansas river, now known to belong to the Red Beds, is represented as of upper Carboniferous age though it is stated in the text that west of Harper the region has been little examined by himself or others "but appears to be represented by the Fort Benton and Dakota groups."[2] This does not agree with the map, for Barber, Comanche and the southeastern part of Clark county, to the west of Harper, are colored as belonging to the upper Carboniferous.

The next paper of importance bearing upon this region is the "Sketch of the Geology of Kansas" by Professor St. John in 1883. On the "Geological map of Kansas[3]" in this report, the line separating the Cretaceous and Upper Coal Measures south of the Arkansas river, is represented as crossing central Reno, eastern Kingman and Harper counties. In the text of this report, the Dakota formation of the lower Cretaceous is fairly well described, and the Red Beds are provisionally correlated with it. Prof. St. John says "In the region south and west of the Arkansas, the deep-red sandstones, presumably belonging to the same formation [Dakota], owing

1 First Biennial Report State Board of Agriculture of Kansas, 2nd ed., p. 47.
2 Ibid., p. 55.
3 Third Biennial Report State Board Agriculture of Kansas, op. p. 575.

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to their soft friable nature no longer afford prominent landmarks, though they still impress their presence upon the soil to which they have imparted its red color and loamy nature over a wide outlying belt immediately underlayed by the upper strata of the Upper Coal-Measures."[1]

In 1885 Professor Cragin accepted St. John's correlation and gave some account of the extent of the series. Professor Cragin followed the line of the Atchison, Topeka and Santa Fe railroad from Wellington to Medicine Lodge. "We come" he says "first upon the red sandstone of the Dakota at Milan. It also appears at certain points in the Chikaskia river. This is the main country rock westward to Medicine Lodge."[2] The Gypsum Hills to the southwest of Medicine Lodge, were briefly described by Professor Cragin in this paper, where he stated that "The Gypsum Hills have their base of the Dakota sandstone. At their eastern outskirts, this formation includes their bulk, though even here they are capped by the Benton[3]."

The following year Professor Cragin referred the great gypsum bed of Barber and Comanche counties to the Dakota formation, the upper part of which he regarded as probably formed by the variegated sandstone (Cheyenne sandstone) while "the overlying dark shales, from which the 'Black Hill' takes its name, [are] the base of the Benton[4]."

In 1887 Professor St. John published his "Notes on the Geology of Southwestern Kansas," in which the Red Beds were referred with a query to the Triassic, where they have generally been placed by subsequent writers. Professor St. John's explanation for this correlation is as follows: "The oldest geological deposits [of the district described by St. John in this paper] appear in the eastern portion of the district, and from their lithological appearance and stratigraphical relations to well-determined formations between which they occur, it is inferred they hold the position of the Triassic Red-Beds which are so well developed along the eastern foot of the Rocky mountains a few hundred miles to the west. . . .

1 Ibid., p. 589.
2 Bulletin Washburn College Laboratory Natural History, vol. I, p. 86. Topeka.
3 Ibid., p. 87.
4 Ibid., vol. I, May 1886, p. 166.

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These deposits form the basis of the uplands in which the Medicine Lodge, in the vicinity of Lake City, . . . have eroded its bed to the depth of at least 150 feet. They also extend westward as far at least as Crooked creek, appearing lower and lower in the valley slopes until they pass beneath their beds as the declivity rises in that direction. East and south they compose the surface rocks in Barber and a large part of Harper county. The formation doubtless attains a thickness of 200 to 300 feet at least in this region, and its erosion by the numerous water-courses in the counties named has produced some of the most picturesque scenic effects to be found in the State."[1] Professor St. John was not successful in finding any fossils in the formation, which has been the experience of all subsequent investigators.

In 1889 Professor Hay, who has since so fully described the general appearance of the Red-Beds of southern Kansas, in a lecture before the Kansas Academy of Science, dwelt upon the extent of the area of the Red-Beds, which he described as thinning to the north, while the Dakota thins to the south. In reference to the age Professor Hay stated "These Red-Beds we call Triassic, but possibly the upper part may be Jurassic. As yet they have yielded no determined fossils in Kansas[2]."

The same year, Professor Cragin changed his correlation of the Red-Beds from the Cretaceous to the Triassic. In his explanation of this change he "called attention to the similarity of the red beds of the Gypsum Hills to those of New Mexico, and deprecated the prevalent fashion of ignoring the claims, by earlier writers, that the Triassic existed in Kansas, since no evidence from fossils disputed such claims, and lithological evidence seemed to favor them. But later, in the article cited, he embraced the error, then current, of referring the red sandstones of southern Kansas to the Cretaceous. . . . The evidence of the Trias in Kansas, though based on lithological resemblances and assumed continuity of the Trias of New Mexico, etc., with occurrences in southern Kansas, is now generally regarded as all but conclusive. Yet the distinctly Permian affinities of the fossils from the lower red-beds of northern Texas

1 Fifth Biennial Report Kansas State Board Agriculture, pt. II., pp. 140, 141.
2 Robert Hay, Transactions Kansas Academy of Science, vol. XI., p. 36.

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and southern Indian Territory should at least make us very wary of assenting to any such thickness of the Triassic in Kansas as that (1100 feet) ascribed to it by Mr. Hay."[1]

The first careful description of the Red-Beds was published by Professor Hay in 1890 under the heading "Jura-Trias." In describing the area of this terrane he gave it as "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 regions of red rock. The area of the formation expands across Indian Territory to the Red river and Texas. . . . 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 sides of narrow canyons pain the eye with their sanguine glare[2]."

Professor Hay's evidence for correlating this terrane with the Jura-Trias seems to have been the appearance, lithological characters and stratigraphic position of the terrane. For after giving a summary of the evidence which he regarded as indicating such correlation he said "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[3]."

On the "Geological Map of Southwest Kansas" accompanying this report the eastern line of the Jura-Trias is represented as crossing Reno, Sedgwick and Sumner counties, while the northwest

1 Bulletin Washburn College Laboratory Natural History, vol. II., pp. 33, 34. Topeka.

2 Robt. Hay, Bulletin U. S. Geological Survey, No. 57.—A Geological Reconnaissance in Southwestern Kansas,—pp. 20, 21. Washington.

3 Ibid., p. 25.

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boundary is represented as extending irregularly southwesterly from Reno across Kingman, Pratt, Barber, Kiowa, Comanche, Clark and Meade counties to the state line.

On the small geologic map of Kansas published by Doctor Williston in 1892 the Red-Beds are called Triassic, and their eastern line is represented as extending from the Arkansas river southeasterly across Reno, Kingman and Sumner counties. The northwestern boundary extends southwesterly from the Arkansas river across Reno, Kingman, Pratt, Barber, Comanche and Clark counties to the state line.

In 1893 Professor Hay changed his correlation of the Red-Beds from the Triassic to the Upper Permian of Kansas and assigned them a thickness of 900 feet.[1] This change in correlation was due to the discovery of fossils in northern Texas in strata which were regarded as of the same general age as those of Kansas. Professor Hay said "The Texas geologists have considered the similar beds there as of Permian age; and Professor Cope, of Philadelphia, has shown me undoubted Permian fossils obtained from the Texas beds. This has led me to place them in the geological scheme as Permian. Still, in the Kansas beds no fossils have yet been found[2]."

On the geologic map compiled by Mr. McGee, the Red-Beds are correlated with the Jura-Trias, and represented on the map as extending from northern Texas across Oklahoma into southern Kansas[3].

Professor Cope, who has thoroughly studied the vertebrate fossils of Texas visited in 1893 the Red-Bds of northern Oklahoma and southern Kansas. On account of the close connection existing between them, his statements in reference to their age are of great importance in correlating the Kansas terrane. He said "Our first object was to examine the red bluffs of Permian or Trias, which bound the canyons north and northwest of the post [Fort Supply in county "N" northern part of Oklahoma], which form part of the drainage system of the Cimarron. These bluffs we ex-

1 Robt. Hay, Eighth Biennial Report Kansas State Board Agriculture, pt. II., p. 101.

2 Ibid., p. 108.

3 Fourteenth Annual Report U. S. Geological Survey, pt. II., 1894, pl. II. Washington.

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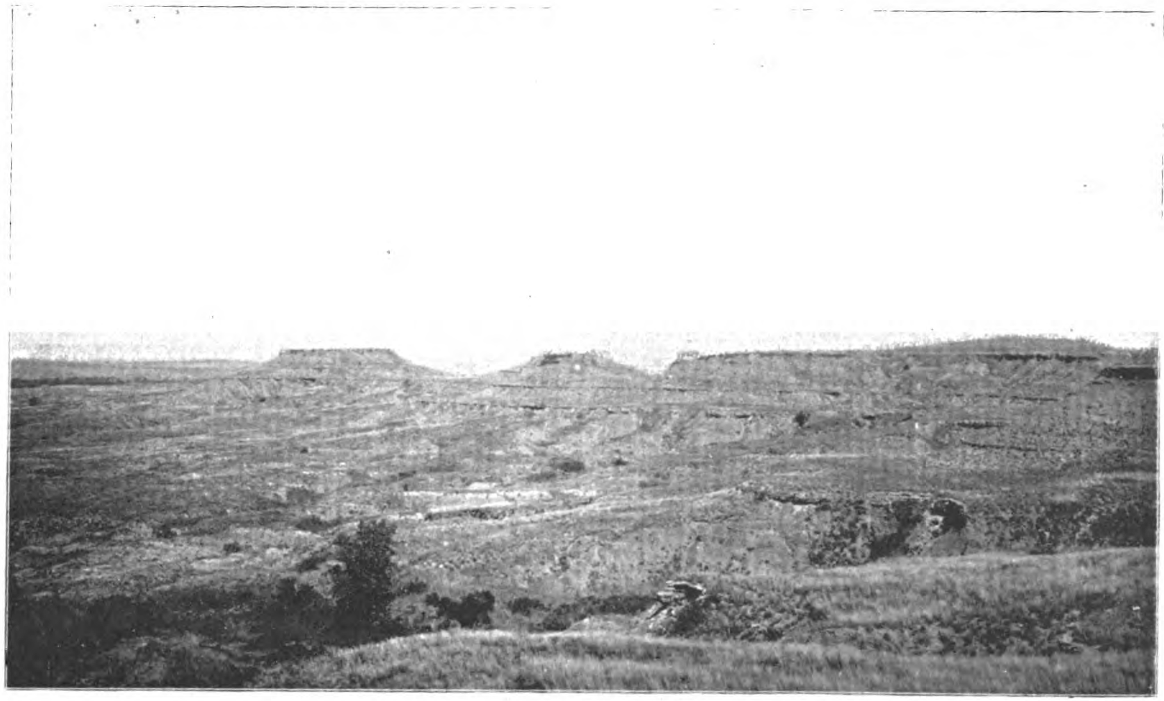

NORTHERN END OF GYPSUM HILLS, NEAR MEDICINE LODGE.
(Photographed by Prosser, 1896.)

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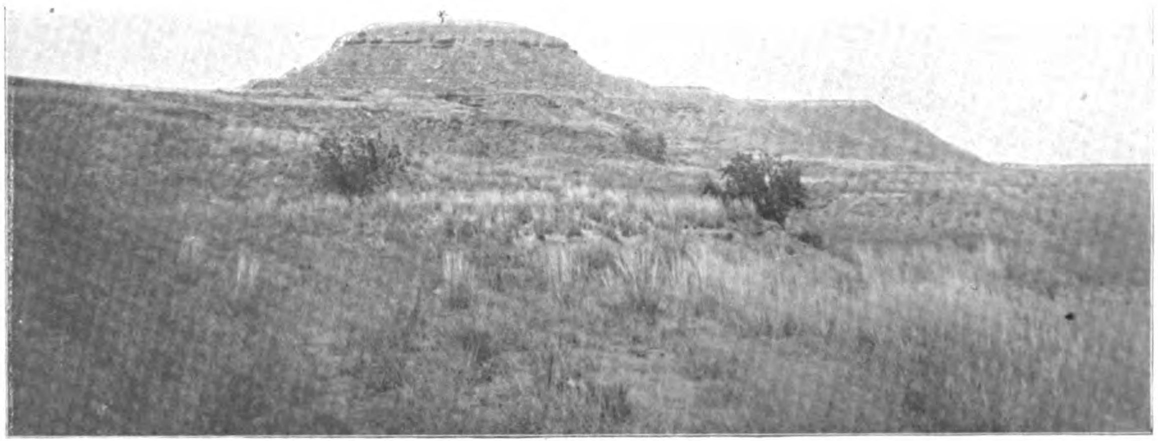

FLOWER-POT MOUND, "RED-BEDS," EIGHT MILES NORTHWEST OF MEDICINE LODGE.
(Photographed by Prosser, 1896.)

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amined at various points and for considerable distances, but without obtaining any traces of fossil remains, excepting some fragments of wood. . . . On our return from Texas, we stopped at Tucker, Oklahoma, near to the Cimarron river, and examined for a day the exposures and bad lands of the Upper Permian of that region. Although the exposures are most favorable for the exhibition of any fossils which the strata may contain, nothing of organic origin was found. Crystallized gypsum is very abundant."[1]

In 1896 Professor Cragin published a detailed account of the Red-Beds, which he referred to the Permian system and subdivided into ten formations. The evidence upon which this correlation is based is apparently about the same as that of Professor Hay. The statement of Professor Cragin is as follows: "The Permian of the Kansas-Oklahoma basin undoubtedly has many similarities to that of Texas, but it is probably in only one or two of the terranes of the Upper Permian, especially in the Medicine Lodge gypsum, that stratigraphic continuity or even parallelism of physico-geographic conditions can be traced between them. It therefore seems unnecessary to treat the Permian north and south of the Ouachita mountain system as belonging to two distinct basins, and profitless to attempt divisional correlations between them.[2] Professor Cragin's table of formations for the Red beds is as follows:

"*The Cimarron Series.*

DIVISIONS.	FORMATIONS.
Kiger.	Big Basin sandstone. Hackberry shales. Day Creek dolomite. Red Bluff sandstones. Dog Creek shales.
Salt Fork.	Cave Creek gypsum. Flower-pot shales. Cedar Hills sandstones. Salt Plain measures. Harper sandstones."[3]

1 E. D. Cope, Proceedings Academy Natural Science, Philadelphia, 1894, pt. I., pp. 64, 67.
2 F. W. Cragin, Colorado College Studies, vol. VI, pp. 2, 3.
3 Ibid., p. 3.

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This division of the Red-Beds seems to have been carried to a greater extent than the differences in the lithologic characters of the rocks would justify for the rank of a formation. Perhaps it is well enough to consider them as sub-formations, and group the whole mass of rocks in three formations, as will be indicated in the closing part of this subject. The names used by Professor Cragin for these divisions are based upon names of localities occurring, with one exception in southern Kansas. The lowest terrane, termed Harper sandstones, which Professor Cragin estimates as having a thickness of 650 feet, is named from the exposures of brownish red sandstone and shale quarried near the city of Harper in Harper county. The Salt Plain measures are named from the Salt Plain along the Cimarron river in the northern part of Oklahoma. The Cedar Hills form the bluffs along the eastern side of the Medicine Lodge river in southeastern Barber county, which is the typical region for the Cedar Hills sandstone. The variegated shales called the Flower-pot shales are well exposed on a mound between East and West Cedar creeks, eight miles southwest of Medicine Lodge, locally known as the Flower Pot mound. The Cave Creek gypsums include the Medicine Lodge gypsum capping the Gypsum Hills southwest of Medicine Lodge, and the higher bed of gypsum in the southeastern part of Comanche county along Cave creek, which has suggested the name for that terrane. The Dog Creek shales are named from the exposures along the creek of that name which enters the Medicine Lodge river between Mingona and Lake City, Barber county. The Red Bluff sandstones are conspicuous along Bluff creek in western Comanche and eastern Clark counties, where they have a thickness of perhaps 200 feet. The thin dolomite in the upper part of the Red-Beds is named Day Creek from its exposures near the head-waters of that creek in the eastern part of Clark county; while the Hackberry shales are named from exposures along the creek of this name in the northern central part of Clark county. Capping the Red-beds is the Big Basin sandstone material named from the Big basin in the western part of Clark county, which is referred by the writer to the Comanche series.

Finally, on the "Geologic map of Kansas" by Professor Haworth this terrane is termed the Red-Beds without making any further

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correlation than assigning it a position between the Permian and Comanche. The northern apex of the Red-Beds is represented on the map as in the southern part of Reno county, its eastern line extending southerly across Kingman and Sumner counties to the state line, then the formation extends westerly across western Sumner, Kingman, Harper, Barber, Comanche and Clark counties into the southeastern part of Meade.

DESCRIPTION.

The greater part of the rocks belonging to the terrane popularly called the Red-Beds, for which it is proposed to adopt Professor Cragin's name of Cimarron series, consists of red sandstones and shales some of which when wet are of a bright red or almost vermilion color. The sandstones are soft and friable, while the shales are arenaceous or argillaceous. Thin layers of grayish to greenish-gray sandstone and grayish spots are not of infrequent occurrence. Near the middle of the terrane the shales contain considerable deposits of salt. This part of the series has been quite fully described by Professor Cragin who considers that the saline crust of the Salt Plain of the Cimarron river in northern Oklahoma is derived from these shales. The rock salt penetrated by the Pratt salt well is also apparently correctly referred to this portion of the Red-Beds. Above these salt shales are some red sandstones after which shales of variegated color predominate for 100 feet or more in which are thin layers of satin spar, selenite and other forms of gypsum. Capping these shales is the main mass of gypsum, which is so conspicuously shown on top of the Gypsum Hills to the southwest of Medicine Lodge and which may be readily followed along the bluffs, to the west of the Medicine Lodge river, into the southeastern corner of Kiowa county; or again, from the Gypsum Hills into the southeastern part of Comanche county. The Medicine Lodge gypsum is correlated by Professor Cragin with the similar massive deposits occurring in the central and southern parts of Oklahoma for he said "the principal stratum of gypsum described and illustrated in their Red River Report by Captain Marcy and Dr. Shumard as occurring on the Canadian and on the forks of the Red river, can scarcely be other

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than the Medicine Lodge gypsum[1]." If this correlation be correct, and the general similarity of the Oklahoma gypsum with that of the Medicine Lodge is well shown in the descriptions of Captain Marcy and George G. Shumard and the accompanying plates,[2] then the Medicine Lodge gypsum is the most important division of the Red-beds for the purpose of classification.

Succeeding the massive gypsum are bright red shales and sandstones that are more brilliantly colored than any other part of the series and are admirably exposed along the bluffs of Bluff creek in Comanche and Clark counties. An excellent illustration of these bluffs is given on p. 39 of Professor Hay's bulletin. Gypsum is not so abundant in this upper portion of the Red-Beds but near the top in Clark county is a conspicuous stratum of magnesian limestone called the Dog Creek dolomite by Professor Cragin.

In western Sumner, Harper and Kingman counties the country is gently rolling and the slopes of the low hills and banks of streams show frequent exposures, though there are many beds of sand along the valleys of the streams which have been generally, and probably correctly, referred to the Quaternary.[3] In eastern Barber county in the buttes to the north of Sharon and the Cedar Hills to the south, the rugged and picturesque country of the Red-Beds begins, which has been so strikingly described by Professors Hay and Cragin. This region, with frequent steep buttes and streams lined by steep bluffs, extends across Barber, Comanche and Clark counties to the eastern part of Meade. These bluffs and buttes afford numerous excellent sections of the upper part of this series, the thickness and general lithologic characters of which may be seen in the various sections accompanying this Report. The best exposures of the middle part of the series, as well as some of the most picturesque portions of this country, may be seen in Barber county, in the Cedar Hills in the southeastern part of the county and along the steep line of bluffs and hills to the west of the Medicine Lodge river, especially in the Gypsum hills to the southwest of the city of Medicine Lodge. When seen from the hills to the east of Medicine Lodge, at a distance of

1. F. W. Cragin, Colorado College Studies, Vol. VI, p. 30.

2 Exploration of the Red River of Louisiana in 1852, published 1854, pp. 23, 165. See also plates 4, 5 and 6. (Ex. Doc. House Rep. 33d Cong., 1st Ses.)

3 See Bulletin U. S. Geological Survey, No. 57, pp. 38-45, Washington.

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ten miles, in the early morning sunlight they form a landscape of striking beauty which once seen will never be forgotten. The reddish color of the steep sides of the hills whose walls suggest gigantic fortifications, is clearly visible, while the top of the hills appears in the hazy distance like a great table land. This scene has been forcibly described by Professor Cragin as follows: "If on the road from Harper to Medicine Lodge, the traveler finds himself looking westward across the valley of the Medicine Lodge river on one of those enchanting days for which southern Kansas yields the palm to no other locality, the autumn air being tinged with just enough of haze to purple the remoter vistas of the ruddy landscape

'The splendor falls on castle walls'

which rear themselves seemingly as low mountains or buttressed escarpments of a table land crowning the further incline of the valley and bounding a considerable part of the western horizon."[1] An earlier brief, graphic description of this region was published by Professor Hay in Harper's Magazine accompanied by a picture giving a characteristic view of several of the hills, or more accurately buttes. Professor Hay said: "A geological series of rocks, termed provisionally Jura-Trias, has been laid bare by immense erosion, and carved into the most fantastic forms of capped pinacles, mansard-roofs, and frowning precipices. . . . Arenaceous limestones [sic.], of a dull red or rich brown, are alternated with beds of red clay or greenish shale glistening with crystals of selenite, and in the precipitous fronts banded with white satin spar for hundreds of yards continuously. Near the top, a massive layer of white gypsum, from eight to eighteen feet thick, makes a prominent ledge, for miles, capping the red precipice with a glaring light."[2]

An idea of these hills, part of which form a mesa of some extent and others simply buttes, capped by the massive Medicine Lodge gypsum, may be gained from Plate XIII. which gives a view of the Northern end of the Gypsum hills, as seen from the south. Two buttes are shown at the northern end of the hills capped by a massive stratum. To the south is the main part of the Gypsum hills the

1 F. W. Cragin, Colorado College Studies, Vol. VI, p. 28.

2 Harper's New Monthly Magazine, Vol. LXXVII, 1888, p. 43. See the picture on p. 41.

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top of which is higher than the buttes. The foreground gives an idea of the broken nature of the country.

A section from Medicine Lodge to the top of the Gypsum Hills, six miles southwest, was measured by the barometer. It is thought, however, that the thickness of the different divisions is quite accurately given since the total thickness of the beds agrees very closely with the altitude of the hills above the level of the Medicine Lodge river, which is 350 feet according to the Medicine Lodge sheet of the U. S. Topographic map.

Section from Medicine Lodge River to the top of the Gypsum Hills.

No.		Feet.
4.	Massive gypsum on top of the Gypsum Hills, 6 miles southwest of Medicine Lodge. The *Medicine Lodge gypsum* of Cragin.	29—349
3.	"Iron rock" of the quarrymen, at the base of the massive gypsum. Then, mainly red shales, though other colors occur with thin layers of gypsum and selenite.	90—320
2.	Greenish-gray sandstone, containing nodules of gypsum, forming a conspicuous stratum near the base of the steepest part of the hills. Below, mainly red shales with some thin layers of gypsum.	80—230
1.	Mainly soft red sandstones with some shales, containing gray to greenish-gray layers and spots. Level of Medicine Lodge river.[1]	150—150

Nos. 2 and 3 of the above section belong in the division which Professor Cragin has named the Flower-pot shales. The soft red sandstones below these shales, forming the upper part of No. 4, belong in the Cedar Hills sandstone of Cragin, while the base of the bluffs near the river is probably in the division that he terms the Salt Plain Measures, though there is hardly any line of separation between the two divisions.

On top of the Gypsum Hills, eight miles by the road, southwest of Medicine Lodge, is Best Brothers' quarry in the massive ledge of

1 Through an error the thickness of this section was not given correctly on the accompanying diagrammatic section.

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light gray to whitish gypsum, where it has a thickness of 29 feet. At the bottom of the quarry is a reddish to greenish very hard stratum termed the "iron rock" by the quarrymen. The base of the gypsum is darker in color than the upper part and is somewhat impure. Next is the hard marble like kind called the *Terra alba*, and above, reaching to the surface is the softer white gypsum said to be of the best quality. On the eastern slope of the Gypsum Hills in the numerous ravines and small canyons which mark their sides are fine examples of erosion. The sloping sides are partly covered with talus and marked here and there by projecting ledges formed by harder strata. From the summit of the Gypsum Hills is a magnificent view displaying a bewildering number of isolated buttes and mounds, separated by small valleys to the west and north, and on the east and south the valley of the Medicine Lodge river limited by the red bluffs to the east. All of this region affords an excellent illustration of the effects of erosion on soft rocks that may well be compared to the Tertiary Bad Lands of Dakota.

To the west of the Gypsum Hills, eight miles southwest of Medicine Lodge is the prominent mound known as the Flower Pot mound. It forms the end of the divide between east and west Cedar creeks and is the type locality of the shales below the Medicine Lodge gypsum which Professor Cragin has called the Flower Pot shales.

Plate XIV gives a view of Flower Pot Mound, as seen from the south. The cedar trees on top of the mound are shown and the heavy stratum forming the top of the steep part stands out quite clearly. Below are two terraces before reaching the base in the eroded valley. An idea of the sparse vegetation covering the slopes of the mound is also given. The upper part is a greenish-gray massive stratum above which on the ridge to the west is the heavy gypsum. The mound consists largely of reddish shales but these have a mottled appearance due to the presence of greenish, bluish and other colored shales, together with immense numbers of small pieces and thin layers of various kinds of gypsum, especially selenite. The steep part of the mound is about 120 feet in hight, the base of which is about 100 feet above the level of East Cedar creek. On account of the gently rolling country over which the lower part of

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the Red-Beds is exposed, it is a difficult matter to determine their thickness from the surface exposures. The well record at Anthony, however, affords reliable data for this portion of the terrane which gives 551 feet of the Red-Beds. All of this is referred by Professor Cragin to the Harper sandstones, while he considers Anthony as 100 feet below the top of this division which would give a thickness of 650 feet for the Harper sandstones. The remaining divisions of the Red-Beds, Professor Cragin, from surface exposures, estimated to have a thickness of from 630 to 680 feet, which would make the thickness of the entire series vary from 1280 to 1330 feet. If Professor Cragin's interpretation of the record of the Pratt well be correct, the total thickness of the Red-Beds must be fully as great as that just given, for the Pratt well passed through 626 feet of red shales and sandstones before reaching the Salt Plain Measures which are given as 155 feet thick. Consequently the Pratt well gives a thickness of 781 feet of Red-Beds before reaching the Harper division.[1] If this 781 feet be added to the 650 feet of Harper sandstones it will give a thickness of 1431 feet which must certainly be regarded as the maximum thickness of the Red-Beds in southern Kansas. Professor Hay first estimated the thickness of the Red-Beds, where not eroded, from Anthony westward as over 1000 feet."[2]

Later, he apparently considered this too great for in his table prepared in 1892 giving the thickness of the Kansas rocks, he gives to the Red-Beds which included the Wellington shales, a thickness of 900 feet.[3]

The result of the studies of the various sections west of the Medicine Lodge river indicates a thickness of at least 590 feet of Red-Beds to the west of this valley, in the regions where the upper part of the beds has suffered the least erosion. Apparently all of the deposits west of the Medicine Lodge river are above the Red-Beds penetrated in the Anthony well, which would give a thickness of 1140 feet for the entire series. It seems to the writer that

1 F. W. Cragin, Colorado College Studies, Vol. VI, p. 23.

2 Robt. Hay, Bulletin U. S. Geological Survey, 1890, No. 57, p. 26. Washington.

3 Eighth Biennial Report Kansas State Board of Agriculture, Pt. II, p. 101, Topeka, 1893. Under the description of the Red-Beds is the statement that from the top of the Salt Measures to the plateau above the gypsum in Barber county they are over 800 feet thick (p. 105). This of course did not include the 200 feet or more of Red-Beds now known above the gypsum in Clark county.

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the above is probably an underestimate rather than an overestimate for the total thickness of the Red-Beds.

Careful search was made in the Red-Beds for fossils, especially in all places where a change of color seemed to indicate a possibility of finding organic remains, but without success. This but repeats the experience of former investigators of this terrane in Kansas and judging from the known scarcity of fossils in similar formations in other regions there seems little probability of finding them in the Red-Beds of southern Kansas. The great assistance that fossils would afford in determining the age of the Red-Beds was fully appreciated and on this account special efforts were made toward their discovery which however proved fruitless.

CORRELATION.

The correlation of the Red-Beds of southern Kansas is a difficult matter and one at present hardly possible to settle in a satisfactory manner. Physically, no break is known between the Wellington and superjacent Red-Beds, though Professor Cragin states that they succeed the former "without break, but possibly with a gradually introduced angular unconformity."[1] In our work, no evidence of a period of interruption in the deposition of the strata was observed. Above, there is abundant evidence of great erosion before the deposition of the Cretaceous or Tertiary, showing that a long period of time elapsed between the deposition of the upper Red-Beds and that of the succeeding formation. This unconformity by erosion, which is very conspicuous when any considerable area of the region is carefully studied, separates the Red-Beds very clearly from the next later Cheyenne and Kiowa formations of the Comanche series. No fossils have been found in them in Kansas, or so far as known to the writer, in Oklahoma with the exception of fragments of fossil wood mentioned by Professor Cope.[2] In Texas, Professors Cope and Cummins, Dr. C. A. White and others have found fossils in layers occurring well toward the top of the Red-Beds."[3] From the vertebrate and invertebrate fossils found in

1 F. W. Cragin, Colorado College Studies, vol. VI, p. 18.

2 Proceedings Academy Natural Science, Phil., 1894, Pt. I, p. 64.

3 According to Professor Cummins, "two species of Ammonites, Orthocerites and Pleurophorus" were found within less than 300 feet of the top of his Double Mountain division which he regards as the highest of the Permian (Geological Survey of Texas, Fourth Annual Report, 1893, p. 230; and ibid., Second Annual Report, 1890, p. 408).

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these rocks, they were correlated with the Permian the upper formation of which is called the Double Mountain division of Professor Cummins and is given a thickness of 2075 feet. It is stated that in this formation occur limestones containing "many casts of fossils" and numerous gypsum beds, some of which are very thick.[1] Overlying unconformably the Permian Red-Beds is another formation also belonging in what is popularly termed the Red-Beds, called the Dockum division by Professor Cummins, the thickness of which he gives as 125 feet in northwestern Texas.[2] This formation has been positively correlated with the Triassic system by Professor Cope on account of the discovery of reptilian genera which occur in this system on the Atlantic border.[3] Professor Cummins studied the Panhandle region of Texas from Mobeetie north to the Canadian valley and then followed it into Oklahoma to a point opposite the lower end of the Wichita range, and saw only the Double Mountain formation. His inference in reference to southwestern Kansas was that "The older beds of the Permian may have been exposed farther northward in Kansas, but I am of the opinion that southwestern Kansas has only the uppermost beds."[4] Professor Hay had already stated that the Kansas formation was "continuous to Red river and appears to be stratigraphically connected with similar rocks beyond,"[5] though the writer is of the opinion that he had not followed the Red-Beds across Oklahoma to the Red river. Professor Hill has represented the Red-Beds or "Permo-Trias" as extending from northern Texas nearly across Oklahoma to Kansas.[6] Their age, it was stated, "certainly ranges from Permian at their base, as shown by the investigations of Cope, Ball and White in Wichita county of Texas, to Triassic, as shown by Newberry and Marcou, in Texas and New Mexico, and probably Jurassic—continuing to the base of the Comanche series, as seen in the Cheyenne sandstones of Kansas."[7] However after studying the Red-Beds of the Medicine

1 Ibid., Second Annual Report, p. 402.
2 See Ibid., pp. 361, 424.
3 Ibid., Fourth Annual Report, 1893, p. 11.
4 Ibid., Second Annual Report, p. 421.
5 Robt. Hay, Bulletin U. S. Geological Survey, 1890, No. 57, p. 25. Washington.
6 Final Geological Report of Artesian and Underflow Investigation, Pt. III, 1892, Map showing "Geographic Features of the Texan Region" (Ex. Doc. 41 Pt. 3, 52d Congress, 1st ses.) See, also, map in American Journal of Science, 3d series, vol. XLII, 1891, p. 112.
7 Ibid., p. 130.

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Lodge valley, Professor Hill referred to them as "the problematical formation known as the Red-Beds, Triassic of various writers."[1]

The Medicine Lodge gypsum has been traced by Professor Cragin to Herman in the Cimarron valley in northern Oklahoma, while he accepts provisionally the statement that it has been traced to Darlington, near El Reno, on the North Fork of the Canadian, in the southeastern part of Oklahoma. He concludes that "the principal stratum of gypsum described and illustrated in the Red River Report of Captain Marcy and Doctor Shumard as occurring on the Canadian and on the forks of the Red river, can scarcely be other than the Medicine Lodge gypsum."[2]

When the above distribution of the massive gypsum is considered in connection with Professor Cummins' statement that "As soon as the beds of the Double Mountain division are passed in ascending order there is no more gypsum,"[3] there seems to be sufficient evidence to warrant us in referring the Kansas Red-Beds provisionally to the Permian system. This tentative conclusion is supported by Professor Cummins' statement that "Only the upper part of the Permian is found north and west of the Wichita mountains and along the Canadian river, and in that there are fewer fossils than elsewhere in the Permian strata, so that anyone visiting that part of the formation might not find fossils sufficient to determine the horizon definitely or satisfactorily, and the mistake might very easily be made of calling all of the beds Triassic; while to the south and southwestward of the Wichita range no such mistake need be made, because the fossils are numerous and distinctive."[4] This conclusion is also supported by Professor Cope who apparently regarded the Red-Beds along the Cimarron river in the northern part of Oklahoma as belonging in the Upper Permian, though in one place they are spoken of as "Permian or Trias."[5]

On comparing the description of the Permian sections of the Red-Beds of Texas with those of Kansas it is readily seen that there is a decided difference in the lithological characters of the

1 American Journal Science, 3d series, vol. L, p. 207.
2 F. W. Cragin, Colorado College Studies, vol. VI, p. 30.
3 Geological Survey of Texas, Fourth Annual Report, 1893, p. 231.
4 Ibid., Second Annual Report, 1891, p. 429.
5 E. D. Cope, Proceedings Academy Natural Science, Philadelphia, Pt. I, 1894, pp. 64, 66, 67.

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rocks occurring in the two regions. Professor Stevenson has already called attention to the dissimilarity in the lithologic characters of the Red-Beds on the Oklahoma-Indian Territory line along the Canadian river and the fossiliferous Permian rocks of northern Texas. Professor Stevenson visited the Texas Permian region in company with Professor Cummins and wrote as follows: "If the beds in that region [northern Texas] are the same with the 'Red Beds' at Purcell and southward in Indian Territory, one will need fossils to prove the identity, for the lithological characters are wholly dissimilar; still the interval between the localities is considerable and change in characters may be gradual."[1]

On account of this dissimilarity in lithologic characters and the absence of fossils in Kansas and northern Oklahoma together with the fact that there is as yet no account of the careful tracing of any part of the Red-Beds across Oklahoma to Texas where their age could be determined by comparison with the fossiliferous terraues, the correlation of these rocks with either the Triassic or Permian is a matter of uncertainty. The writer is of the opinion that there can be no satisfactory correlation of the Kansas Red-Beds until they have been followed across Oklahoma to Texas, and the age of the Red-Beds of Oklahoma settled.

CLASSIFICATION.

As stated under the description of this series in Kansas, the Red-Beds consist essentially of a mass of reddish shales alternating with friable sandstones, with the exception of the massive gypsum so well shown on the Gypsum Hills southwest of Medicine Lodge. Again, near the central part of the Red-Beds there are beds of rock salt as shown by the deposits of the Great Salt Plain of the Cimarron river and in the Pratt well. The nature and general appearance of the formation has been well described by Professor Hill in the following language: "Its name [Red-Beds] is derived from the fact that the surface of the whole country underlaid by it is of conspicuous red colors, glaring vermilion or deep-brown chocolate sometimes prevailing, varied only here and there by a bed of snow-white

1 Transactions New York Academy Sciences, November 1895, p. 59. See pp. 56, 57 for a similar statement.

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gypsum. To one accustomed to the green-clad landscapes of the east or its sombre-colored formations, the vast landscapes and brilliant colors of the Red-Beds is striking, especially if seen in some bold cliff for scores of miles. A landscape in color that of red brick dust is the only familiar comparison[1]."

On account of this repetition of lithologic characters in the Red-Beds it was the author's opinion at first that in so far as Kansas and northern Oklahoma are concerned they should be considered as forming only a single formation. Since a geographical name is needed for the formation in place of the simple descriptive term Red-Beds and as Professor Cragin had already proposed the appropriate name of Cimarron series for this mass of rocks it was at first thought best to use the name Cimarron formation. There are strong arguments in favor of such a classification and it has been favored by Professor Hill as may be seen from the following: "Whatever their age [Red-Beds], they have the same unmistakable characteristics of color and unconsolidation and are probably a single unbroken formation, representing the sediments of an ancient inland sea[2]."

The Red-Beds were also apparently regarded by Professor Hay as a single formation. It will be remembered, as stated in the historical review of the Red-Beds that recently Professor Cragin has divided the series into ten formations.[3] These subdivisions may be recognized in the localities from which they are named; but it would be difficult to trace part of them for any distance for the purpose of geological mapping. They are often helpful as subformation names, and in this sense frequent use is made of the later ones.

On considering the prominence of the Cave Creek gypsum along the Medicine Lodge valley in Barber and the southeastern part of Comanche county together with Professor Cragin's account of its southern distribution in Oklahoma, it seems to the writer that this may serve as a means of dividing the mass of rocks. The principal objections to this are probably that first, the gypsum is not known at present to the northeast of Barber county and secondly, that by

1 Final Geological Report Artesian Underflow Invest., Pt. III, 1892, p. 127, Washington.

2 Ibid., p. 130.

3 F. W. Cragin, Colorado College Studies, Vol. VI, pp. 3, 18-49.

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the time southern Oklahoma is reached there are probably other beds of gypsum, at different horizons, of as great thickness and prominence as the one in southern Kansas. In answer to the first objection it may be said that it is thought the gypsum horizon may be followed farther to the northeast than it is now known. The fact that the Cave Creek gypsum may be readily followed and mapped in southern Kansas and northern Oklahoma, makes it worthy, in the opinion of the writer, to be ranked as a formation.

Professor Cragin divided the Cimarron series into two divisions, the lower of which is the Salt Fork, named from the stream of that name in Comanche and Barber counties and northern Oklahoma; and the upper, the Kiger from a creek of that name in Clark county. The Cave Creek gypsum is the upper formation of his Salt Fork division, so that it may be used to separate the two divisions which the writer regards as formations. Consequently the name of the lowest formation of the Cimarron series, or Red-Beds, is the Salt Fork,[1] that of the middle the Cave Creek gypsum, and the highest formation the Kiger. The Salt Fork formation includes the Harper sandstone, Salt Plain measures, Cedar Hills sandstones and Flower-Pot shales of Professor Cragin; while in the Kiger formation are the Dog- Creek shales, Red Bluff sandstones, Day Creek dolomite, and Hackberry shales. The Big Basin sandstone which Professor Cragin gives as forming the top of the Kiger seems, to the writer, to belong in the Comanche series. This classification may be expressed in the following table:

Upper Permian?	Cimarron series	Kiger formation
		Cave Creek gypsum
		Salt Fork formation.

Professor Cragin has kindly informed me, in advance of publication, of the great prominence of dolomite in the Dog Creek shales of central Oklahoma. From his account it is quite probable that in central Oklahoma this terrane is entitled to the rank of a formation in which case its northern extension into southern Kansas would have the same rank. His description is as follows: "The Dog Creek persists and finds great emphasis in Oklahoma, being more

1 On some of the maps this stream is called the Nescatunga river until it unites with the Medicine Lodge river to form the Salt Fork in the northern part of Oklahoma. This name is more euphonious and has the advantage of being only one word, but the rule governing priority would decide in favor of retaining Salt Fork.

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positive there in its character than in Kansas and thicker and more complex than the Cave Creek; and if the latter should be ranked as a formation, the Dog Creek should be also. In central Oklahoma the Dog Creek is a great *dolomite* formation, laminated dolomites occupying a very great part of its thickness, and a great body of such dolomite forming there its uppermost member. Thus it is strongly distinguished from the Kiger above it as well as from the Cave Creek below. It is well displayed in the stony hills, east of Watonga, which take their name from the profusion of irregularly broken plates and slabs formed by weathering upon its outcrops. It is shown quite as well in the infrasylvan amphitheater at the head of Salt creek, where the formation is at least 100 feet thick.

"The Cave Creek persists in its tripartite character, the Sheiner gypsum having a thickness of 15 to 18 feet in central Oklahoma, and the Medicine Lodge gypsum and Jenkins clay being correspondingly well developed. The Cave Creek should undoubtedly be raised to what you call formation rank."

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CRETACEOUS.

COMANCHE SERIES OF KANSAS.

REVIEW OF PREVIOUS WORK.

The geology of southern Kansas south of the Arkansas river was comparatively unknown until within a few years. However, during the last decade, thanks to the earnest investigations of St. John, Cragin, Hay and Hill, we are now as familiar with the stratigraphy and classification of its rocks as with those in any part of the western half of the state. Before beginning the description of the Cretaceous formation it is believed that a brief historical review of the development of our knowledge of the Cretaceous rocks of southern Kansas will prove of interest to the reader. No attempt will be made to mention every reference to the geology of this part of the state, but it is thought that at least all the important papers will be considered.

Mudge, 1878.—The "Geology of Kansas" was the first work that really attempted to give a description of the geology of the entire state[1]. On the "map showing the superficial strata of Kansas," that portion of the state south of the Arkansas river is colored as belonging to the Upper Carboniferous and Cretaceous systems; the line of division commencing in the northwestern part of Reno county and running southwesterly across Pratt, the southeastern part of Edwards [now Kiowa], Comanche and Clark counties.[2]

Under the account of the Cretaceous system we have the following statement: "That portion [of the state] south of the Arkansas river, and west of Harper county has been little examined, either by myself or others, but appears to be represented by the Fort Benton and Dakota groups" [upper Cretaceous[3]].

1 Swallow's Preliminary Report of the Geological Survey of Kansas, 1866, apparently makes no reference to the geology of southwest Kansas. The description of the geology of central Kansas is very meagre, while it is stated that the Tertiary occupies "a considerable portion of western Kansas; but we have had no opportunity of examining these formations, and therefore cannot give any detailed description of them." (P. 40).

2 First Biennial Report State Board Agriculture of Kansas, p. 47.

3 Ibid., p. 55.

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St. John, 1883.—The next important paper is St. John's "Sketch of the Geology of Kansas,"[1] and on his "Geological Map of Kansas" all the county south of the Arkansas river is mapped as upper Coal Measures and Cretaceous, though the line of division is represented considerably farther east, crossing the counties of Reno, Kingman and Harper in a nearly north and south line.[2]

In the description of the Dakota formation it is stated that in the Arkansas valley, horizons similar to those near Brookville [Saline county] have been discovered "which are characterized by a molluscan fauna, some of whose forms, at least, indicate more intimate affinities with the Texan Cretaceous fauna than has heretofore been observed so far north in deposits of this age."[3]

Cragin, 1885-'86.—In this year Professor Cragin published his "Notes on the Geology of Southern Kansas."[4] The greater part of the paper is given to a description of the Red-Beds and Gypsum Hills, but the latter part of the paper gives an account of the overlying formations. Professor Cragin says: "The deposits above the gypsum I examined but little, and only in western Barber and eastern Comanche counties. They belong to the Benton [Upper Cretaceous] and later deposits. * * * A locality a few miles southwest of Sun City, locally known as the 'Black Hills,' affords an easily recognized horizon for reference in any studies that may be made of the neighboring formations, being well up above the gypsum, conspicuous, and quite unique. It may be designated as the 'Black Hill horizon.' The deposit from which the hill takes its name is a bed of carbonaceous and rapidly decomposing shale. In connection with the shale are found fragmentary seams of poor lignite. Immediately above and below this is a layer of shell conglomerate made up largely of *Ostrea* and *Gryphaea.*

"Below these is a formation quite unlike any other I have seen or heard of in Kansas, and well worth a visit to the place to see. It is a variegated sandstone, unfortunately too friable for utility, but displaying a most beautiful variety of colors. Brown, purple, blue,

1 Third Biennial Report State Board of Agriculture of Kansas, p. 571.

2 See map between pp. 574 and 575.

3 Ibid., p. 588.

4 Bulletin Washburn College Laboratory Natural History, Vol. 1, April 1885, pp. 85-91, Topeka.

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crimson, scarlet, pink, orange, lemon-yellow, and white: these and many intermediate shades may be seen, in brightest contrast and most delicate blendings. Streaked and interstreaked in a tortuous manner, clouded and blended, blotched and blurred, the dispositions of the colors are as endless as their shades. * * * In the upper portions of these hills remains of large fossil turtles are reported. I succeeded in securing only some fragments; insufficient to determine whether they are to be referred to the Niobrara or the Tertiary, but sufficient to verify the truth of the reports. I have no positive evidence of the Niobrara here as yet, but I am inclined to think it here, and that it would be found to begin shortly above the horizon of the Black Hill shale."[1] In this paper we have the first mention of a section which has been so well described in the later papers of Professor Cragin. The various colored sandstone above the Red-Beds is that formation which is now known as the Cheyenne; the black shales of the Black Hill southwest of Sun City belong in the Kiowa shales of Cragin; while the tops of the hills are capped by Tertiary.

The following year Professor Cragin modified the above correlation, concluding that "The variegated sandstone * * * probably marks the upper limit of the Dakota, and the overlying dark shales, from which the 'Black Hill' takes its name, the base of the Benton.

"The large turtles mentioned in the same article are probably Tertiary, occuring only upon the very highest hills fifteen to forty miles north and west of Medicine Lodge."[2]

St. John and Hay, 1887.—Professor St. John published his "Notes on the Geology of Southwestern Kansas" in 1887, in which he stated that "Only the Dakota and Niobrara members [Cretaceous] have been with certainty identified in this southwest region." He described the Dakota formation as consisting in the lower portions "of soft white-and-yellow stained sandstone, in places obliquely laminated, with hard, indurated layers, the weathering of which produces monumental forms, recalling those which the elements have fashioned in the Tertiary sandstones on Monument creek in Colo-

1 Ibid., p. 90.
2 Ibid., vol. I, 1886, p. 166.

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rado. This sandstone horizon is evidently very variable in thickness and may indeed be absent locally. It is succeeded by dark blue, drab and buff shales 50 to 70 feet above a soft yellow, sometimes reddish, obliquely laminated sandrock, five feet, more or less, and below a stratum of drab sometimes sandy, shale, two to five feet, containing streaks of lignite and fragments of bituminized wood * * *

Succeeding the shale horizon occur successive beds of shaly limestone, alternating with drab and buff, more or less arenaceous shales, which are charged with fossils, mostly belonging to a species of *Gryphaea* resembling *G. Pitcheri*, an *Exogyra*, *Trigonia*, *Turritella*, etc. The latter also occurs in the upper portions of the underlying shales. The association of species and abundance of individuals strongly recall occurrences in Texas. * * * Judging from data at present accessible, it would appear that the present region marks the limits of the northern extension of this peculiar southern fauna of the Cretaceous."[1]

In a "Report on Geology" to the Kansas Academy of Science in 1885 Professor Hay stated that "The beautifully variegated sandstones referred to by Professor Cragin in a printed notice of a run through Barber county I am inclined to consider as undoubtedly Dacota, but in the only place where I got at their base they seemed to rest on the eroded surface of the Red Rock."[2]

Cragin, 1889-'90.—In his "Geological notes on the region south of the Great Bend of the Arkansas" Professor Cragin states that he "wrongly assigned all the formations beween the great gypsum horizon and the base of the Tertiary southwest of Sun City to the Benton epoch.[3]

In this paper Professor Cragin describes a section of these rocks as shown in a ravine, and higher on a hill side to the southwest of Belvidere, on the Medicine Lodge river. So far as known this is the first accurate section of the Cretaceous rocks of southwest Kansas. Following the section were lists of fossils from the differ-

1 Fifth Biennial Report Kansas State Board of Agriculture, pp. 143, 144.

2 Transactions Kansas Academy Science, Vol. X, 1887, p. 22.

3 Bulletin Washburn College Laboratory Natural History, Vol. 2, February 1889. p. 33. Topeka.

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ent divisions.[1] As a result of this study Professor Cragin stated that "The above partial study of the Medicine river Cretaceous suffices to show something very like the fauna of the recently discovered Comanche series of Texas, which is said to be lower than the Dakota, or the lowest hitherto known American Cretaceous."[2] Professor Hill referred to the above paper in his book on the "Neozoic Geology of Southwest Arkansas" stating that the rocks of the above section "Undoubtedly represent the Comanche series," correlating No. 5 of Professor Cragin's section, with the Fredricksburg division of the Comanche, and No. 6 of Cragin probably as identical with the Trinity.[3]

In December of the same year Professor Cragin named the variegated sandstones at the base of the Cretaceous in the Medicine Lodge valley, the Cheyenne sandstone from the Cheyenne rock at Belvidere, Kansas.[4] In this article Professor Cragin described the first fossil from the Cheyenne sandstone, part of a Cycad, for which he proposed the name *Cycadaidia munita* and doubtfully correlated the formation with the Trinity of Texas. The following year Professor Cragin published an article "On the Cheyenne sandstone and Neocomian shales of Kansas,"[5] in which he gives an excellent description of the Cheyenne sandstone, stating its lithological characters, thickness and distribution. The typical region of the development is given as Belvidere, where it attains a thickness of 40 feet and is reported "In parts of Barber, Pratt, Kiowa and Comanche counties."[6]

In reference to its age Professor Cragin says: "While this sandstone seems to be closely related to the Potomac and Tuscaloosa divisions of the Atlantic states, to the Trinity division of Texas and Arkansas, and to the Atlantosaurus beds of Wyoming and Colorado, it would be premature to assert positively, at this time, the precise identity of any two of these. Incomplete geographic and stratigraphic data suggest a probability that the above-described sandstone represents a portion of the Trinity division; but reference of

1 Ibid., pp. 35-37.
2 Ibid., p. 37.
3 Annual Report Geological Survey Arkansas for 1888, Vol. II., p. 115, f. n.
4 F. W. Cragin, Bulletin Washburn College Laboratory Natural History, Vol. II, Dec., 1889, p. 65, Topeka.
5 Ibid., Vol. II, Mar., 1890, pp. 69-81.
6 Ibid., p. 69.

it to the Trinity division in any way, until the Indian Territory interval has been explored, is of course merely a supposition however probable."[1]

The latter part of the paper describes quite fully the distribution and stratigraphic characters of the shales between the Cheyenne and Tertiary. This outcrop is described as very irregular, beginning in the northwestern part of Barber county, near the headwaters of the Medicine Lodge river and extending in an irregular line from that locality across Comanche and Clark counties to the eastern part of Meade county. The thickness of these shales is given as variable, nowhere exceeding 150 feet, their maximum being in Kiowa county south of the Medicine Lodge river. Sections of the Cretaceous are described at Belvidere and Blue Cut Mound in Kiowa county, and upper West Bear creek and Bluff creek in Clark county. The sections are divided into zones, the lithological characters of which are described together, with lists of the more characteristic fossils occurring in them.[2]

Hay, 1890.—During the summer of 1885 Professor Hay, under the direction of the U. S. Geological Survey, studied that portion of Kansas south of the Arkansas river. The description of this work was not published until 1890, when it appeared as a bulletin of the U. S. Geological Survey entitled "A Geological Reconnaissance in Southwestern Kansas."[3]

The "Geological Map of Southwestern Kansas" accompanying this bulletin represents the formations of the country south of the Arkansas river as belonging to the Jura-Trias, Cretaceous, Tertiary and Pleistocene systems. The line of division between the Jura-Trias and Cretaceous or between the Jura-Trias and Tertiary where the Cretaceous is not represented, extends in an irregular line from Stafford county through Reno, Kingman, Pratt, Barber, Kiowa, Comanche, Clark and Meade counties to the state line. Professor Hay described the Dakota formation near the Barber and Comanche county line as "being mostly composed of yellow, greenish, white

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1 Ibid., pp. 69, 70.

2 For the description of these sections see Ibid., pp. 75, 76, 77 and 79. The above article was republished in the American Geologist for October 1890 and June, 1891; in Vol. VI, pp. 233-238, and Vol. VII, pp. 23-33.

3 Robt. Hay, Bulletin U. S. Geological Survey, No. 57, pp. 49 and Map, Washington.

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and red sandstones" which are separated unconformably from the subjacent Red-Beds. He stated that "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 form[1]." The above sandstone is evidently the one described by Professor Cragin as Cheyenne. The overlying fossiliferous shales are mentioned by Professor Hay as occurring in the hills north of Sharon, Barber county, and beyond the Barber and Comanche line, while "Specimens of the shells were given to us from localities near the northwest corner of Barber county and the neighboring part of Edwards [now Kiowa county]. The bed at the three localities where we observed it was composed almost entirely of small shells in a matrix of limy conglomerate, the pebbles being very few, the shells making up three-fourths of the mass[2]." In correlating this bed Professor Hay stated that "with reserve we are inclined to place the stratum called the 'Shell bed' * * * in the Fort Benton group."[3] Professor Hay referred to St. John's hesitation in correlating this bed with the Benton of northern Kansas, and he also referred to Professor Hill's description of the Lower Cretaceous in Texas "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 [Cheyenne], 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."[4]

Cragin, 1891.—In this year Professor Cragin published an article entitled "Further notes on the Cheyenne sandstones and Neocomian shales."[5] Professor Cragin states that he had examined the Comanche of northern Texas in company with Professor Hill and agreed with him in correlating No. 5 of his Belvidere section with

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1 Ibid., p. 27; see Fig. 5, p. 28, which represents a section about six miles southwest of Sun City where the Dakota is represented as resting on an eroded surface of the **Jura-Trias**.

2 Ibid., p. 28.

3 Ibid., p. 27.

4 Ibid., pp. 29, 30.

5 American Geologist, Vol. VII, March, 1891, pp. 179-181.

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the Fredericksburg shale and No. 6 of the Belvidere with the Trinity sandstone of Texas. He further said: "The paleontologic and lithologic identity of No. 5 of my Belvidere section with a certain, shell-conglomerate occurring at Weatherford—the lowest Gryphaea-bearing horizon of Texas—is such as to warrant me in asserting the essential chronologic equivalency of the two horizons."[1]

Williston, 1892.—The small geologic map prepared by Professor Williston is the first one to represent approximately the geological formations south of the Arkansas river as they are now defined. Beginning with the lower Professor Williston indicates the following terranes for this portion of the state: On the eastern side to the west of the Arkansas river, upper Carboniferous and Permian; thin Triassic followed by a band of Comanche Cretaceous, the greater part of the region north and west of this being covered by Loup Fork Tertiary, with a small deposit of Niobrara Cretaceous in the northern part of Meade, southeastern corner of Gray, and southwestern corner of Ford counties; south of the Great Bend of the Arkansas river, parts of Edwards, Stafford and Reno counties are represented as covered by the Dakota Cretaceous. The area of the outcrops of the Comanche Cretaceous is represented as beginning in the southwestern part of Kingman county, extending westerly across the northern part of Barber into the southeastern corner of Kiowa, whence it makes a turn running southeasterly into the western part of Barber thence in an irregular line westerly, southwesterly and northerly across Comanche county into the southwestern corner of Kiowa and thence to the southwest diagonally across Clark county into the southeastern corner of Meade county. In general the line between the Cretaceous and Triassic is represented as extending southwest from Reno county across Kingman, Pratt, Barber, Comanche and Clark counties to the state line.

Hay, 1893.—On the "Geological and Topographical Map of Kansas" accompanying Professor Hay's "Geology and Mineral Resources of Kansas"[2] the approximate eastern boundary of the Cretaceous formations is represented as extending in general south-

1 Ibid., p. 180.

2 Robt. Hay, Eighth Biennial Report Kansas State Board of Agriculture, pp. 99-163.

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westerly from the valley of the Arkansas river across Stafford, Pratt, Barber, Comanche and Clark counties. This paper discusses the different geological formations of Kansas, which are arranged in tabular form on page 101. In his description of the Cretaceous, the Trinity sands and Comanche Peak beds are described as the two lowest formations of this system as follows: "In the northwest corner of Barber county, in a ravine on the south side of Medicine river, is an outcrop of beds, the bottoms of which rest on an eroded surface of Red-Beds something over 100 feet above the great gypsum horizon. The whole is not more than 25 or 30 feet of vertical exposure[1], * * * when I first saw these, I was inclined to synchronize them with the Cretaceous beds (Dakota and Benton) which were known to exist on the south of the Arkansas river further west. Professor St. John, however, who saw the beds in the region further south, pointed out the resemblance of the fauna of the shell bed to Texas Cretaceous forms, and afterwards others have worked out the stratigraphy of the beds up the valley of the Medicine and some of its tributaries and made collections of paleontological remains. Professor R. T. Hill, of Texas, has also seen fossils belonging to these beds, and there seems now no doubt that they belong to lower horizons than the Kansas Dakota. There is no reason why the Texan names given to the beds—Trinity for the lower, fine-grained sandstones, and Comanche Peak for the upper strata—should not be permanent, but some of the paleontologists still differ as to whether certain of the shells are lower Cretaceous or of the Jurassic type. In the table I have placed them as lower Cretaceous. They do not seem to have large areal development, but they thicken to the west. The rocks are well shown in the upper Medicine valley, on Thompson creek and in the Land creek ravines to the southwest, but the 'plains marl' and quaternary formations hide their extensions under the body of the high prairie."[2] A good picture of the Osage rock, Cheyenne sandstone on Medicine Lodge river above Belvidere appears in this report.[3]

Cragin and McGee, 1894.—In this year appeared Professor Cragin's

1 The thickness of Trinity sands and Comanche Peak beds is given as 175 feet each in the table of the rocks of Kansas. See p. 101.

2 Ibid., pp. 108, 109.

3 Ibid., p. 109.

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ERODED LEDGE OF CHEYENNE SANDSTONE IN HELL'S-HALF-ACRE, WESTERN SIDE BARBER COUNTY.
(Photographed by Prosser, 1896.)

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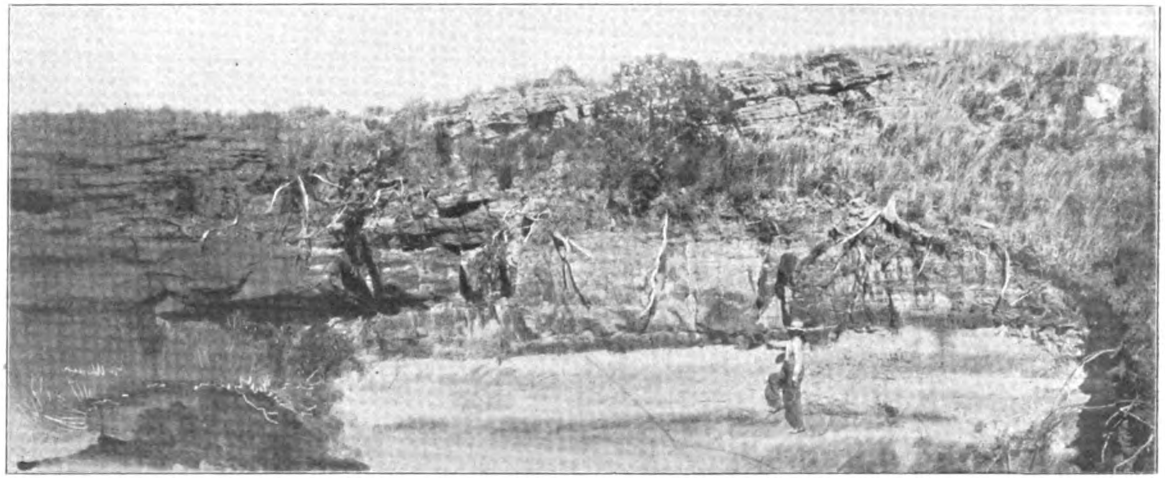

CONTACT OF CHEYENNE SANDSTONE AND "RED-BEDS" SHOWING UNCONFORMABILITY, WESTERN SIDE BARBER COUNTY.
(Photographed by Prosser, 1896.)

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description of certain "New and Little Known Invertebrata from the Neocomian of Kansas."[1] The invertebrates described in this paper were collected in Kiowa and Clark counties. In connection with the description of these species are notes explanatory of the typical sections of this formation. The geological systems covering Kansas south of the Arkansas river as represented on McGee's reconnaissance map of the United States,[2] are the Cretaceous Jura-Trias and Neocene.

Cragin and Hill, 1895.—Professor Cragin published further "Descriptions of Invertebrate Fossils from the Comanche Series in Texas, Kansas and Indian Territory[3] which was followed by another article entitled "Vertebrata from the Neocomian of Kansas."[4] In this paper Professor Cragin names the fossiliferous shales overlying the Cheyenne in Kiowa county, his definition being as follows: "The designation, *Kiowa shales,* is proposed for the inferiorly dark-colored and superiorly light-colored shales that outcrop in several of the counties of southwestern Kansas, resting upon the Cheyenne sandstone in their eastern and upon the 'Red-Beds' in their middle and western exposures, and being overlaid by brown sandstones of middle Cretaceous age, or Tertiary or Pleistocene deposits according to their locality.

"The Kiowa shales are a locally modified southern extension of part of Hill's Comanche series, cut off from the main part by erosion. They are named from the place of their typical occurrence, Kiowa county, Kansas; and in that county they outcrop only in those southern townships which once formed the northern part of Comanche county. The fossils of these shales are chiefly those which, in Texas, are most common in the Fredericksburg division [Comanche series]."[5] In June of this year Prof. Hill first announced the "Discovery of a typical dicotyledonous flora in the Cheyenne sandstone" * * * "This sandstone has heretofore been referred to the Trinity Division of Texas by Prof. F. W. Cragin,

1 F. W. Cragin, American Geologist, Vol. XIV., July, 1894, pp. 1-12, and plate I.

2 Fourteenth Annual Report U. S. Geological Survey, Pt. II., 1894. Reconnaissance map of the U. S., showing distribution of the geologic systems so far as known; compiled from data in possession of the U. S. Geological Survey, by W. J. McGee, 1893. Washington.

3 F. W. Cragin, Colorado College Studies, Vol. 5, April, 1895, pp. 49-69.

4 Ibid., pp. 69-73, Plates I, II.

5 Ibid., p. 49

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but the flora as determined by Prof. F. H. Knowlton of the U. S. Geological Survey consists entirely of species hitherto supposed to be peculiar to the Dakota Group, while the flora of the Trinity Division of Texas as has been reported by Professor Fontaine is all of the non-dicotyledonous Potomac type. The Cheyenne sandstones are separated from the true Dakota sands of Kansas by nearly 200 feet of shale, containing a molluscan fauna composed of fifteen species characteristic of the Washita Division of the Comanche Series of Texas, and about twenty littoral species peculiar to the locality."[1]

In September of the same year Professor Hill published an extended article "On Outlying Areas of the Comanche Series in Kansas, Oklahoma and New Mexico"[2] in which the flora of the Cheyenne sandstone and the fossils of the overlying shales are fully discussed. The introductory part of the paper is an excellent description of the topographic features of southern Kansas, followed by a brief discussion of the correlation of the Cretaceous rocks of that region. Professor Hill's route was from the town of Medicine Lodge up the river valley along which the Red-Beds are excellently exposed, to Sun City where he crossed the river and made a section from the river valley to the top of Stokes Hill (called Black Hills in the paper) in the southeastern part of Kiowa county. In discussing the former denudation of this region, Professor Hill said "Near the head-waters of this river [Medicine Lodge] a thin group of Cretaceous formations lies between the Tertiary and the Red-Beds. To the east the Plains formations rest directly upon the Red-Beds, the intervening Cretaceous deposits having there been denuded in early Tertiary time."[3] Prof. Hill published a complete and accurate section of Stokes hill, making a number of divisions in the Kiowa shales, which in his article are called Belvidere shales. In a foot note Professor Hill stated that since writing his paper "Professor Cragin had proposed the name Kiowa for the shale beds. The name would no doubt have priority over the one herein used by me, but owing to doubt as to which subdivision Professor Cragin would

1 American Journal Sci., 3d series, Vol. 49, June 1895, p. 473.
2 Ibid., Vol. 50, pp. 205-235.
3 Ibid., pp. 205, 206.

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have included the beds 2, 3 and 4, I prefer to retain for the present the term Belvidere shales."[1] It is stated that "As we approach Belvidere the Cheyenne sandstone begins to form the principal slope of the river basin, and west of that village the bed of the river rises until it is upon the Cheyenne sandstones, while some bluffs and castellated remnants of the sandstones are beautifully exposed in the north side of the valley.

"Five miles west of Belvidere the railroad has made magnificent cuts into the beds so that they are there seen better than at any other locality. Here the comparatively steep wall of the valley affords a fine section from the old deposition plain of the Great Plains Tertiaries down into the Cheyenne sandstone, the buttes on the south margin of the river valley being remnants of the main body of the plains to the northward."[2] Following this is a detailed section of the Blue Cut which gives Cheyenne sandstone, Belvidere shale and Dakota sandstone capped by the Plains Tertiary. It is stated that "The shales overlying No. 4 we call the Belvidere shales from the town near which they can best be seen." Following this is a generalized section showing the classification of these rocks. At the bottom are the Red-Beds followed by the Belvidere beds which are subdivided into —b. Blue and black shale with fossils and —a. the Cheyenne sandstone. Above is the Dakota sandstone finally capped by the Plains Tertiary.[3] A list of fossil plants from the Cheyenne sandstone as identified by Professor Knowlton is given, followed by a critical discussion of the species. In conclusion, Professor Knowlton says "All the above mentioned species belong to the Dakota group as it is usually accepted, but as a matter of fact no detailed stratigraphic work has yet been done with a view to ascertaining the range and association of the fossil plants referred to this formation. * * * But all that can now be stated is that these species belong to the Dakota group as it has usually been accepted, and have never before been identified outside of it."[4]

The fossils collected from the Kiowa shales were identified by

1 Ibid., p. 211.
2 Ibid., p. 209.
3 Ibid., p. 211.
4 Ibid., 213, 214.

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Mr. Stanton, whose lists are given accompanied by critical discussion of certain species. Following this is an analysis by Professor Hill stating from what other formations they have been identified. As a result of this study Mr. Hill concludes "Mr. Stanton's studies of the fossils of the Belvidere shales also demonstrate the opinions I have long entertained, that these fossils are largely of the age of the Washita division of my Texas section, and not solely the Fredericksburg and Trinity divisions as maintained by Cragin. I am glad to have my own conclusions sustained by such an authority, and I fully agree with him that the Belvidere beds represent in general the Washita division and probably the attenuated Fredericksburg as seen in the north Texas sections."[1]

In reference to the correlation of the Cheyenne, Professor Hill says: "Prof. Knowlton's determination of the dicotyledonous Dakota flora in the top of the Cheyenne sandstone shows that from a paleontologic standpoint these sandstones have no resemblance to the flora of the Trinity divisions at Glen Rose, Texas, beds which contains a flora of typical Potomac non-dicotyledonous species. The Cheyenne sandstones are of far later age than the Trinity, and occupy a stratigraphic position at the base of the Washita midway between the Trinity and Dakota. * * * Concerning the correlations of the Belvidere beds with the Neocomian, as done by Professor Cragin, we can only repeat our opinion, founded upon facts previously given, that the Washita division is homotaxially nearer the equivalent of the Gault, and that the lower lying beds of the Trinity divisions are more nearly the nearer equivalents of the Neocomian in the United States."[2] Professor Hill's final statement is "These beds represent the modified attenuated northern extension of the Washita division and probably a portion of the Fredericksburg division of the Comanche series of Texas, which as we have previously shown, far overlapped to the northward those of the Trinity division."[3]

The previous paper was followed in three months by Professor Cragin's, entitled "A Study of the Belvidere Beds."[4] Professor

1 Ibid., p. 223.
2 Ibid., pp. 226, 227.
3 Ibid., p. 234.
4 F. W. Cragin, American Geology, vol. XVI, Dec. 1895, pp. 357-386.

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Cragin states that he had formerly used the name Belvidere in manuscript as a designation for the Comanche shales of southern Kansas, but rejected the name on account of its similarity to the Belvedere beds, a name applied to certain Tertiary sands of Austria. He proposes, however, that if the term Belvidere be retained, it be used as a name for the division to which he refers the Cheyenne sandstone, Champion shell-bed and Kiowa shales, which is identical with the usage already proposed by Professor Hill for this term in his "Plains Section" in the article just reviewed.[1] A part of this paper is devoted to a discussion of the former one of Professor Hill's and is of a controversial nature. Professor Cragin here suggests for the first time, a number of names for divisions of the Cheyenne sandstone and Kiowa shales. The lower part of the Cheyenne sandstone is termed the Corral sandstone which "is so named from having a considerable portion of its thickness exposed in the walls of the 'Natural Corral.' The latter is a short box canyon on the Lanphier claim in the southeastern corner of Kiowa county."[2] The upper part of the Cheyenne sandstone is termed the Elk creek beds, and they are separated into two subdivisions termed respectively the Lanphier beds and the Stokes sandstone. The Lanphier beds "frequently observed but not treated of hitherto by the writer, have recently been described by Professor Hill, being No. 2 of his Black Hills and Blue Cut sections. * * * The Lanphier beds pass gradually upward into the similarly leaf-bearing *Stokes sandstone*, a few feet in thickness (No. 3 of Professor Hill's Black Hill's section)."[3] For the thin stratum of gray shale-conglomerate which caps the Cheyenne sandstone at Belvidere, its upper surface forming the floor beneath the paper shales, Professor Cragin proposes the name Champion shell-bed. This division is evidently regarded as a formation by Professor Cragin who gives it a rank equal to that of the Cheyenne sandstone and Kiowa shales. Following the description of the Champion shell-bed is a list of its fauna which numbers thirty six species, twenty two of which are known to extend into the Kiowa shales, though it is stated that the number of species common to the Champion and Kiowa will prob-

1 American Journal vol. L, p. 211.
2 Loc. cit., p. 366.
3 Ibid., pp. 367, 368.

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ably be increased by further explorations. The Kiowa shales are stated to have a maximum thickness of at least 125 feet on the Medicine Lodge river and 150 feet on Bluff creek in Clark county. The fauna consists of fifty one invertebrate species and thirteen vertebrate. Following the lists of species are critical notes in which Professor Cragin discusses some of the conclusions of Stanton and Hill. The Kiowa shales are subdivided into two divisions, the lower known as the Fullington shales and the upper the Tucumcari. The Fullington shales are named after the great Fullington ranch at Belvidere on which they have most extensive outcrops. Professor Cragin says "They are not sharply separated from the overlying Tucumcari shales either lithologically or paleontologically. * * * At Belvidere they are separable into two principal subdivisions, the lower of which is the Black Hill shale * * * The name was derived from the Black Hill adjoining Hells Half Acre on Elk creek in Comanche county. The terrane consists of a bed of black carbonaceous clay-shale fifteen or twenty feet thick, resting upon the Champion shell-bed and characterized by a peculiar method of disintegration, breaking down under the weather into small, flat and thin, sharp-edged spalls resembling wafers, a peculiarity that has suggested for this shale the name of *Wafer-shale*.[1] The upper division of the Fullington shales is termed the Blue Cut shales from the deep railway cut a few miles south-southwest of Belvidere, which is known as the Blue Cut. The Tucumcari shales or upper division of the Kiowa is "Characterized in part by this variable *G.* [*Gryphaea*] *tucumcarii*, the name *Tucumcari shales* is here given, after Mount Tucumcari, New Mexico, where the zone of *Gryphaea tucumcarii* was originally discovered by Mr. Jules Marcon.

These shales are well developed in the vicinity of Otter creek, on Thompson creek, and on heads of several branches of the Medicine Lodge river.

They are chiefly clay-shales and lighter hued as a whole, than the Blue Cut shales which graduate insensibly into them. At their summit they frequently contain bands and concretions of clay ironstone."[2]

1 Ibid., pp. 379, 380.
2 Ibid., p. 382.

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Finally under the heading "Correlation" Professor Cragin reviews the facts at hand and concludes that "The evidence taken altogether seems to point to the conclusion that the Kiowa shales of Kansas, * * * represent a group of sediments intermediate between the Fredericksburg and Washita divisions [of the Comanche], and one which, as a meeting ground of the faunas of these two divisions, can not satisfactorily (though it may arbitrarily) be referred to either."[1]

Haworth, 1896.—On Professor Haworth's "Reconnaissance Geological Map of Kansas"[2] the geological formations south of the Arkansas river are represented more accurately than on any previous map. In the eastern part of this region in Sedgwick and Sumner counties are Permian rocks west of which in Kingman, Harper, south Comanche and Clark are the Red-Beds, succeeding which is a band of Comanche extending from the northwest corner of Barber in an irregular southwesterly line across Comanche and Clark counties into the southeastern part of Meade county. The remainder of this area to the north of the Comanche and Red-Beds is mapped as of Tertiary age.

CLASSIFICATION.

In this Report all the Cretaceous deposits studied south of the Arkansas river, occurring in Barber, Kiowa, Comanche and Clark counties, except a few exposures of Dakota-like sandstone, will be referred to the Comanche series. As is well known, the extent and details of the most interesting formations composing this series in northern Texas were first accurately described by Professor Hill through whose enthusiasm and indefatigable efforts the series has since been traced far southward into Mexico.

The writer considers that in Kansas the Comanche series is composed of two formations which may be readily distinguished by both their lithologic and paleontologic characters and may also be easily followed in the field for the purpose of areal representation.

1 Ibid., p. 383.
2 University Geological Survey of Kansas, vol. I, pl. XXXI.

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CHEYENNE SANDSTONE.

For the lower formation it is proposed to use the name Cheyenne sandstone which was first proposed by Professor Cragin in 1889[1] and well characterized by him a few months later[2]. This formation is composed mainly of a rather coarse-grained, friable sandstone, in general of yellowish-gray to whitish color, but frequently spotted and striped with bright colors as purple, crimson, brown, etc. In places it is conspicuously cross-bedded, as for example, in the arroyo a short distance south of Belvidere, termed by Professor Cragin, the Champion draw, as may be seen in the plate illustrating the Cheyenne sandstone at this locality, Plate XVII.

The maximum thickness of the formation is in the Medicine Lodge region in the adjoining corners of Kiowa and Barber counties. Professor Cragin gives it as varying from about 40 to 65 feet;[3] Professor Hill's section of the Black Hills gives a total of 71 feet for the Cheyenne,[4] while the writer's measurements in this region give a thickness varying from 40 to about 55 feet. The outcrop of this formation is usually rugged. There are layers of variable thickness that have been more firmly cemented but, on account of the friable nature of the sandstone, the ledges have been carved by erosion into pillars, chimney rocks and other fantastic and striking forms. An interesting locality to visit for the purpose of observing these effects of erosion where may be seen a "chimney rock" and a number of small pillars is that which is known locally as Hell's Half Acre, in Comanche county near the Comanche-Barber county line, eight miles southeast of Belvidere, Plate XV. There are numerous excellent exposures from the above locality toward Belvidere, as in the "Natural corral" on the Lanphier claim five and one half miles southeast of Belvidere; along the bluffs of Walker creek; in the Champion draw near the foot of the hill south of Belvidere; and especially on the north side of the river above Belvidere where the Osage rock forms a conspicuous landmark. An

1 F. W. Cragin, Bulletin Washburn College Laboratory Natural History, Vol. II, December 1889, p. 65, Topeka.

2 Ibid., March 1890, pp. 69-73.

3 F. W. Cragin, American Geologist, Vol. XVI, pp. 366, "the corral sandstone is ordinarily 30 to 50 feet"; 367, the Lanphier beds are "10 or 15 feet" and the "leaf-bearing Stokes sandstone, a few feet."

4 American Journal Science, 3d Series, Vol. L, pp. 207, 208.

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excellent photograph is given of this rock from the western side —Plate XVI—but its massive form and varied colors can only be appreciated when seen in the bright sunshine of the early morning.

The fossils of the Cheyenne consist entirely of plants, with the exception of some shells found by Mr. Beede and the writer in a sandstone referred to the Cheyenne occurring north and south of Avilla.

Fossil wood is common in various localities. In the upper part of the sandstone Hill found the dicotyledonous flora which according to Professor Knowlton consists of the following species:

Rhus Uddeni Lx.
Sterculia Snowii Lx.
Sassafras Mudgei Lx.
Sassafras cretaceum Newby., var. *obtusum* Lx.
Sassafras n. sp.
Glyptostrobus gracillimus Lx.
Sequoia sp.;[1]

to which perhaps should be added the cycad described by Professor Cragin in 1889 under the name of ***Cycadoidea munita***[2]. As has already been mentioned, Professor Knowlton states that up to the present time the dicotyledons identified from the Cheyenne sandstone are not known outside of the Dakota formation.

In October 1896, Professor Lester F. Ward of the U. S. Geological Survey studied some of the exposures of the Cheyenne sandstone in Comanche and Barber counties. Judging from the published report of his paper before the Philosophical Society of Washington, Professor Ward considers the Cheyenne flora to belong in rocks of Lower Cretaceous-Comanche age instead of Dakota. The secretary of the society reported Professor Ward as follows: Fossil plants were obtained at three different horizons, showing corresponding changes in the flora. So far as they go they confirm Mr. Hill's conclusion that at least the upper part of the Cheyenne sandstone belongs to the Washita Division of the Comanche Series. It may be

1 American Journal Science, 3d Series, Vol. L, p. 212, which is copied by Professor Cragin in American Geologist, Vol. XVI, p. 367.

2 F. W. Cragin, Bulletin Washburn College Laboratory Natural History, Vol II, p. 66.

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approximately correlated with the Raritan Clays or the Albirupean series of the Potomac formation[1]."

KIOWA SHALES.

For the upper formation it is proposed to use the name Kiowa shales which was first published by Professor Cragin in 1895.[2] This formation name is accepted in the sense in which it was first defined by Professor Cragin as resting on the Cheyenne sandstone or Red-Beds and capped by deposits in the different localities, varying in age from brownish sandstones, generally called the Dakota, to Tertiary or Pleistocene. Later, Professor Cragin separated from it the lower stratum—No. 5 of his Belvidere section—which he names the "Champion shell bed" and gives it a rank equal to that of the Cheyenne and Kiowa in his classification.[3] The Champion shell-bed as exposed in Kansas does not appear to the writer to differ sufficiently from the superjacent Kiowa to be regarded as a distinct formation, and in this discussion is considered as the basal part of that formation. However, in correlating this bed with the Texan formations Professor Cragin advances a careful argument in favor of its rank as a formation. The following clear statement of his position was courteously furnished me by him—"It is impossible to judge correctly of its [Champion shell-bed] value by the study of Kansas alone. It can only be understood by first acquainting one's self with the formations of the Comanche series in Texas. Such comparative study shows clearly that the Champion bed is merely the extreme northern attenuated representative of the *Comanche Peak* limestone. The latter is the central member of Hill's Fredericksburg division, or the upper member of that division where, as in northern Texas and southern Indian Territory, the Barton creek (Capuria) limestone is missing. Studies made since the publication of my article 'A Study of the Belvidere beds,' make this clearer than ever. Indeed, with the exception of a few forms which are possibly peculiar to the northern shore-region of the Comanche Peak sea, the Comanche Peak and Champion faunas are identical. The Kiowa shales represent the Kiamitia and the Tucum-

1 Science, N. S., Vol. IV, Dec. 11, 1896, p. 883. Reported by the secretary, Mr. Bernard R. Green.

2 F. W. Cragin, Colorado College Studies, vol. V, April 5, 1895, p. 49.

3 American Geology, vol. XVI, pp. 361, 368.

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carri of Texas, Indian Territory and New Mexico. In the typical Texas area the Comanche Peak is a great formation, while the Kiamitia and Tucumcarri are limited. In Kansas, the Kiamitia and Tucumcani are amply developed and closely related, the lower formation shading into the upper, while the Comanche Peak (here called the Champion) is of little thickness and limited to the eastern part of the Comanche area, though rich, as everywhere, paleontologically. It is of course true that the Champion bed has many things in common with the Kiowa, and, where (as pardonably in this case) geology is to be bounded by state lines, may be viewed as a part of it. But viewed in the light of the fuller knowledge available, the Champion belongs to the *Fredericksburg* division, while the Kiowa shales belong to a higher division which I call the *Kiowa* but which Hill includes in his *Washita.* The flora of the Cheyenne sandstone, as reported by Hill and Knowlton, shows conclusively that this sandstone belongs to a later time than the Glen Rose, and its affinity with the Dakota flora probably brings it up out of the Bosque division altogether. So the Cheyenne also probably belongs to the Fredericksburg. There are therefore good paleontological grounds for separating the Champion bed from the Kiowa shales and considering it as nearly related to the Cheyenne. Genetically, the Champion bed seems to be closely related to *both* the Cheyenne and the Kiowa and to be transitional between them; but the bed, whether thus transitional or not, was *certainly deposited in Fredericksburg time,* as no one intimately acquainted with its paleontology and that of the Comanche series of Texas could possibly question."[1]

Again, Professors Hill and Cragin have proposed the term "Belvidere beds" as a general name for the Cheyenne sandstone, Champion shell-bed and Kiowa shales of southern Kansas; but if such a name be needed another term would better be substituted on account of the similarity to the Austrian name as already shown by Professor Cragin.

The maximum thickness of the Kiowa is given by Professor Cragin as "at least 125 feet on the Medicine Lodge river in Kiowa county, and 150 feet on Bluff creek in Clark county."[2] Professor

1 Letter of Professor Cragin, dated Dec. 14, 1896.
2 Ibid., p. 372.

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Hill obtained a thickness of 122 feet in his Black Hills' section, and 102 feet in the one at the Blue Cut.[1] The thickness of the sections measured by the writer is as follows:—Stokes' Hill (Black Hills of Hill) 112 feet; hill south of Belvidere 121 feet; Blue Cut Mound 131 feet; Avilla Hill in southern part of Comanche county, 110 feet; hill south of Hackberry creek, Clark county 135 feet; to the north in the Amphitheatre section of Bluff creek 140 feet; and on Mt. Nebo in the western part of Clark county 74 feet. In all of these sections the entire thickness is given, with the exception of the first two mentioned in which the Kiowa is not capped by another formation.

The rocks composing the Kiowa formation consist largely of shales as indicated by the name, Kiowa shales. A thin, hard stratum composed largely of calcareous and arenaceous material mixed with gypsum, containing usually great numbers of a small *Gryphaea*, is generally found at the bottom. Above this are very black, thin argillaceous shales with occasional thicker layers suggesting the name paper and wafer shales; while above, these change gradually to those that are coarser and bluish-black to gray in color. These fine black and coarser bluish-black to grayish shales form that portion of the formation which Professor Cragin calls the *Fullington* shales.[2] In turn these gradually change to yellowish-gray argillaceous shales with thin layers of limestone either yellowish or pinkish in color that contain an abundance of fossils, especially *Ostrea* and *Gryphaea*. For this upper part of the formation Professor Cragin has proposed the name *Tucumcari* shales.[3] This formation is well developed in that area formed by the adjacent northwest part of Barber, southeast corner of Kiowa and northeast corner of Comanche; in the southern part of Comanche county and across the central part of Clark county.

The fossils of the Kiowa consist of both vertebrates and invertebrates, a total of 78 species having been reported by Professor Cragin. The Champion shell-bed at the base of the formation contains 36 species according to Professor Cragin, twenty two of which occur above in the higher Kiowa, while fourteen are only known

1 American Journal Science, 3d series, vol. L, pp. 209, 210. The thickness of the Black Hills' section is given as 106 feet on p. 209, which is apparently a mistake as the sum of the thickness of the various layers enumerated is 122 feet.

2 F. W. Cragin, American Geology, vol. XVI, pp. 361, 379.

3 Ibid., pp. 361, 381.

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from the shell-bed. In the remaining and by far the greater thickness of the formation are 51 species of invertebrates and 13 of vertebrates.[1] From the collections made by Professor Hill and Mr. C. N. Gould at the Black Hills and Blue Cut Mound, Mr. Stanton identified either specifically or generically 31 forms.[2] All the geologists who have studied this formation in recent years are agreed in referring it to the Comanche series of Texas, though there is a slight difference of opinion as to which division of the series it is most nearly related. Mr. Stanton thinks that "taken altogether, the evidence seems to indicate about the horizon of the Kiamitia"[3] which are the lowest beds of the Washita division of the Comanche. Professor Hill agrees with this conclusion saying, "I fully agree with him [Mr. Stanton] that the Belvidere beds represent in general the Washita division and probably the attenuated Fredericksburg as seen in the North Texas section."[4]

While Professor Cragin believes that the Kiowa of Kansas and Kiamitia of the southern part of the Indian Territory with some other beds should be united to form another division of the Comanche series, for which he proposed the name Kiowa and which "represent a group of sediments intermediate between the Fredericksburg and the Washita divisions."[5] Finally, in answer to a letter regarding the classification of these formations, Professor Hill under date of December 7, 1896, kindly wrote me as follows: "I think if you will use the term Cheyenne sandstone and Kiowa shales of the Washita Division of the Comanche series you will not be far from right." This was illustrated by the following diagram:

	Divisions.		*For Kansas.*
Comanche series.	Washita.	Belvidere Beds.	Kiowa. Cheyenne.
	Fredericksburg.		
	Trinity.		

1 Ibid., pp. 369, 372, 373.
2 American Journal Science, 3d series, vol. L, p. 219.
3 Ibid., pp. 217, 218.
4 Ibid., p. 223.
5 F. W. Cragin, American Geology, vol. XVI, pp. 383, 385.

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"DAKOTA" SANDSTONE OF SOUTHERN KANSAS.

Capping the hills at several localities is a coarse-grained, brownish to blackish ferruginous sandstone, containing fragments of plants which in southern Kansas has generally been referred to the Dakota formation on account of its lithologic resemblance to the sandstones of this formation in central Kansas. The writer is not aware that any fossil plants characteristic of the Dakota north of the Arkansas river have been found in this region, and in correlating this sandstone doubtfully with the Dakota simply follows the general custom[1]. The writer, however, understands that Professor Cragin in his last paper has proposed for this ledge the name *Reeder* (Dakota?) sandstone from its occurrence over the Kiowa shales in the upper part of the Medicine Lodge river valley near the Reeder post-office, Kiowa county. Some of the best outcrops of this sandstone noted by the writer are on top of Blue Cut Mound southwest of Belvidere; on the southern side of the Medicine Lodge river in the eastern part of Reeder township and on the head waters of Hackberry, West Branch, Bear and Little Sandy creeks, Clark county.

DISTRIBUTION.

On the accompanying map, Plate XLIV, the distribution of the Comanche series in southern Kansas as determined by the work of the summer of 1896 is given. In tracing the outcrops of this series the author was assisted by Messrs. J. W. Beede and C. N. Gould in the eastern part, and by the latter in Clark county. In part of the region the series forms a mass of rocks of considerable thickness, varying from about 25 to 160 feet, which is readily enough shown on the map. For the remainder of the distance the thickness varies from less than 25 feet to nothing and for a part of this area is indicated on the map by simply a line. The great denudation inclosing Mesozoic or early Tertiary time swept away all or nearly all of the Cretaceous in a portion of this region so that the Tertiary rocks rest upon simply a thin bank of Cretaceous, or where the Cretaceous was completely eroded, upon the underlying Red-Beds.

By referring to the map it will be seen that in the east, the series

1 F. W. Cragin: Bulletin Washburn College Laboratory Natural History, Vol. II, pp. 76, 77, where the Dakota is mentioned as capping the Blue Cut Mound and Upper West Bear creek sections. Hill: American Journal Science, 3d Series, Vol. L, p. 210, gives the "Dakota" near the top of Blue Cut Mound.

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begins in the northeastern part of Barber county north of Medicine Lodge, runs northwesterly across the northern part of the county to the southeastern corner of Kiowa county. In Kiowa county it follows up the Medicine Lodge river and its branches to the vicinity of their head waters, when it turns southeasterly crossing the northeastern corner of Comanche county and extends into the western part of Barber county. In part of this region it has a thickness of from 100 to 160 feet. Then making a loup in the western part of Barber county it turns northwest up the ridge north of Mule creek into Comanche county, whence as a thin line it extends first southwest and then northwest across the central part of the county, and then in a very irregular line nearly across the central part of Clark county, disappearing not far southwest of the Great Basin. In the southern part of Comanche county south of Avilla is an isolated area which has been separated by the erosion of Salt Fork valley from that of the more northern area.

In only a portion of this region does the series attain a thickness of more than 20 feet; and its whole extent may be conveniently divided into three such areas, as follows: the Kiowa-Barber-Comanche; the southern Comanche, and the Clark. The local details of thickness, lithologic characters, and sections will consequently be given under the above headings.

KIOWA-BARBER-COMANCHE AREA.

This includes that part of the Comanche series found in the western and northwestern part of Barber county; in the northeastern part of Comanche and the southeastern portion of Kiowa county, which in many respects is the classic part of the field since it was first discussed here by Cragin and later he and Hill described it fully. Again the series reaches its maximum thickness in southern Kansas in the Belvidere region, and both the Cheyenne and Kiowa formations are well developed.

Mr. Gould found Kiowa shells six miles northeast of Medicine Lodge which is the fartherest east that he found them south of the Arkansas river; and again he found them four miles northeast of Sun City. Professor Cragin has reported several of the Kiowa species as imbedded in "the basal calcareous conglomerate of the Tertiary in the border of the upland north of Sharon," which is

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about seven miles east of the occurrence reported by Mr. Gould.[1] Professor Cragin has also reported loose specimens of *Gryphaea* and *Exogyra* in the western part of Harper county[2]. In the northwestern part of Turkey creek township, Barber county, both the Kiowa shales and Cheyenne sandstone are represented though the thickness is slight, as reported by both Beede and Gould. From there to the point northeast of Medicine Lodge a line of Comanche based mainly upon data furnished by Mr. Gould, is represented as separating the Red-Beds and the Tertiary.

In the northwestern part of Barber county the best outcrops of the Comanche series are along the Barber and Kiowa-Comanche county line which may be readily reached from Belvidere or Sun City. It is in this region that the Comanche series was first studied by Professors Cragin and Hill and the writer.

Along the Medicine Lodge river in the vicinity of Sun City the first steep bluffs both north and south of the river are capped by the Medicine Lodge gypsum, above which is some 80 feet of the upper Red-Beds when the base of the Cheyenne is reached which has a thickness of 52 feet, above which the Kiowa shales extend to the top of the high hill in the southeastern corner of Kiowa county which Professor Cragin has named Stokes Hill. The top of this hill which, according to the Medicine Lodge sheet of the U. S. topographic map is 390 feet higher than the river at Sun City, is about five and one half miles west of Sun City with frequent exposures of the rocks on the sides of the steep bluffs or in the draws so that it forms a good locality to study the Comanche formation and the upper part of the subjacent Red-Beds. This is the locality so well described by Professor Hill under the name of the Black Hills section,[3] and the one first studied by the writer.

Section north of west from Sun City to the top of Stokes Hill.

In general, the section published by Professor Hill agrees closely with the author's; some slight changes only occurring in reference

1 F. W. Cragin, Bulletin Washburn College Laboratory Natural History, Vol. II, p. 37.

2 Ibid., p. 80.

3 On account of the term Black Hill being applied to several hills of this character in Comanche and Kiowa counties, Professor Cragin has proposed the name Stokes Hill for the one under consideration (American Geologist, Vol. XVI, p. 63, f. n.) restricting the name Black Hill to the one first visited and described by him in the northeastern part of Comanche county in the vicinity of Hell's Half Acre on Elk creek (Bulletin Washburn College Laboratory Natural History, Vol. 1, 1885, p. 90; and American Geologist, Vol. XVI, pp. 379, 380).

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to the thickness of its different divisions. All of the divisions were readily recognized except those forming the upper part of the section which on account of being partly covered were not so easily defined. The numbers of Professor Hill with the thickness of the corresponding beds are given in the first two columns as a means of assistance in comparing the two sections.

Hill's. Nos.	Hill's. Thickness.	Prosser's. Nos.		Thickness of each division. Feet.		Total thickness. Feet.
II 17	32	21	Near the top of the Stokes' Hill though across a draw to the west it is somewhat higher. Covered slope.	15	—	385
16	16	20	Partly covered slope. Yellowish argillaceous shales containing fossils, alternating with thin yellowish to pinkish limestones.	25	—	370
15	17	19	Fine argillaceous shales with thicker layers containing *Exogyra*, *Cyprimeria*, *Turritella* and other species.	15	—	345
13	20¾	18	At top mainly bluish and blackish, fine argillaceous shales. Near the center coarser yellowish fossiliferous shales containing abundant fossils. At the base about 9 feet fine black shales.	20	—	330
12	5	17	Black very thin, argillaceous shales like paper shales.	4+	—	310
11	1	16	Brownish yellow harder shales with abundant *Gryphæa*.	1	—	306
10	5	15	Fine black and yellowish argillaceous shales, partly drab color. The yellowish are sandy and contain pebbles.	8	—	305
9	2	14	Yellowish coarse shales alternating with black argillaceous shales. Harder than the shales below, being sandy and gypsiferous.	2	—	297
8	4	13	Black paper shales like those below	4	—	295
7	2	12	Gypsiferous layer containing black pebbles and small concretions. These contain *Lingulas*, fossil teeth with some other species.	2+	—	291
6	15½	11	Very black thin sleek argillaceous shales, "paper shales" of Hill. Sparingly fossiliferous in the lower part.	15½	—	289
5	¼	10	Light gray to whitish sandstone of variable thickness, from 1 inch to 6 inches. Contains molluscs.	½	—	274
4	1½	9	Grayish sandy shales, partly cemented by gypsum, containing selenite. Immense numbers of *Gryphæa Pitcheri* (according to Hill) occur in this stratum. This is the one called the Champion shell-bed by Cragin who says the abundant fossil is *Gryphæa Hilli* Crag. Base of the *Kiowa* shales.	1½	—	273½
3	4	8	White to yellowish sandstone	2	—	272

Hill's. Nos.	Hill's. Thickness.	Prosser's. Nos.		Thickness of each division. Feet.	Total thickness. Feet.
2	10	7	Dark gray sandy and argillaceous shales, in places iron-stained, containing selenite. Occasionally a friable sandstone. This layer contains the dicotyledonous leaf impressions.	10	270
1	57	6	In the main light to yellowish gray friable sandstone. In places irregularly bedded, showing fine examples of cross-bedding. On weathering often dark brown and in places light yellowish or vermilion. The writer is confident that the thickness of this portion of the Cheyenne is not much greater than 40 feet. It was measured in the "Natural Corral," described by Professor Cragin, the sides of which gave 26 feet, and then but a short distance away, to its top. This forms what Professor Cragin calls the "Corral Sandstone" named from this small canon known as the "Natural Corral." Base of the *Cheyenne* sandstone, first seen on the red butte, 3½ miles west of Sun City.	40	260
I 1		5	Partly covered slope. *Red Bluff* sandstone of Cragin in upper part. *Dog creek* red shales of Cragin in lower part.[1]	65	220
1	300	4	Massive gypsum, the *Medicine Lodge gypsum*	15	155
		3	Below massive gypsum, about 8 feet covered, below which is a prominent iron-stained sandstone stratum.	10	140
		2	Mostly covered for 20 feet, but in the base a greenish-gray conspicuous stratum, with gypsum nodules, similar to the one seen in the Gypsum Hills, southwest of Medicine Lodge.	20	130
		1	Largely covered slope to the level of river. "*Flower-pot shales*" of Cragin. Level of Medicine Lodge river.	110	110

1 Up to the base of the Cheyenne sandstone the thickness was determined by the Aneroid barometer, and for the remainder of the section by the Locke level. The barometer gave only 65 feet from the top of the Medicine Lodge gypsum to the base of the Cheyenne on the red butte, three and one half miles west of Sun City, while on Walker creek, four miles northwest, carefully measured by tape and level, the thickness of the beds from the top of the massive gypsum to the base of the Cheyenne is 116 feet. However, the topographic map indicates only a thickness of 230 feet for the barometric section of 220 feet, consequently, I consider this difference due to unequal erosion previous to the deposition of the Cheyenne. The thickness of 65 feet between the top of the gypsum and the base of the Cheyenne agrees closely with that given by Professor St. John who reported the thickness of the intervening strata as 60 feet. The varying thickness of the beds between the gypsum and the base of the Cretaceous for this region was clearly stated by Professor St. John to be due to pre-Tertiary erosion and his comment on this particular region was as follows: "On the borders of Barber and Comanche counties, in the highlands south of the Medicine Lodge, the base of the Cretaceous occupies a still lower stratigraphical position on the Red-Beds (than in Clark Co.), occurring within 60 feet of the gypsum ledge, indicating the removal of quite 100 feet thickness more of Red-Beds strata in this quarter prior to the deposition of Cretaceous sediments" (Fifth Biennial Report Kansas State Board Agriculture, p. 142, Topeka, 1887).

It will be seen from the above table that the total thickness of this section, which extends from the level of Medicine Lodge river at Sun City to near the top of Stokes hill five and one half miles

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west, is 385 feet. On the topographic sheet of the U. S. Geological Survey the difference in elevation for this section is 390 feet, which agrees very closely with the above. The section gives 220 feet for the upper Red-Beds, 52 feet for the Cheyenne sandstone and 113 for the Kiowa shales, the top of the latter formation not being reached. The first outcrop of the Comanche seen on the bluffs west of the Medicine Lodge river caps a red butte, three and one half miles west of Sun City. This outcrop is somewhat farther east than the one reported by Professor Hill as four miles west of Sun City. A little farther west in an arroyo below the Comanche are red argillaceous shales in place, and on top, yellowish very sandy shales which belong in the Cheyenne formation. This exposure gives the contact between the red shales and Cheyenne sandstone. A little farther west at the side of another arroyo is an irregular line of contact between red shales and grayish sandstone, apparently a line of unconformability between the Cheyenne sandstone and subjacent Red-Beds. At their contact there are bright red shales belonging to the Red Bluff sandstone of Cragin, then one foot of white sandstone, and red shales again, upon which rests the Cheyenne sandstone the base of which consists of very white sand that becomes more yellowish on top, and the exposure terminates in a covering of soil in which are large numbers of pebbles especially those similar in color to the Dakota sandstone. At the head of the Lanphier draw, on the eastern side of Stokes hill, where the black Kiowa shales are well exposed there is a dip of between 1 deg. and 1½ deg. S. 10 deg. W. In this draw the dip is quite marked, though its general amount is probably increased by a small fold. In the Kiowa shales exposed around the eastern side of Stokes hill are somewhat coarse layers, as indicated in the section, which contain abundant fossils. From these shales many species were collected, as was also the case in Professor Hill's work, and from his collection the following species were identified by Mr. T. W. Stanton:

1. *Gryphæa forniculata* White.
2. *Corbula crassicostata* Cragin.
3. *Exogyra texana* Roemer.
4. *Cardium mudgei* Cragin?
5. *Cardium bisolaris* Cragin.

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6. *Roudaria? quadrans* Cragin.
7. *Mactra antiqua* Cragin.
8. *Anchura Kiowana* Cragin.
9. *Trochus texanus* Roemer.
10. *Schlœnbachia peruviana* von Buch.
11. *Avicula belviderensis* Cragin.
12. *Avicula leveretti* Cragin (?)
13. *Trigonia emoryi* Conrad.
14. *Cardita belviderensis* Cragin.
15. *Cardium* (*Protocardia*) *texanum* Con.
16. *Turritella*, sp. cf. *seriatim—granulata* Roem.[1]

About three miles south of Stokes' hill is the locality known as Hell's Half Acre, on Elk creek, in the northeastern part of Comanche county. Adjoining is a steep hill known as Black Hill, which is the locality fist visited and described by Professor Cragin in 1885.[2] The black shales so well exposed around the base of this hill, belong to the same part of the Kiowa formation as the black paper-shales described by Professor Hill and the writer in the Stokes' hill section. For this part of the Kiowa Professor Cragin has proposed the name Black Hill shale, describing it as a terrane consisting "of a bed of black carbonaceous clay-shale 15 or 20 feet thick, resting upon the Comanche shell-bed."[3] Below this hill in the region designated Hell's Half Acre are excellent exposures of the Cheyenne sandstones showing irregularities of outcrop due to differences in the erosion of the sandstones. Professor Cragin has admirably described this locality and named some of the more conspicuous sandstone columns the "Chimney rock," and the row of six small pillars the "Cheyenne Brothers."[4]

The view of an *Eroded ledge of Cheyenne sandstone*—Plate XV—gives an excellent idea of the appearance of a part of the ledge of Cheyenne sandstone at this locality, near the Barber-Comanche county line, eight miles southeast of Belvidere. One of the pillars shows conspicuously near the right hand side of the picture, while the rough and jagged nature of a portion of the ledge is fairly well

1 T. W. Stanton, American Journal Science, Vol. L, Sep. 1895, p. 218.
2 F. W. Cragin, Bulletin Washburn College Laboratory Natural History, vol. I, p. 90.
3 F. W. Cragin, American Geology, vol. XVI, p. 380.
4 Ibid., p. 366.

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indicated. Down the ravine below the prominent exposure of Cheyenne sandstone, just described, is shown the contact of the Cheyenne and Red beds. In this ravine the rocks composing the upper part of the Red beds are a very bright red color and beautifully exposed. The upper part of the red shales near the contact consist of 2½ feet of variegated red and yellow colors, then 3 feet of yellowish-gray argillaceous shales in texture similar to the shales below, and above these the coarse-grained sandstone of the Cheyenne. The latter is variously colored although the prevailing one is white to yellowish-white; and is very irregularly bedded, exhibiting excellent examples of cross-bedding. The Cheyenne sandstone at first consists of fine clear quartz sand in which are frequently small pebbles. It is probable that during the sedimentation of the Red-Beds in an inland sea there was a period of great quiet with steady deposition of sandstones, shales and gypsum in brackish water; then came a series of oscillations as shown by the coarse and irregular deposits of the Cheyenne, changing the inland sea of the Reds to the marine sea of the Kiowa which contains thin, even, shales and calcareous rocks with an abundant marine molluscan fauna. The section of this small ravine is as follows:

No.		Feet.
4.	On top coarse-grained very irregularly bedded Cheyenne sandstone.	
3.	Gray to greenish-yellow argillaceous shale which in the upper part contains very fine grains of quartz sand.	3 —45½
2.	Red and yellowish shales, transitional from the gray Cheyenne sandstone to the bright red shales of the Red-Beds.	2½—42½
1.	Red shales and sandstones......................	40 —40

In a ravine to the southeast of Hell's Half Acre there is an excellent exposure of the contact between the Cheyenne sandstone and the Red-beds showing clearly a line of unconformity between these two formations, indicating a pre-Cheyenne erosion of the Red-beds. It also shows conclusively that at the top of the Red-beds there are variegated shales from 2 to 3 feet in thickness, then 3 feet of sandy light gray to yellowish shales, above which is the coarse irregularly

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bedded brownish-yellow sandstone of the Cheyenne. In the base of this sandstone are quartz pebbles. The Cheyenne rests on an irregularly eroded surface of the gray shale. The picture called the *Contact of Cheyenne sandstone and Red-beds showing unconformability*—Plate XVI—shows nicely the upper part of the Red-beds with the contact between the latter and the Cheyenne sandstone. In the picture the top of the Reds is shown by Mr. Beede's left foot, the bottom of the gray shales 3 feet in thickness by his right foot and the line of unconformability by his hand. A conspicuous place of erosion in the pre-Cheyenne rocks shows just back of Mr. Beede. This locality is an important one in any discussion concerning the age of the Cheyenne and Red-beds since it shows conclusively that at least in this ravine they are clearly separated by a line of prominent unconformability which of course indicates a physical break and therefore a time interval of considerable duration between the close of the Red-beds epoch and the deposition of the Cheyenne sandstone.

To the north of Stokes hill is Walker creek, a southern branch of Medicine Lodge river, along which are fine exposures of the upper Reds and the Cheyenne sandstone. On the southern bank, opposite Mr. Frank Abel's house, at a point two miles northwest of Stokes hill and three and one half miles southeast of Belvidere, a section of the bluff was accurately measured by means of the tape and Locke level. This place is located on the southwest corner of the northwest quarter section 26, Lake township, Kiowa county.

Section of Walker Creek Bluff.

	Feet.
Cheyenne sandstone, light gray and yellowish colored partly cross-bedded. Base of *Cheyenne sandstone.*	37—158
Yellowish gray shale	5—121
Red shales	14—116
Red, soft, friable sandstone. Forms the *Red Bluff sandstone* of Cragin.	66—102
Red shale containing thin layers of gypsum. *Dog Creek shales* of Cragin.	31— 36
Massive white to light colored gypsum. *Medicine Lodge gypsum* of Cragin.	5— 5

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The bed of the creek at this locality gives a good exposure of the top of the Medicine Lodge gypsum followed by 3 feet of red shales with thin layers of gypsiferous rock of greenish tint and somewhat arenaceous. The remainder of the Dog Creek shales show conspicuously in the side of the bluff with occasional thin layers of gypsum. On top of these shales is a massive bright red sandstone which forms the upper 66 feet of the perpendicular bluff on the south side of Walker creek. In the Dog Creek shales are light gray streaks, and in the Red Bluff sandstone large patches of light gray color, in both cases caused by deoxidation. At the top of the Red Bluff sandstone are 5 feet of yellowish-gray shale underlying the coarse yellow sands of the Cheyenne. On account of the gradual transition from the red shale into these yellowish shales, the break between the formations appearing to be at the top, they are referred to the Red Bluff sandstone. The Cheyenne is very irregularly bedded as at the localities of Stokes and Black Hill. Following down the south bank of the creek the gypsum forms a prominent ledge at an increasing elevation above creek level. Above the gypsum the greater part of the bluffs show exposures of red shales and sandstones reaching an elevation apparently higher than the base of the Cheyenne sandstones opposite Mr. Abel's. Still higher is a prominent ledge evidently the base of the Cheyenne sandstone, indicating a dip to the southwest. The general dip is therefore apparently a number of feet per mile in a southwesterly direction. There are also small rolls shown in the bluff along the south bank of the creek. This locality is perhaps the best to be found in the Belvidere region for studying the character of the upper Red-Beds, that portion between the Medicine Lodge gypsum and the base of the Cheyenne sandstone, inasmuch as there is a complete exposure of the rocks intervening between these two horizons.

The thickness of this portion of the Red-Beds in this locality is 116 feet. Only 37 feet of the Cheyenne sandstone was measured, but this number does not represent the entire thickness since the section does not extend to the top of the formation.

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Section of the Champion Draw and Hill one half mile south of Belvidere.

				Feet.	Feet.	
The remainder of the section comprises 1, 2, and 3 of Cragin.	100—120	15	Top of hill. Yellowish shales with thin layers of pinkish limestone containing specimens of *Ostrea*.	29	214	Kiowa, 122 ft.
		14	Prominent layer of shaly pinkish limestone containing abundant specimens of *Ostrea*.	1	185	
		13	Yellowish argillaceous shales which become blackish shales at the base.	30	184	
		12	Layer of sandy shales with limestone at the bottom containing abundant specimens of *Gryphæa*, 1½ feet in thickness. Partly yellowish and blackish shales about 10 feet in thickness. Lower 4 inches limestone containing abundant specimens of *Gryphæa*.	12	154	
		11	Black argillaceous shales similar to the paper shales of Stokes hill.	7	142	
		10	6 inch stratum containing great numbers of *Cyprimeria*, *Turritella* and other fossils, 4½ feet thin black shales. Stratum of 8 inches with *Cyprimeria*. Black shales 4 to 5 feet in thickness. Thin sandy layer containing gypsum and specimens of *Gryphæa* and other fossils — about 4 inches.	10	135	
		9	Black shales that are somewhat coarser and yellowish near the bottom.	10	125	
		8	Thin black argillaceous shales	4	115	
		7	Yellowish slightly coarser shales, 1½ to 2 feet in thickness.	2	111	
4	15—20	6	Thin black shales same as No. 6 of Hill's section at Stokes hill. They weather into very thin pieces containing plenty of selenite.	15	109	
		5	Thin sandstone stratum, 1 to 3 inches		94	
5	5—1	4	Brownish to gray rock containing a large amount of selenite and gypsum and abundant specimens of *Gryphæa* and other fossils. *Champion shell-bed* of Cragin.	1½	93½	
6	20—40	3	Cheyenne sandstone, upper part yellowish to ash color; coarse-grained containing pebbles and very irregularly bedded. Generally brownish yellow to grayish tints; also white iron-brown, etc.	40	92	Cheyenne, 40 ft.
7		2	Yellowish to gray argillaceous shales	2+	52	Red-Beds, 52 ft.
		1	Red sandstone and shales, the lower part covered, extending to level of Medicine Lodge river.	50	50	

The above section is the one first accurately measured and described by Professor Cragin in 1889,[1] and which reappeared the

1 F. W. Cragin, Bulletin Washburn College Laboratory Natural History, Vol. II, p. 35, Topeka.

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following year on page 75 of the same publication. This section was carefully studied and measured with the Locke level by the writer and the result compared with Professor Cragin's in the following section. The first column gives Professor Cragin's numbers, the second the thickness as he determined it, and the third the writer's numbers.

Along the Champion draw, a short distance south of Belvidere, are fair exposures of the Red Bluff sandstone with numerous large spots of greenish-white sandstone in the midst of the red. It is very friable, crumbling readily in one's fingers. At the top of the red sandstone are yellowish shales similar to those seen in the section of Walker creek, Stokes, and Black Hill. Near the base of the Cheyenne sandstone, especially in the bed of the draw are efflorescences of sulphur, salt, and other minerals. The Cheyenne sandstone is very irregularly bedded at this locality, an excellent idea of which is given by the picture of *Cross-Bedding in Cheyenne sandstone, near Belvidere*—Plate XVII—which is a photograph of the eastern bank of the Champion draw. The bottom of the picture represents the lower part of the Cheyenne sandstone with its layers nearly horizontal, while in the upper part of the bluff the beds are very much inclined. This portion represents the middle and upper parts of the formation.

No. 5 of Cragin's Belvidere section, which he has lately named the Champion shell-bed is the same stratum as No. 4 of Hill's section at Stokes' hill. This stratum weathers to a dirty iron-yellow color and contains immense numbers of *Gyphaea* shells with other fossils, and plenty of gypsum. In some places it is mainly a shell rock, containing little gypsum, but composed almost entirely of fossil shells. Then comes the black paper shales, above which are quite prominent layers containing immense numbers of *Cyprimeria* and *Turritella* shells, while the upper part of the hill is composed of yellowish argillaceous shales alternating with thin layers of pinkish, shaly *Ostrea* limestone.

The total thickness of the Cheyenne sandstone in this section is 40 feet above which are 123 feet of Kiowa shales the top of which is not shown. This indicates a thickness of over 163 feet for the

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Comanche series in the Belvidere section which is believed to represent nearly its maximum thickness in southern Kansas. Across a small ravine near the foot of the hill, for a distance of 30 yards, these shales show a noticeable southern dip.

One mile above Belvidere on the northern side of the river, at the point of the ridge east of Thompson's creek, is a commanding ledge of Cheyenne sandstone, known as Osage rock. The picture of the *Osage Rock above Belvidere*—Plate XVIII—gives very clearly the characteristic appearance of this rock which forms the end of the divide to the east of Thompson's creek. This locality has historic interest on account of being the scene of a battle between the Cheyenne and Osage Indians. The main part of the rock is 20 feet high, capped by a pillar 5 feet in hight.

From Belvidere the Comanche series was followed up Spring creek to the vicinity of Mr. Roberts' house about three miles north of the station where along the sides of the creek are the upper black shales of the Kiowa, above which are the yellow and coarser Kiowa shales. Still higher, the Tertiary sandstone is shown on the west side of the creek capped by a calcareous deposit. A section on the west side of Spring creek just above Mr. Roberts' house was levelled.

Spring Creek Section.

No.		Feet.
4.	Near the top of the hill marl and calcareous deposit several feet in thickness.	
3.	Covered slope..................................	15—78
2.	Coarse-grained pebbly sandstone ledge from 2 to 3 feet in thickness. Base of Tertiary.	2-3—63
1.	Yellowish shales; near the bottom blackish shales to the level of Spring creek. Kiowa shales.	60—60

From this locality the divide between Spring and Thompson's creeks was crossed, all of which belongs to the Tertiary rocks. From the base of the Tertiary to the top of the Cheyenne sandstone on the eastern branch of Thompson's creek, the difference in altitude is 120 feet and all the rocks belong to the Kiowa shales, making their thickness approximately the same as in the hill south of Belvidere. The *Gryphaea* bed at the base of the Kiowa shales, on the hill north of the Medicine Lodge river at the mouth of Thompson's

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creek, is 60 feet above river level which indicates that some 20 feet of the Red-Beds are above river level at this locality. As near as could be determined, the top of the Red-Beds in the Medicine Lodge valley is reached near the mouth of Otter creek. On the plateau west of Thompson's creek the Tertiary marl is well shown near the top of the prairie. Twenty eight feet below the base of the marl, the interval being covered, in the head of a draw, is an excellent exposure of the pinkish shaly limestone of the upper Kiowa containing large numbers of *Ostrea,* and furnishing an excellent locality for collecting specimens of this shell. This locality is one and one half miles west of Thompson's creek and one and one half miles north of Medicine Lodge river. Loose on the surface, above the Kiowa shales, are brownish sandstones greatly resembling sandstones referred to the Dakota; but no stratum was found in place. Along the river valley, above this point, the upper Kiowa shales are exposed at intervals in the river bluffs to the forks of the Medicine Lodge seven miles west of Belvidere. By the side of the river a short distance below the forks is an exposure of the pinkish shaly limestone; and west of the forks in the eastern part of Reeder township is a steep point, a section of which was measured.

Section West of the Forks of the Medicine Lodge River.

No.		Feet.
3.	Top of hill and all the high country to the north and west covered by Tertiary. Base of ledge in place 115 feet above river level.	
2.	Below Tertiary partly covered, abundance of iron-brown sandstone similar to the rock termed Dakota sandstone and probably belonging to that formation. In the lower part this sand changes into yellowish shale. Base of Dakota?	25—115
1.	Ninety feet above river level are shown argillaceous and calcareous shales of the upper Kiowa containing plenty of fossils. In a small draw at this locality immense numbers of *Gryphaca dilatata* var. *tucumcarii* occur on the surface; the largest number of specimens seen anywhere in the Belvidere region. River level.	90— 90

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About two miles below the forks of Medicine Lodge river and on its south side is a prominent butte the sides of which near the summit are covered with large blocks of dark brown to iron-colored very quartzitic sandstone. This stratum is regarded as being an excellent exposure of the so-called Dakota sandstone of southern Kansas, and is probably several miles east of the exposure for which Professor Cragin has proposed the name Reeder sandstone referring it with question to the Dakota formation.[1]

Section of Butte South of Medicine Lodge River.

No.		Feet.
5.	At the top a Tertiary cap of white rocks which cover all the high prairie to the south and west.	
4.	On the east side of the butte the rock is mainly a yellowish friable sandstone containing plenty of iron concretions. In some respects this rock is similar to the Tertiary sands rather than the Dakota though the greater part of it is very similar to the ordinary exposures of Dakota sandstone. On the north side of the mound, the upper part of this division is partly covered but the lower part is a massive stratum of iron colored concretionary sandstone.	30—170
3.	Light gray to yellowish sand partly consolidated. Base of Dakota-like rock 130 feet above river level.	10—140
2.	Partly covered but showing argillaceous and calcareous shales. Kiowa.	25—130
1.	At 105 feet above river level fossiliferous sandstone, while pinkish shaly limestones are well exposed in the side of the hill 80 feet above river level.	105—105

The Dakota-like sandstone of this butte is the thickest exposure of that rock in the Belvidere region and also the one most closely resembling the Dakota formation of central Kansas.

On the south side of the Medicine Lodge valley the Kiowa shales are shown along the sides of the bluffs, with the Cheyenne at

1 American Geology, vol. XVI, p. 381.

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their base as we aproach Otter creek, near the mouth of which is the top of the Red-Beds. On the south side of the Medicine Lodge river the Comanche series extends farthest south up the Otter creek, and not far from the mouth of the creek, in a draw crossed by the railroad and a short distance north of the Blue Cut, the top of the Cheyenne sandstone is exposed together with the Champion shell-bed. This cut and the Blue Cut mound, three or more miles southwest of Belvidere, have already been mentioned as described by Professors Cragin and Hill.

Section of the Blue Cut and Mound.

No.		Feet.
6.	On the summit of the mound, or "nipple," loose pieces of Tertiary marl.	
5.	Partly covered slope. Large blocks of brown and iron colored sandstone occur, some apparently coming from a stratum in place.[1]	20—151
4.	Thin limestone containing *Gryphaea* and other fossils. The slope of the mound from the base of the brownish sandstone to the top of the railroad cut is mostly covered. The section of Gould and Hill gives 48 feet.	45—131
3.	At top of railroad cut is a shaly *Ostrea* limestone of pinkish color, No. 18 of Hill and Gould's section. Lower are yellowish shales and shaly limestones.	11-8—86
2.	Dark gray to blackish shaly limestone perhaps weathering to a pinkish color. Bluish-black shale in the lower part of the railroad cut in which are three prominent bluish limestone layers containing abundant specimens of *Ostrea*. Base of railroad cut.	22½—74½
1.	From the railroad cut to the top of the Cheyenne sandstone, which is exposed in a draw north of the cut, the intervening space being mostly covered, there is a barometrical difference in altitude of 52 feet.	52—52

1 In describing this section Professor Hill gives 20 feet of black ferruginous sandstone which is referred doubtfully to the Dakota. Thirty rods north of the line of his section he states that the "Tertiary rests directly on the Belvidere shales, the Dakota having been eroded" (American Journal Science, 3rd series, Vol. L, p. 210).

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The above section, provided the thickness of the lower part is correct, gives 131 feet for the Kiowa shales, the greatest thickness noted in the Belvidere region. On the hill south of Belvidere and about three miles northeast of this locality the Kiowa shales are shown to have a thickness of at least 123 feet, the top not being defined by a succeeding formation. In the Blue Cut section of Professor Hill, the thickness of the Kiowa shales is given as 102 feet; but it is thought that the lower part of the shales is thicker than is indicated on his section.[1] In Professor Cragin's section the thickness of the Kiowa shales is given as ranging from 110 to 130 feet.[2] The Dakota sandstone (?) on top of Blue Cut mound is very similar to the outlier seen on top of the butte south of the Medicine Lodge river. Above the highest thin limestone stratum containing large shells are apparently thin shales, then a layer of somewhat iron-colored rock varying from dark red to brownish red. Loose on this part of the hill, but disposed as though coming from a ledge in the vicinity, are large boulders of coarse-grained brownish sandstone. On the summit of the mound are similar boulders mixed with some of the Tertiary marl. Part of the sandstone boulders are covered by a white incrustation possibly from having been imbedded in the Tertiary and possibly merely a deposit from the Tertiary.

From Blue Cut Mound the Kiowa shales were traced up Otter creek to the base of the Tertiary. To the east is a high ridge covered entirely by Tertiary rocks, forming the divide between Otter and Walker creeks. Near the head of Walker creek are sandy Tertiary marls below which are yellowish shales of the upper Kiowa that contain fragments of *Gryphaea* shells, apparently near the dividing line between Kiowa and Tertiary. In another of the head branches of Walker creek the yellowish and pinkish shales are well shown near its head, while farther down, black shales of the lower part of the Kiowa are exposed. On the southwest branch of Walker creek Tertiary sandstone and marl are exposed near the head of the branch; just below are pink shaly limestones containing *Ostrea* and belonging in the uppper part of the Kiowa. Down the creek

1 Ibid., p. 210.

2 F. W. Cragin, Bulletin Washburn College Laboratory Natural History, Vol. II, pp. 76, 77.

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the black Kiowa shales are again well exhibited, the top of the Kiowa being from 50 to 60 feet below the general level of the prairie. To the southeast of the head branches of Walker creek, is Elk creek around the head of which the line of division between the Tertiary and Kiowa is quite well marked. The top of the shaly *Ostrea* limestone of the Kiowa occurs in this creek about 50 feet below the top of the prairie. The large *Gryphaea*, as well as numerous specimens of iron colored stone which are noticed in all these draws, occur at about the same stratigraphic position in every case. On the creek below are conspicuous outcrops of the black paper-shales which are so well exposed in the vicinity of Hell's Half Acre. Extending from the southeastern part of Kiowa county southeasterly for a number of miles into western Barber county, is a prominent ridge which forms the divide between the Medicine Lodge river and its tributaries, as the Otter, Walker, Elk, Bear, Dog, Little Bear and Cedar creeks, on the north; and Mule creek with the branches of Salt Fork on the south. Forming the northern spurs of this divide are the Stokes, Belvidere and Blue Cut hills which have been frequently mentioned. On these hills are numerous exposures of Cheyenne sandstone and Kiowa shales, which here reach their greatest thickness for the area under consideration.

From the northeastern part of Comanche county to the south, the Comanche series thins rapidly. The rocks composing the upper part of the divide and forming all of the high prairie to the west belong to the Tertiary. This Tertiary capped ridge extends well into the western part of Barber county, underlying Deer Head, and continuing some miles farther to the southeast. The Comanche series follows the eastern side of this divide from the locality at which it is so well developed near the corner of Comanche and Kiowa counties, into the western part of Eagle township, Barber county. In this township the line of outcrop forms a large loop turning again northwesterly and following the southwest slope of the divide along the northern side of Mule creek until within about three miles of Wilmore, where the Comanche passes beneath the surface, but may be followed again in an irregular line on the western bluffs of the creek. The outcrop continues in this general southerly direction until the head waters of Indian

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creek are reached when it turns to a more westerly course appearing in the various branches forming the head-waters of the Nescatunga creek in the central part of Comanche county. Thence the outcrop is represented as a somewhat indefinite line a little further south, to the northeast of Avilla, running thence nearly northerly around the eastern branches of Cavalry creek, to the southwest of Coldwater, where it extends northwesterly to near the western part of Comanche county on the head-waters of Sand creek.

To the southeast of Deer Head in the western part of Barber county these formations have greatly decreased in thickness although they may be readily followed around the loop and up the northern side of Mule creek valley as well as for some distance on its western side. Beyond this locality there is in general only an occasional outcrop of the rock but loose specimens of the shells are of quite frequent occurrence in the draws, and have been taken as indicating the line of demarcation between the Tertiary and Red-Beds. It is probable that over some of this area the pre-Tertiary erosion has removed all of the Comanche and a portion of the upper part of the Red-Beds, so that the line indicated as the outcrop of the Comanche does not represent the actual position of that series. The area denominated Kiowa-Barber-Comanche may be regarded as terminating to the southwest on the upper branches of Mule creek.

The rapid thinning of the Comanche series in the northeastern part of Comanche and the western part of Barber counties to the southeast of the Stokes hill region is well shown by sections on the head-waters of several of the creeks of that region. One of these sections is the following near the Comanche-Barber county line, about a mile north of parallel 20° and about four miles east of south of Stokes hill, on the southwestern branch of Elk creek.

Section at Head of Elk Creek.

No.		Feet.
4.	Top of level divide mainly covered, showing Tertiary marl in places.	50—127
3.	Top of Kiowa shales. A little below the Tertiary rocks plenty of *Gryphaeas* occur in the yellowish soil; and a little farther down the draw are large slabs of pinkish limestone and the coarse shales of	34— 77

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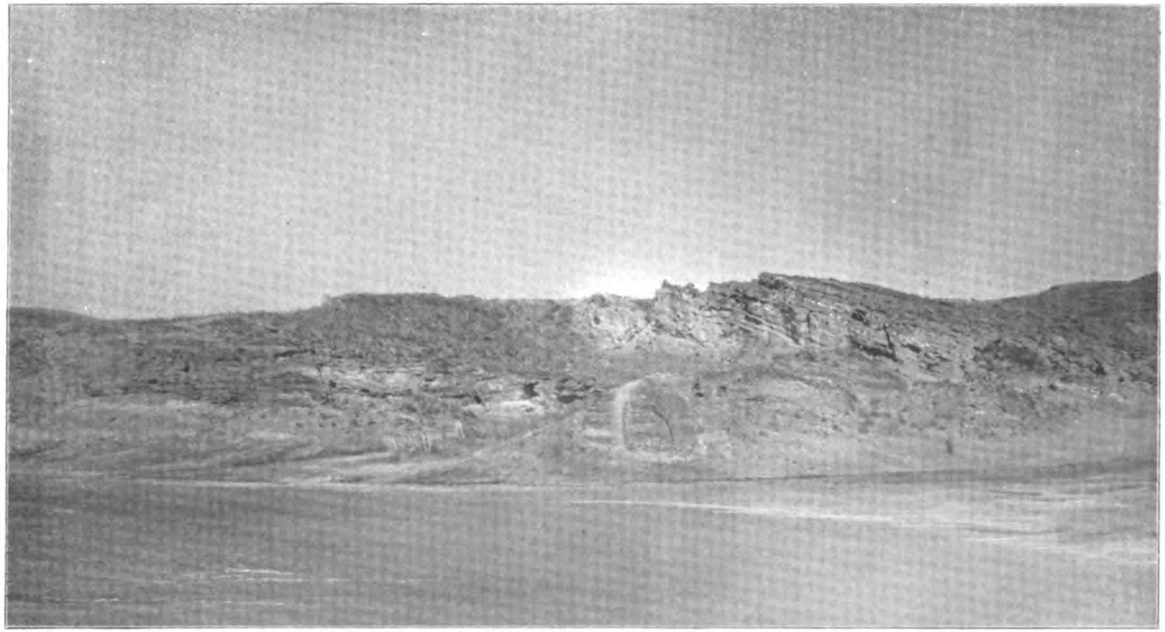

CROSS-BEDDING IN CHEYENNE SANDSTONE, NEAR BELVIDERE.
(Photographed by Prosser, 1896.)

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OSAGE ROCK ABOVE BELVIDERE, CHEYENNE SANDSTONE.
(Photographed by Prosser, 1896.)

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No.		Feet.	
	yellowish color forming the upper part of the Kiowa. Near the bottom blackish shales.		
2.	Top of *Cheyenne* sandstone. Coarse sandstone in general with the characters of the Cheyenne.	43—	43
1.	Top of *Red Bluff sandstone.*		

In the above section the Cheyenne sandstone has as great a thickness as in the Belvidere region to the northwest; but the Kiowa shales have decreased from 120-130 feet to 34 feet. Perhaps this section shows a decrease in the actual thickness of the Kiowa deposits, for the coarser shales of the upper Kiowa form a considerable portion of the upper 34 feet, so that the black shales of the lower part of the Kiowa do not have a thickness corresponding to that found in the more northwesterly sections. If this be true it shows that the decrease in thickness of the Kiowa is due only in part, at least, to pre-Tertiary erosion and in part to thinning of the sediments. This decrease is shown still more strikingly in the southwest branch of Bear creek, northern part of Deer Head township, Barber county. This locality is six miles southeast of the one just described at the head of Elk creek, and three miles west of north of Deer Head post-office.

Section at Head of Bear Creek.

No.		Feet.
4.	Top of level prairie occasional exposures of Tertiary marl,	65
3.	Loose *Gryphaea* shells in soil from thin shale exposed in places. Thickness indeterminate.	
2.	Coarse gray sandstone of the Cheyenne................	21
1.	Top of Red-Beds.	

The above section shows a decided thinning of the Comanche series in a straight line six miles to the southeast. It is probable that former erosion has swept away nearly, if not quite all, of the Kiowa shales and perhaps a part of the Cheyenne, so that the Comanche series is represented by only about 21 feet. Across the divide to the southwest of this locality the Comanche series is found reduced to a thickness of perhaps 15 feet. On a hill about five miles northwest of Deer Head the Comanche shells occur in the shale between the Tertiary marl and the top of the Red-Beds. In places the Cheyenne sandstone is visible and below are the reddish sand-

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stones of the Red Bluff division, showing now and then layers of sandstone varying from a light gray to a greenish-gray color, and shales 2 feet in thickness. There is quite a strong southerly dip. On Mule creek about one mile below the former Gallagher post-office, near the Powell-Logan township line, is the top of the Medicine Lodge gypsum. It forms a prominent ledge along the side of the creek a short distance below the present Gallagher house. To the southeast the gypsum stratum may be readily followed as it rises higher and higher in the bluffs along the creek. In this vicinity the top of the Medicine Lodge gypsum is about 100 feet below the base of the Cheyenne sandstone. Above Gallagher's, on the north side of Mule creek one mile west of Jacob Keel's, the Cheyenne sandstone is clearly exposed. The Kiowa shales are not found in place in this locality; but loose specimens of *Gryphaea* occur in the soil.

Jacob Keel Section.

No.		Feet.
5.	Soil one foot	1 —112½
4.	Yellowish to whitish sandstone	2½—111½
3.	Blackish to bluish fine shales	9 —109
2.	Yellowish to white sandstone with a layer of yellow shale at the base. Base of Cheyenne.	20 —100
1.	Red-Beds, partly covered to level of Mule creek	80 — 80

It will be noticed in the above section that a layer of black shale is given in the Cheyenne. Perhaps the 2½ feet of yellowish sandstone might be regarded as a thickened layer of the sandstone noticed in the lower part of the Kiowa in the Stokes hill and Belvidere sections. No fossils, however, were found in the black subjacent shales either at this section or in those studied in other places, which fact has led the writer to refer this shale with the overlying sandstone to the Cheyenne formation. The Cheyenne sandstone is well exposed on the south side of Mule creek above William Powell's ranch and below the John Pyle farm at an elevation of 40 feet above the creek level. The formation is partly covered but shows at the base white sandstone, then blackish to bluish shales with red streaks and a yellowish sandstone on top. Plenty of loose *Gryphaea* shells occur on the surface above the Cheyenne sandstone. This locality is 3 miles southeast of Wilmore and is the last conspicuous outcrop

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of the Cheyenne seen on upper Mule creek, the higher country to the north, west and south being composed entirely of Tertiary grit and marl.

South of Mule creek and the John Pyle farm is a fairly steep bluff composed for the greater part of white sand and marls belonging to the Tertiary. At an elevation of 70 feet above creek level covered by soil is a prominent stratum of white sand above the coarser grit. Some five miles to the southeast of the above mentioned locality is the head of a small southern branch of Mule creek known as Horse gulch.

Section south of Horse Gulch.

No.		Feet.
6.	At top of prairie fine sand and grit changing at bottom to sandy marl. Tertiary.	
5.	Covered slope..................................	20—250
4.	Yellowish soft friable sandstone.................	2—230
3.	At top yellowish shales; greater part of thickness blackish shales with red streaks giving them a somewhat mottled appearance. Perhaps this thickness is too great as their measurement is somewhat difficult.	37—228
2.	Light gray to whitish sandstone some of it thoroughly indurated.	29—191
1.	Red sandstone and shales partly exposed along the lower part of bluff and Horse gulch to level of Mule creek.	162—162

The interesting part of the above section is a zone of blackish shale containing red streaks having a thickness of 37 feet in which somewhat careful search was made and particularly in the yellowish shales at its top for fossils. None, however, were found, and there seems no evidence, except color, for referring this zone to the Kiowa shales. Apparently the blackish shales, 9 feet in thickness one mile west of Jacob Keel's on the northern side of Mule creek, represent the same zone. Much thinner similar blackish shales with red streaks, overlying massive Cheyenne sandstone were first noticed in the southeast draw of Elk creek, in the western part of Barber county. It is probable that following around the high divide to the north of

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Mule creek this band of shale continues with increasing thickness until it attains its maximum of 37 feet on the hill south of Horse Gulch. It is referred doubtfully to the Cheyenne formation though perhaps there is about as much evidence in favor of correlating it with the black paper-shales of the lower Kiowa. Two and one half miles southwest of the Horse Gulch section is the head-waters of Indian creek. A section constructed on the upper part of this creek gives a difference in elevation of 135 feet from the top of the high prairie down to the top of the sandstone belonging to the Cheyenne. Over this slope are outcrops here and there of Tertiary grit and marl. All of this thickness of 135 feet is referred doubtfully to the Tertiary.

Section at head of Indian Creek.

No.		Feet.
4.	Tertiary	135—160
3.	Yellowish to whitish friable sandstone and shales with numerous iron concretions of different forms. Cheyenne sandstone.	15— 25
2.	Yellowish to whitish argillaceous shale...........	2— 10
1.	Red sandstones belonging to *Red Bluff* sandstone. Level of Indian creek.	8— 8

In this creek no indication of the Kiowa shale was found though perhaps they may be concealed by the covered slope above the 15 feet of Cheyenne sandstone. For a considerable distance above this sandstone there are no outcrops. So that it is impossible to decide this point. The dip in this section is, as at Horse Gulch and on the north side of Mule creek, to the southeast. About nine miles to the south would be the locality mentioned by Professor St. John where shells and gravel occur in connection with a gypsum ledge at "a locality on Little Cave creek a few miles west of Evans-Ville".[1] It is evident that these shells did not come from a ledge in place but were washed from the remains of the Kiowa shales occurring some miles to the north.

Eleven miles to the southwest and about three miles northeast of Avilla, in the head of a draw east of the Coldwater-Avilla highway, are loose yellowish sandy shales similar to those of the upper

1 Fifth Biennial Report Kansas State Board of Agriculture, Pt. II, p. 142.

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Kiowa, containing small Lamellibranch shells apparently identical with those found near the top of the hill south of Belvidere. The draw contains abundant specimens of loose *Gryphaea* shells and quite a large number of pieces of the arenaceous shale containing the upper Kiowa fauna. Small pieces of the pinkish shaly limestone also occur. In a sandstone stratum outcropping somewhat lower in the draw, a few imperfectly preserved fossils were found by Mr. Beede. Mr. T. W. Stanton, mesozoic paleontologist of the U. S. Geological Survey, a well known authority on the Cretaceous invertebrate faunas writes as follows in reference to one of these specimens: "It contains fragmentary impressions of two or three bivalves and of a dicotyledon, none of which have been specifically identified. The shells apparently belong to the fauna that occurs in the overlying shales" [Kiowa]. The Cheyenne sandstone at this locality which is at least 20 feet in thickness, shows a layer of white sandstone, then a layer of blackish shale, above which is a yellowish-brown sandstone. The sandstone containing the fossils found by Mr. Beede is referred with hesitation to the Cheyenne. Heretofore, so far as known to the writer, fossil shells have not been found in the Cheyenne sandstone; but, as will be noticed later, a number of Lamellibranchs were obtained on the slope of Avilla hill south of Avilla. In a draw to the southeast of Avilla the top of the Red-Beds is about 100 feet below the level of the high prairie to the north. There is a marked dip to the southeast. All the high prairie between Avilla and Coldwater as well as to the north and west of the latter city is composed of Tertiary rocks.

This locality completes the discussion of the Comanche which we have referred to the Kiowa-Barber-Comanche area. From the hills to the north of Avilla the outcrop of the Comanche series or the division between the Tertiary and Red-Beds is represented as an irregular line extending in a general northwesterly direction across of the western central part of Comanche county.

SOUTHERN COMANCHE AREA.

To the south of Avilla, conspicuous in the early summer twilight of a bright Kansas day, is a prominent hill the summit of which is seven miles directly south of this town. If the atmospheric con-

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ditions are favorable it will be seen that the western slope, apparently steep and broken by ravines, is of a blackish color suggesting the not uncommon name in Comanche county, of Black Hill, by which it is generally known in the southern part of the county. As the same name has been given to two hills in the Kiowa-Barber-Comanche area, it is proposed, in order to avoid confusion to designate this one Avilla hill from the name of the township in which it occurs and of which it forms the most prominent elevation. The extreme top of the hill is 2140 feet so that it has the same altitude as the high prairie to the north of Avilla and about Coldwater. From the top of Avilla hill one sees that it is a large butte carved out of the former great plain by prominent streams on all sides. To the north is the upper part of Salt Fork (termed on the Comanche county map, Red Elk creek, and on some other maps Red Fork); to the east Mustang and other southern branches of the Salt Fork; to the northwest Cavalry creek and to the west and south the great Cimarron river. The view from the butte is a commanding one, for to the north are the bluffs of Salt Fork with the high prairie stretching far away in the distance, while in the opposite direction is the white Salt Plain of the Cimarron river bounded on the farther side by the southern bluffs of that river. If the observer happens to stand on the summit of this hill on one of those scorching midsummer days peculiar to southwestern Kansas he will see the saline incrustation of the Salt Plain and the sand dunes along the river gleaming white in the brilliant sunshine and the air below him vibrating intensely. It furnishes an experience long to be remembered and one that, possibly, the traveler would not care to have repeated very frequently.

The rise from South Fork toward the hill for about five miles is quite gradual, averaging from 130 to 160 feet, when the steep part of the hill is reached, with a rise of perhaps 150 feet in the next mile. On the western and southern sides the flanks are very precipitous for 160 feet and are greatly seamed and broken by the heads of numerous ravines. The measured section is from Salt Fork level along the road, that stands one half mile west of Avilla, to the foot of the hill and then up its steep western flank.

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Section of Avilla Hill.

No.		Feet.
6.	Tertiary	14—266
5.	Arenaceous shales alternating with pinkish *Ostrea* limestone.	26—252
4.	Yellow fossiliferous shales. Large numbers of *Gryphaea Pitcheri*, Mort. — *G. forniculata* White. In the lower part rather coarse *Cyprimeria* shales alternating with blackish and yellowish shales.	90—226
3.	Mainly black shales, possibly thin streaks of yellowish shales in the upper part. Base of *Kiowa shales.*	20—136
2.	In part very hard, quartzitic sandstone and some yellowish, reddish and brownish soft sandstone containing poorly preserved Lamellibranch shells. *Cheyenne* sandstone.	6—116
1.	Top of the Red-Beds; red shales and sandstones. Slope covered to a considerable extent. Level of Salt Fork.	110—110

The above section gives a thickness of 142 feet for the Comanche series, the upper 136 feet of which belong in the Kiowa shales, while the variously colored sandstone at least 6 feet thick at the base is called Cheyenne. To be sure the Cheyenne sandstone has not heretofore been identified to the southwest of the northeastern part of Comanche county; but this sandstone has the same variety of colors, is composed of rather coarse grains of quartz sand about like those of the Cheyenne and is found in the same stratigraphic position; bright red rocks below, while immediately above are black thin shales succeeded by coarser yellow to gray shales containing abundant Kiowa fossils. The great hardness of this stratum, in places becoming almost a quartzite, might be mentioned as an evidence of dissimilarity between these two sandstones; still this change from extreme friableness to great hardness is found in other sandstones of similar texture in Kansas as, for instance, in the Dakota which, in general, in Saline and McPherson is of a friable nature, but on South Twin Hill and the ridge in Bonaville township in the northeastern part of McPherson county, the sandstone is as hard as a quartzite. The other and greater argument against non-

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correlation of these sandstones is the presence in the Avilla Hill sandstone of a considerable number of Lamellibranch shells. On account of the texture of the rock in which they are found, however, they are, in general, imperfectly preserved. A few of these specimens were referred to Mr. T. W. Stanton who reported as follows: "The specimens from the quartzitic sandstone of southern Comanche county, Kansas, apparently do not include any forms that can be considered characteristic of a known horizon. The most of them I cannot venture to identify even generically, as neither the hinge nor the surface characters are preserved. One specimen has on it an *Avicula* that may be the same as *belviderensis* Cragin. Another appears to be a *Cucullaea* and it also is possibly identical with the Kiowa species *C. terminalis* var. *recedens* Cragin. There can be no doubt that the quartzite is Cretaceous, but that is about all that could be said if its stratigraphical position were unknown."[1]

This sandstone, called the Cheyenne, is well exposed in several small ravines at the foot of the steep western side of the hill, where it varies from very hard to quite friable. The prevailing color is yellowish-brown, iron-stained to a very dark brown; but other colors are also conspicuous. Below, the Red-Beds are clearly shown upon which the Cheyenne rests. This stratum forms a conspicuous ledge on the northern slope of the hill five miles south of Avilla. At this place the sandstone is very hard, being decidedly quartzitic, of brownish color and contains numerous iron concretions. The rock contains a good many poorly preserved specimens of Lamellibranch shells, more numerous here than on the western side of the hill and it afforded the species studied by Mr. Stanton.

This outcrop is a little east of the highway one half mile east of Avilla and five miles south. The readings of the barometer made the sandstone ledge at this place about 30 feet higher than on the western side of the hill. However, there was an interval of three hours between some of the readings so that the apparent difference in altitude is perhaps due to a variation in the instrument. Time did not permit to prove or disprove the above supposition by tracing the horizon around the side of the hill.

Near the road the stratum is greatly broken, and large blocks

1 Letter of Mr. T. W. Stanton, Dec. 3, 1896.

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of the quartzitic sandstone lie loose on the ground. Above this sandstone, on the northern side of the hill, the rocks are mostly covered, but near the summit, six and one half miles south of Avilla, large blocks of the *Gryphaea* limestone lie loose on the surface. On the western side, near the foot of the steep portion of the hill, around the heads of the numerous *arroyos* are good exposures of the fine argillaceous black shales resting on the Cheyenne sandstone similar to those occurring near the base of the Kiowa shales in the Kiowa-Barber-Comanche area. These grayish to yellowish shales become coarser and contain in layers abundant specimens of *Cyprimeria* and *Turritella.* In the upper part of the hill are quite thick layers of the pinkish *Ostrea* limestone, from which large blocks have fallen, alternating with yellowish arenaceous shales that contain a Lamellibranch fauna composed mostly of small species. There is also a thin stratum containing an abundance of Gastropods. On the surface in the upper part of the western side of the hill are great numbers of excellent specimens of *Gryphaea Pitcheri* Mort. as figured by Marcou on pl. IV, figs. 5 a, b, and 6 — *G. forniculata* White, of his Geology of North America. Around the escarpment of the hill are numerous large blocks of the shaly pinkish limestone of the upper Kiowa shales, which at this locality is thicker and more massive than is generally the case. Many of these rocks were drawn to Avilla and used for foundations when the town was built and large blocks may now be seen about the hamlet.

It is thought the quartzitic character of the sandstone just described, and especially the presence in it of fossils will serve to show that at this locality there is a most interesting exposure of the Cheyenne. Above it is the typical series of the Kiowa shales the lower part of which consists of black shales containing but few fossils, followed by the coarser yellowish to pinkish shales and shaly limestones containing abundant fossils. The thickness of the Kiowa is 136 feet, being nearly as great as that in any of the sections studied in southern Kansas. As far as the writer is aware, the only previous references to the occurrence of the Comanche series on this hill are brief statements by Professors St. John and Cragin.

In St. John's notes on the Geoolgy of Southwestern Kansas are

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apparently three references to the Cretaceous of this locality, though they are very meagre. In one place it is simply stated that "In the high lands east of the Cimarron, in the southwest portion of Comanche county, the lower strata of the formation [Cretaceous] apear at about 90 feet above the gypsum ledge [Medicine Lodge gypsum (?)]."[1] Later, in describing the pre-Tertiary erosion, St. John wrote that "Judging from data at present accessible, it would appear that the present region marks the limits of the northern extension of this peculiar southern fauna of the Cretaceous; and these occurrences are of much interest in connection with the physio-biological history of the period. These upper deposits have been excessively eroded in this eastern belt, occurring in the highland ridges and in isolated remnants like that in the Black Hills between Salt Fork and the Cimarron, on the southern border of Comanche county. Upon the uneven surface thus formed, Tertiary deposits were laid down, which extend east into Barber and Pratt counties."[2]

Professor Cragin referred to the presence of Kiowa shells on this hill as follows: "The black hill south of Avilla which I have crossed, I have never found time to examine; but I have casually observed *Gryphaea Pitcheri*, *Ostrea Franklini*, *Cyprimeria crassa*, etc., as among its fossils. The wide separation of this hill from other outcrops, and the numerous loose specimens of *Gryphaea* scattered about to the west and to the northwest of Avilla, taken in connection with the outcrops on Elk and Mule creeks, testify to the former existence of the Neocomian series over the entire county, and to its subsequent extensive erosion."[3]

The above Comanche area is about 32 miles northeast of the one mentioned by Professor Cope on the divide between the Cimarron river and Beaver creek, five miles northwest of Camp Supply, which is described as "of limited extent, being cut off to the north by the drainage of the Cimarron river, and to the south by the drainage of the North Fork of the Canadian. Its horizontal extent cannot exceed fifty square miles."[4]

1 Fifth Biennial Report Kansas State Board of Agriculture, 1887, p. 142. On the following page is a mention of the Dakota, as St. John called the Comanche, "in the Black Hills, in southwest Comanche."

2 Ibid., p. 144.

3 F. W. Cragin, Bulletin Washburn College Laboratory Natural History, vol. II, 190, p. 80.

4 E. D. Cope, Proceedings Academy Natural Sciences, Philadelphia, 1894, Pt. I. p. 65.

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The section as described may be tabulated as follows:

No.		Feet.
4.	Yellowish impure limestones containing fossils........	24
3.	Coarse yellowish sand in places, with horizontal red streaks.	6
2.	Marls, black above, whitish in the middle, and buff below, with no fossils.	24 (?)
1.	Red-Beds.	

The age of the marine Cretaceous beds of the above section, is said by Prof. Brown to correspond "with the Comanche Peak terrane of the Texas geologists."[1]

From collections made at this locality, Prof. Brown identified the following invertebrate species:

Exogyra texana.
Gryphæa pitcherii.
Ostrea subovata.
Ostrea (?) *crenulimargo.*
Ostrea sp.
Cucullæa terminalis.
Neithea occidentalis.
Plicatula incongrua.
Trigonia sp.
Trigonia emoryi.
Turritella seriatim granulata.
Schlœnbachia peruviana.

And Professor Cope identified the following vertebrates:

Lamna 2 sps.
Lepidotid scale.
Uranoplosus arctatus.
Uranoplosus flectidens.
Cœlodus brownii.

Plesiosaurus vertebræ, crocodile fragments, and fragments of a tortoise.[2]

Professor Hill has discussed the fossil remains from the Camp Supply beds and considers that "The vertebrata from these beds

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1 Loc. cit.

2 Loc. cit.; and see Journal Academy Natural Science, Philadelphia, 2d series, vol. IX, Pt. 4, 1895, pp. 445-447 for descriptions of the fishes in the above list.

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strikingly resemble those described by Williston and Cragin from the Belvidere beds of Kansas with the exception of two species of Pycnodont fishes belonging to the genera Uranoplosus and Coelodus, for which this is a new horizon"; while the invertebrate fossils served as a basis for correlating them with the typical Texan formations and Professor Hill further says: "From the Molluscan species it will be seen that these beds paleontologically more resemble the Washita division than the Fredericksburg. Furthermore they show the same general association of Molluscan species as do the Belvidere shales, and like them differ from the beds of the Central Texas region by containing vertebrates. That they are a southern extension of the Belvidere beds there can be no reasonable doubt."[1]

Another area containing the same invertebrate fossils was described by Professor Cope, at a point about twelve miles south of Fort Supply and south of the North Fork of the Canadian.[2]

Much farther to the southeast on the southern side of the Canadian river, in county G of Oklahoma territory according to Professor Hill, is the Comet creek area of Cretaceous discovered by Prof. Jules Marcou who briefly described it as "the remains of beds of a limestone filled with shells, which I connect with the *Neocomian* of Europe; or in other words, with the Lower Division of the *Cretaceous rocks*."[3] In reference to this remnant of the Cretaceous, Professor Hill concluded that "Inasmuch as these beds lie in the Kansas province, i. e., the region north of the Ouachita system of mountains, and is completely cut off from the Texas region by them, it is reasonable to infer, until the localities can be visited, that the Comet creek bed is a part of the same general formation as those near by at Camp Supply and Belvidere."[4]

Finally, the thorough survey that Professor Hill is now making of the Territory under the auspices of the U. S. Geological Survey will undoubtedly furnish complete information in reference to the geology of this interesting region. As a part of that work, the boun-

1 American Journal Science, 3d series, vol. L, p. 228.
2 E. D. Cope, Proceedings Academy Natural Sciences; Philadelphia, Pt. I, 1894, pp. 65, 66.
3 Geology of North America, Zurich, 1858, p. 17.
4 American Journal Science, 3d series, vol. L, p. 229.

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daries of the Kansas formations are being traced from the Kansas border to Texas.

CLARK COUNTY AREA.

In following northwesterly from Avilla to the western part of Comanche county there are but few outcrops of the Comanche series. In general the Tertiary appears to rest directly upon the Red-Beds. On the upland about three miles northwest of Avilla old cellars and wells show yellowish to grayish shale on top of the bright red rocks. For some distance in this region the country is comparatively level only an occasional outcrop showing around the heads of the small branches of Cavalry creek. Near the head of one of these branches, about five miles south of Coldwater and two miles west, and 70 feet by the barometer above the hamlet of Avilla is a thin ledge, at least 3 or 4 feet thick of the Kiowa shales. The rock consists of shaly limestone of the upper Kiowa containing plenty of specimens of *Cyprimeria* and *Ostrea.*

In a draw two miles southwest of Coldwater the Kiowa shales were not observed, though it seems to be very near the line of division between the Red-Beds and Tertiary. The Tertiary grit is well exposed in the cliff above the draw and there is plenty of loose sandy marl in the side of the bluff. This outcrop is undoubtedly above the Red-Beds, though a streak of reddish soil shows very clearly near the foot of the bluff. Apparently at the base is a deposit of Tertiary sand in which pebbles occur; so that it seems to be clearly enough above the horizon of the Red-Beds. In the sand are layers of white chalky marl similar to the characteristic marls of the Tertiary. On the road directly west from Coldwater toward Sand creek no exposures of the Comanche were found though places near the line of contact between the Tertiary and Red-Beds were examined. In the northeastern part of Protection township seven or eight miles west of Coldwater the bluffs to the east of Sand creek[1] are composed of red rocks belonging to the Red Bluff

1 This creek is termed Sand creek on the Coldwater sheet of the U. S. Geological Survey. On the county map of Comanche county Sand creek is given as one of the head branches of this creek in the northwestern part of Coldwater township. I am in doubt whether this name is intended to apply to the main portion of the creek since that is generally known by the residents of that part of Comanche county as Kiowa creek; and the branches in Irwin township as East, Middle and West Kiowa creeks respectively. A Bluff creek tributary just west of here is popularly known as Sand creek. A name applied to dozens of little streams in western Kansas.

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formation of Cragin. The thickness of this sub-formation increases quite rapidly in passing from the southern part of Comanche county to its western border. In this bluff are loose pieces of pinkish, shaly, limestone containing *Ostrea;* and also sandy, yellowish, shales of the upper Kiowa. The top of this bluff is 95 feet above the level of Sand creek (or Kiowa creek) to the west. Judging from the hills one half mile east of this place, the Red-Beds extend somewhat higher and the loose Kiowa shales are below the horizon of the Comanche. On the western side of Sand creek are exposures, of some thickness, of the black shale belonging to the Kiowa. This locality may be regarded as forming the eastern end of the Clark county area of the Comanche series. On the flanks of the hills to the northwest of Sand creek, on section 21, Irwin township, 110 feet above creek level are thin black shales exactly similar to those of the lower Kiowa in the southeastern part of Kiowa county. Some of this shale weathers to a bluish and gray tint and a little of it to a brownish yellow. Near the base of the shale as exposed in a small draw is a 2 or 3 foot layer of soft yellowish sandstone containing fossils, as *Cyprimeria* and other species. At this place the top of the Red-Beds is not shown, the lower slope of the hill being covered by soil; neither is the line of contact between the Kiowa and Tertiary shown, this portion also being similary covered. Between 25 and 30 feet, however, of the yellowish and black shales were measured at this point. On the county map of Comanche county an elliptical area in the western part of Irwin township is marked "Coal Cropping." After an examination of this township it is evident enough that the Kiowa black shales suggested the idea of coal beds to the early settlers. In a similar manner coal was also inferred to occur in Powell township on the headwaters of Big Mule creek in the northeastern part of the county. In the eastern part of the latter area, black shales of the Kiowa outcrop in the creeks and draws. From the western part of Irwin township the Kiowa shales were followed westerly along the hills some distance to the north of Bluff creek, and were found to have a constantly increasing thickness. The top of the Red-Beds on section 21 of Irwin township is at least 40 feet higher than at their occurrence on the branch of Cavalry creek five miles southwest of Coldwater.

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The high prairie around the head-waters of Kiowa and Sand creeks, using the local names, is composed of Tertiary rocks, outcrops of which are shown frequently in the small branches and draws forming the heads of these creeks. About three miles west of the outcrop on section 21 of Irwin township is a section along a small branch of Cavalry creek and one half mile east of it showing the entire Comanche series.

Section one half mile east of Cavalry.

No.		Feet.
4.	Upper portion partly covered, but showing occasional outcrops of calcareous marls of the Tertiary. Base of Tertiary about 50 feet below the level of the prairie.	50—92
3.	Yellowish argillaceous to calcareous shales and pinkish shaly limestone containing *Ostrea.* In the yellowish soil evidently formed in part by the decomposition of these yellow shales are abundant specimens of loose *Gryphaea* shells. Lower part black, yellow, and drab shales in which no fossils were noticed.	30—42
2.	The lower part of the section shows soft, friable sandstone which in lithological characters closely resembles the Cheyenne sandstone as exposed in Kiowa and Comanche counties. At the base of this sandstone a thin layer of black shale. Thickness 10 to 12 feet. Base of Cheyenne (?)	10-12—12
1.	Top of Red-Beds.	

Perhaps this sandstone is the representative of the thin sandstone noticed along Mule creek above a bed of blackish shale containing red streaks. If this be true, then in this locality the sandstone has increased considerably in thickness, while the shales below are much thinner, being represented by a very small thickness in this outcrop. To the west of Cavalry creek the Kiowa shales are exposed on the bluffs along Lone Tree, Granger and Fish creeks or their branches from three to four miles north of Bluff creek. On Lone Tree and East Granger creeks the slopes are more or less covered so that the exact thickness of Kiowa shales was not de-

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termined. On Fish creek, however, their approximate thickness was determined.

Section on Fish Creek.

No.		Feet.
3.	Top of high prairie. Covered slope showing ledges of Tertiary rocks.	50—105
2.	Yellowish shales changing to blacker shales at the base. Kiowa.	40— 55
1.	Red rocks extending to level of creek at this locality.	15— 15

Along the creek east of Messing's ranch[1] the Red-Beds show conspicuously along the bank and up its slope for quite a distance. Higher are conspicuous ledges of Tertiary rock, the Kiowa being more or less concealed by soil. Between Fish creek and the one east of Messing's ranch, about three fourths of a mile northeast of Bluff creek, is a prominent butte the top of which is composed of Kiowa shales. This butte has been separated by erosion from the Kiowa outcrops a mile or more to the north, which follow the main line of bluffs bounding the northern part of the Bluff creek valley. On the south side of Bluff creek, nearly opposite Messing's house, are steep bluffs with numerous projecting points and buttes along the prominent ledge of the escarpment. At this locality a section was measured from the level of Bluff creek to the general level of the divide to the south. Messing's Bluff is suggested as an appropriate name for the conspicuous bluff on the southern side of Bluff creek at this locality.

Section of Messing's Bluff.

No.		Feet.
6.	Base of Tertiary near top of bluff.	
5.	Mainly yellowish sandy argillaceous shales........	53—226
4.	Mainly black shales of the lower part of the Kiowa.	53—173
3.	Red rocks consisting of arenaceous shales and friable sandstones. This is the division called the Hackberry shales by Professor Cragin, the name being derived from the exposures along Hackberry creek about 2 miles west of this locality.[2]	20—122

1 The Messing ranch is a well known locality in the Bluff creek valley near the southern end of the Bluff creek canyon. It is about eleven miles north and one and one half miles east of the city of Ashland and in the northern central part of Clark county, or more precisely section 17, township 31 s., range 22 w.

2 F. W. Cragin, Colorado College Studies, Vol. VI, p. 46.

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CLIFF AT THE ENTRANCE OF THE "AMPHITHEATER" ON BLUFF CREEK, FIFTEEN MILES NORTH OF ASHLAND, CLARK COUNTY.
(Photographed by Prosser, 1896.)

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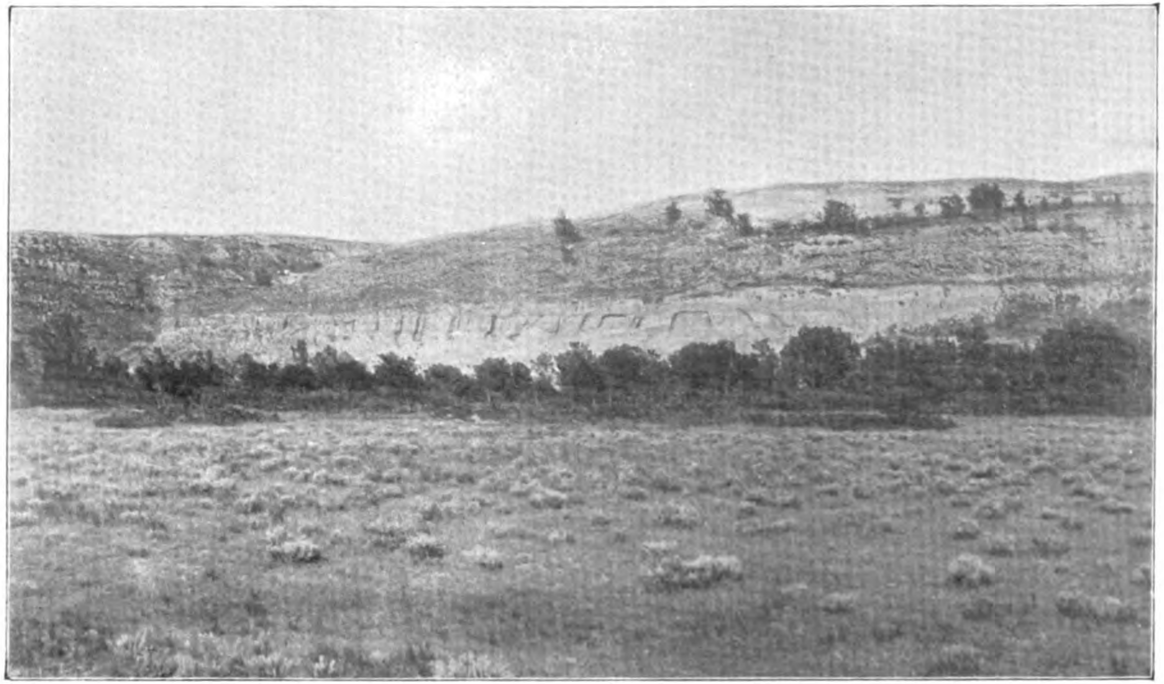

EASTERN SIDE OF THE "AMPHITHEATER."
(Photographed by Prosser, 1896.)

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No.		Feet.
2.	Massive magnesian limestone or dolomite varying somewhat in thickness, of drab to whitish color, in places containing flint. This stratum is the one termed the "Day Creek Dolomite" by Professor Cragin, being named from outcrop near the head of Day creek in the south central part of Clark county six or seven miles southeast of this locality.[1]	2—102
1.	Partly covered slope showing frequently layers of bright red sandstone belonging to the Bluff creek division of Cragin. Level of Bluff creek.	100—100

Along the bluff on the north side of the creek just above Messing's house, the Day creek dolomite forms a conspicuous stratum at the top of the bluff with its base 85 feet above creek level. Between one and two miles north of west of Messing's the cañon of Bluff creek begins. From this locality for a distance of 7 or 8 miles to the west of north the creek flows generally between high walls. In many places, for a considerable distance, these walls are nearly perpendicular for from 100 to 200 feet. In the lower part of the cañon the walls of the bluff are composed of bright red shales and sandstones broken by a white stratum of Day creek dolomite. Frequently these bluffs of red sandstones and shales show from a number of rods to a mile or more in length with a hight of from 50 to 100 feet giving a most excellent idea of the general character of the rocks forming the upper portion of the Red-Beds, or Kiger formation. About 3 miles above Messing's on the west side of the creek is a conspicuous ledge of the Kiger formation, above which is a stratum 10 feet or more in thickness composed of gray soft sandstone; and above this is a layer containing immense numbers of small *Gryphaeas*. Following this are blackish shales 5 feet in thickness above which is another calcareous layer containing numerous specimens of fossils belonging to a number of species. The *Gryphaea* bed of limestone is very similar in appearance to the Champion shell-bed near Belvidere. If this limestone represents the Champion shell-bed it would seem to follow that the subjacent

1 Ibid., p. 44.

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sandstone is a representative of the Cheyenne sandstone. In this region Professor Cragin also remarked the similarity of this limestone to that of No. 5 of his Belvidere section[1] (which he termed later the Champion shell-bed) and he also noted another similar stratum from 50 to 75 feet higher. The gray sandstone and first fossiliferous stratum show occasional blotches of red. Along this bluff there is not as sharp a line of separation between the top of the Red-Beds and the Comanche as is generally seen in the Kiowa-Barber-Comanche area. The Red-Beds extend along the valley of Bluff creek to near the base of that part of the cañon known as the "amphitheatre" which is five or six miles above Messing's house and on section 17 township 31 s. range 22 w. The top of the Red Beds shows in the creek bed just below the prominent point forming the lower end of the Amphitheatre. This locality is the one called the Bluff creek section by Professor Cragin. The lower end of the Amphitheatre bluff on the eastern side of the creek, was carefully measured by Locke level and forms the most accurate section of the Comanche series for Bluff creek.

Amphitheatre Section of Bluff Creek.

No.		Feet.
6.	Near the general level of the high prairie, pinkish colored deposit of marl, slope of which is partly covered. This represents the Lake marl slope or No. 1 of Professor Cragin's section.	35—228
5.	Calcareous sand or grit containing remains of vertebrate animals. The division termed the *Loup Fork grit*, or No. 2 of Professor Cragin.	53—193
4.	Yellowish sandy shale with thin layers of pinkish shaly limestone forming upper part of this division. Blackish shales with thickness of several feet. From 1 to 1½ feet of arenaceous rock containing large numbers of *Gryphaeas*. Thickness 55 feet. No. 3 of Cragin's section.	55—140
3.	Yellowish soft and friable sandstone which forms a conspicuous stratum near the middle of the	10—85

1 F. W. Cragin, Bulletin Washburn College Laboratory Natural History, Vol. II, p. 79, Topeka.

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No.		Feet.
	steeper part of the bluff. No. 4 of Cragin's section lithologic characters of which are compared to those of the Cheyenne sandstones.	
2.	Mainly blackish shales with thin layers of yellowish to whitish rock. Fossils infrequent.	75—75
1.	Bottom of section—level of Bluff creek, Red-Beds occurring a short distance down stream.[1]	

This section gives a thickness of 140 feet for the Comanche series all of which it is perhaps safe to refer to the Kiowa shales. The lower 75 feet of shales are nearly unfossiliferous and represent a greater thickness than is the case with the black "paper shales" of Kiowa county. Perhaps these might be referred to the black shales seen in the bluffs of Big Mule creek which were also capped by thin sandstone. In this event the sandstone forming No. 2 in the above section would probably represent that sandstone. The similarity of this sandstone to the Cheyenne has already been mentioned by Professor Cragin, and if this supposition be correct perhaps the lower 85 feet of the amphitheatre section could be referred as well to the time interval denominated the Cheyenne; while the fossiliferous superjacent rocks would represent the Kiowa. The writer, however, considers the entire section of 140 feet as belonging to the Kiowa formation, regarding the Cheyenne as wanting. From the top of the Kiowa shales to the general level of the prairie is from 80 to 100 feet with occasional exposures of Tertiary rocks. A general idea of this bluff may be gained from Plate XIX which gives a view *At the Entrance to the "Amphitheatre" on Bluff creek* in which the black shales of No. 1 are partly concealed by foliage, above which is a conspicuous stratum representing the sandstone of No. 2; then to the vicinity of the summit of the bluff, we have the upper Kiowa shales capped near its shoulder by the Tertiary rocks. Plate XX, the *Eastern side of the "Amphitheatre,"* gives a view of the middle part of the eastern wall of the Amphitheatre some distance above the former picture. The black shales form the lower part of the wall, then comes the sandstone stratum

1 For Professor Cragin's section see Bulletin Washburn College Laboratory Natural History, vol. 2, p. 79. Topeka.

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with the coarser Kiowa above, upon which rests the Tertiary. The light colored cliffs above the upper line of trees in the highest part of the picture belong in the upper division of the Tertiary.

Three miles above the Amphitheatre and near the old Vauheim post office the course of Bluff creek turns westerly. This point is near the termination of the narrow valley which has been termed the cañon of Bluff creek. Along the bluffs above the Amphitheatre the Kiowa shales are well shown until near Vauheim. Their upper limit passes below creek level somewhat west of this locality on Section 14, Township 30 S., Range 23 W. On the map the Kiowa shales are shown as a blue rock extending northerly along the narrow valley of Bluff creek, to the northern part of the county to within about two miles of the Clark-Ford county line.

Near the lower end of Bluff creek cañon, Hackberry creek enters from the west. The sides of this creek are very steep and its narrow valley thus forms a lateral canyon to the west of the main one. On the south side of this creek, between two and three miles southwest of Messing's house the thickness of the Kiowa shales was measured. At the bottom of the section and considerably higher than creek level is a yellowish to whitish sandstone which is supposed to represent the same sandstone that occurs in the Big basin near the western edge of Clark county and to which Professor Cragin gave the name of Big basin sandstone.[1]

Section of Hill South of Hackberry Creek.

No.		Feet.
4.	Upper part Tertiary grit.	
3.	Yellowish shales with some arenaceous layers. At the base is a sandstone the thickness of which was not determined. This sandstone seems to occur near the same horizon as the one in the Amphitheatre section (No. 2 of that section). Thickness 55 feet.	55—135
2.	Yellowish shales in the upper part changing to mainly blackish in the lower part. Thickness 80 feet.	80—80

1 Colorado College Studies, vol. VI, p. 46.

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No.

1. Top of sandstone which is thought to represent the Big basin sandstone of Cragin. Thickness of section below this point not measured.

A comparison of the three sections in the cañon region of Bluff creek indicates some variation in the thickness of the Kiowa shales. In the Amphitheatre section they have a thickness of fully 140 feet. In the one south of Hackberry creek, about five miles south of the Amphitheatre, the thickness of the same formation is approximately the same or 135 feet; while in the section of Messing's Bluff, about three miles east of the Hackberry section its thickness is only 106 feet. In the latter section the top of the Red-Beds was clearly shown as also the base of the Tertiary, consequently there cannot be any considerable error in measurement. At the head of one of the southern branches of Hackberry creek toward its upper end is an interesting exposure of iron brown coarse sandstone similar to that which has generally been referred to the Dakota. This is one of the three prominent exposures of this sandstone seen in the rugged region of the northwestern central part of Clark county.

In this vicinity decided breaks have been formed by the erosion from the general level of the high divide to the north, which separates the Arkansas river valley on the north from the tributaries of the Cimarron on the south. The bluffs thus formed are conspicuously shown near the headwaters of Hackberry, East and West Bear and Little Sandy creeks. Near the top of these bluffs at the heads of Hackberry, West Branch Bear creek, and Little Sandy, are the three outcrops of the so-called Dakota sandstone. The one on Hackberry creek is about three miles southeast of the hamlet of Letitia on Section 21, Township 31 S., Range 23 W. At the head of the creek, from 20 to 25 feet of the brownish to iron colored sandstone is shown resting on the Kiowa shales. These shales in the upper part are very arenaceous and iron stained; but they contain *Gryphaeas* and other fossils of the upper Kiowa. The top of the Kiowa shale is about 60 feet below the general level of the prairie in this vicinity. The prairie near the head of this creek is somewhat lower than the prairie near Letitia, the latter being 2540 feet above sea level. The hugh divide capped

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by Tertiary rocks, separating Hackberry and Bluff creeks on the north from Day, Bear and Sandy creeks on the south, extends from near the head of Hackberry creek in a southeasterly direction for a distance of fifteen miles. The elevation of this divide varies from perhaps more than 2500 feet A. T. near the head of Hackberry creek to 2300 in a Tertiary capped butte near the southeastern extremity of the divide. About six miles southeast of Messing's house is a prominent point on the ridge just described known as Mount Jesus, which is on Section 11, Township 32 S., Range 22 W. In the depression between the above mentioned butte and Mt. Jesus the Tertiary rock has been removed by erosion, the highest part of the ridge at present showing only rocks belonging to the Kiowa. In a creek heading in the northeastern slope of this mountain, the Day Creek dolomite forms a conspicuous stratum at an elevation of 131 feet above the level of Bluff creek. In the immediate vicinity there is evidence that the Kiowa was deposited upon an irregular sea-bottom. At only a short distance from the locality where the Day Creek dolomite is so well exposed, there is an exposure of the Kiowa resting upon the Red Beds; but at places both the Hackberry shales and Day Creek dolomite are eroded so that the Kiowa shales rest upon the upper part of the Red Bluff sandstone at a position which is of course below the horizon of the Day Creek dolomite. Professor St. John in his early exploration of southwest Kansas also mentioned the uneven bed upon which the Cretaceous formation was deposited, his description of this region being as follows: "The formation [Red-Beds] was also subjected to extensive denudation, as evidenced in the apparent uneven surface upon which the more recent Cretaceous formation was deposited, and in places it has received even late Tertiary deposits. In the region of Bluff creek, the base of the Cretaceous deposits varies in level more than 100 feet. On Sand creek, three miles northeast of Lexington, the latter formation appears at a level nearly 120 feet lower than its base on Cat creek, seven miles to the west. In the south slope of Mt. Lookout, south of Bluff creek, the Cretaceous deposits are very nearly level with the exposures on Cat creek, and they occur within 50 feet of the upper limestone of the Red-Bed series."[1] At the base of

1 Fifth Biennial Report Kansas State Board of Agriculture, Pt. II, p. 142.

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the Kiowa shales in this vicinity is a yellowish sandy layer from 3 to 4 feet in thickness. Above are black shales which are well exposed for some distance. Higher the upper part of the Kiowa is largely covered so that its top was not determined with accuracy. Apparently the Kiowa shales have a thickness of at least 60 feet in the northern slope of Mt. Jesus. The Tertiary above dips toward the northeast and rests upon the top of the Kiowa at a lower elevation than at the almost vertical exposure in the south side of the mountain. I am inclined to think that the superjacent Tertiary on the northern slope of the mountain has fallen to some extent on account of the later erosion of the Kiowa shales and so conceals the upper portion of the latter formation. On the south side of the mountain is an excellent exposure of the Tertiary and the Kiowa shales reaching to the upper part of the Red-Beds.

Section on South Side of Mt. Jesus.
(U. S. Signal Station 2300 A. T.)

No.		Feet.
4.	Upper part of cap composed of Tertiary marls; lower portion Tertiary sands and grit—total 80 feet; Tertiary.	80—173
3.	Yellowish and pinkish shales changing to blackish shales in the lower part. Kiowa.	85— 93
2.	Red shales belonging to the Hackberry shales of Cragin—8 feet.	8— 8
1.	Day Creek dolomite.	

The top of Mt. Jesus is eight miles northeast of Ashland. The Kiowa shales follow the ridge forming the divide between Bluff creek on the north and the tributaries of the Cimarron on the south to a point four miles southeast of Mt. Jesus when the outcrop turns and extends in an irregular line westerly, forming the southern slope of the mountain with its top 80 feet below the summit. Mt. Jesus is a conspicuous land mark in the eastern central part of Clark county. From its summit may be seen to the south the great valley of the Cimarron, the river itself being fourteen miles south. The ridges and lower bluffs along the sides of the creeks of this valley are composed of the rocks of the Cimarron series or Red-Beds as may be seen for a long distance from Mt. Jesus. Along the im-

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mediate valley of the river, as seen from the mountain, are low rounded hills, appearing white in the bright sunlight of a midsummer Kansas day, which are composed of sand washed by the river from the Tertiary rocks to the west and northwest forming the sand planes and dunes along the river valley. To the southwest of the mountain are the smaller valleys of East and West Bear creeks and near their junction the city of Ashland which is distinctly visible from the mountain's summit. Along the south side of the divide from Mt. Jesus westward are very conspicuous cliffs of Tertiary rocks. Some miles to the south of these, the cliffs appear as a high range of bluffs, like a mountain escarpment, of almost snowy whiteness. This is especially noticeable in the steep cliffs forming the edge of the divide between five and six miles directly north of Ashland. An idea of this appearance from a close view may be obtained from Plate XXI, which represents a part of the *Tertiary cliffs north of Ashland,* in which a heavy stratum of Tertiary marl is conspicuous. To the south and southwest of Mt. Jesus are the head-waters of Day creek about which are exposed the dolomite to which Professor Cragin has given the name of Day Creek dolomite. This rock forms a rather conspicuous stratum extending around the lower bluffs south of the Tertiary escarpment already described. This limestone was also noticed by Professor St. John who described it as a "gray, cherty, sometimes gypsiferous limestone, 2 to 5 feet thick," which he mentioned as occurring toward the top of the Red-Beds, forming a marked stratigraphic feature in the slopes descending from the highlands which rise to the north nearly 200 feet above this limestone.[1]

On the ridge four miles northeast of Ashland the Day Creek dolomite is conspicuously shown while to the west of Ashland, five miles southwest of the above locality, it was also found at an elevation 30 feet higher according to the barometer. This gives a dip of approximately 6 feet per mile to the north of east. On the slope of Mt. Jesus and at various other localities along this divide a marked dip toward the south and southeast was noticed. This accords fairly well with the direction of the prevailing dip as determined by Professor Cragin in northern Oklahoma and southern

1 Fifth Biennial Report Kansas State Board of Agriculture, Pt. II, pp. 141, 142.

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Kansas, which he stated to be a little east of south.[1] In Professor St. John's exploration, the southerly dip was noted, for he says: "In the vicinity of Mt. Lookout, north of Ashland, the limestone horizon [Day Creek dolomite] appears at a level 25 feet lower on the south side than it holds in the bluffs on Bluff creek." However the Professor gives the general direction of the dip for the Red-Beds of this region as southwesterly.[2] Between five and six miles north of Ashland are steep Tertiary cliffs which mark the line of division between the high and comparatively smooth prairie to the north and the broken country to the south forming the upper part of the valley of the Cimarron river. A stratum of the Loup Fork Tertiary in this region is massive, from 6 to 10 feet in thickness forming a sharp line around the upper part of the bluffs. A good idea of this stratum with the weathered, softer Tertiary grit below and above may be gained from Plate XXI, the photograph for which was taken directly north of the city of Ashland. The cliffs for a number of miles are very conspicuous from the city of Ashland and from points even farther south. Five miles north of the eastern line of Ashland, on sections 18 and 19, township 32 s., range 22 w., is a good exposure of the Loup Fork Tertiary and Kiowa shales with a sandstone at the base.

Section five miles north of Ashland.

No.		Feet.
4.	Calcareous grit belonging to the Loup Fork Tertiary. 40 feet.	40—310
3.	Shales partly covered, blackish at the bottom belonging to the Kiowa.	60—270
2.	Yellowish to grayish sandstone with reddish streaks—probably represents the Big Basin sandstone of Cragin, which is considered by the writer as belonging to the Cheyenne. Thickness not measured.	210—210
1.	Red-Beds, composed of red shales and sandstones to level of Bear creek at Ashland. From the top of the Big Basin sandstone to the level of Bear creek, just east of Ashland, is 210 feet.	

1 F. W. Cragin, Colorado College Studies, Vol. 6, p. 31.
2 Fifth Biennial Report Kansas State Board of Agriculture, Pt. II, p. 142.

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The sandstone noted above, with yellowish and grayish color also shows streaks of other colors as reddish, brown, etc., and thus in its lithological character closely resembles the Cheyenne sandstone while it also occurs at a similar stratigraphic position, between the Red-Beds and the base of the Kiowa. About three miles northwest of the locality just described, on the divide between the east and west forks of the East Branch of Bear creek the Comanche series was again measured. This locality is on section 3, township 32 s., range 23 w., and eight miles northwest of the city of Ashland.

Section between the Forks of the East Branch of Bear creek.

No.		Feet.
6.	Calcareous grit belonging to the Tertiary. From the top of the high prairie on the divide, to the base of the Tertiary 105 feet.	105—424
5.	Yellowish sandy shales which are fossiliferous and change into blackish shales in the lower part. 32 feet.	32—319
4.	Sandstone and yellow arenaceous shales forming a conspicuous division of this formation and here similar in lithological appearance to the one described in the Amphitheatre section on Bluff creek; but occurring in the present section 25 feet higher in the formation. 5 feet.	5—287
3.	Mainly yellowish shales—in places somewhat arenaceous. 60 feet.	60—282
2.	Thin sandstone stratum. Yellowish sandy shales which in the lower part are black fine argillaceous shales containing abundant crystals of *selenite* some of which are the twinned form. 42 feet—base of Kiowa.	42—222
1.	Top of Red-Beds. Red shales and sandstones for 180 feet to the creek level at forks of East Branch Bear creek.	180—180

One of the most interesting places to study, in the central part of Clark county is a canyon near the upper part of the West Branch Bear creek. Near the northwest fork of the creek is a narrow cañon with steep rocky sides, composed entirely of coarse brown-

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ish sandstones and arenaceous shales belong to the Dakota (?). The cañon is about fourteen miles northwest of Ashland, probably on section 36, township 31 S., range 23 W. In this region the high prairie at the heads of the creeks is composed of the calcareous grit of the Loup Fork Tertiary, apparently very much thinner than at the head of the streams somewhat farther east. Near the head of the northwest fork of the West Branch Bear creek, the locality just named, there is an excellent exposure of the contact line between the Tertiary and the Dakota brown sandstone. From this point the sides of the small canyon down to the main creek are mostly rocky showing plenty of exposures of brownish and brownish-yellow sandstones with yellowish-brown to iron colored coarse sandy shales aggregating a thickness of about 75 feet. The lithologic appearance of the rock in this canyon as well as the general appearance of the rocks forming its sides and also the upper walls of the main creek suggest very forcibly the similar appearance in the ravines in the area of the Dakota sandstones of central Kansas. This is the thickest exposure of Dakota seen by the writer south of the Arkansas river. From general appearance probably no one would hesitate seriously to correlate these sandstones with the Dakota of central Kansas. No fossils were found, but Professor Cragin has reported "meagre fragments of dicotyledonous leaves" from No. 2 of this section along upper West Bear creek which he called Dakota sandstone.[1]

Where the northwest fork joins the West Branch Bear creek, the upper part of the eastern bluff is composed of the coarse sandstones and shales, just described as Dakota, which apparently rest unconformably on bluish shales of the Kiowa below. In the upper part of the Kiowa of this cliff are thin layers of yellowish shales somewhat similar to those in the superjacent Dakota sandstone, but running at a different angle from the layers of the latter so as to suggest the idea of unconformability. At the base of the cliff, however, the layers of the Kiowa shales are nearly horizontal, so that perhaps the oblique structure of the yellowish arenaceous shales, alternating with clay shales, may be explained as due to cross-

1 F. W. Cragin, Bulletin Washburn College Laboratory Natural History, vol. II, p. 77. Topeka.

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bedding. The upper part of these shales contains numerous clay-ironstone concretions which in places are so numerous that they form almost a distinct stratum. In the lower part of the cliff fragments of *Gryphaea pitcheri* and a few other Kiowa species were found. In this bluff about 30 feet of the Kiowa shales are exposed. A little farther down the creek are coarser layers, in the upper Kiowa, of greenish-gray sandstone which contain *Cyprimeria*, *Gryphaea* and quite a large number of small Lamellibranch shells. The Dakota sandstone from the junction of the two forks forms a conspicuous stratum along the bluffs on the western side of the creek for a distance of two miles or more down stream. At the latter point the top of the red shales appears along the banks of the creek with nearly the full thickness of the Kiowa exposed in the slope of the hill to the west. The average of several barometric readings gives for these shales a thickness of 130 feet. Above is the brownish coarse-grained Dakota sandstone the thickness of which at this place was not determined. Professor Cragin described a section which he termed the "upper West Bear creek section," in which he gave a thickness of 40 feet for the Dakota sandstone, evidently measuring it in the bluff along the west side of the creek and not in the side cañon where it has its greatest thickness. Below the Dakota, Professor Cragin gave 20 to 30 feet of grayish clay shales interstratified with yellowish brown sandstone containing numerous clay-ironstone concretions. From the lower part of these shales he reported fragments of *Gryphaea pitcheri*. Below and forming No. 4 of his section is from 75 to 90 feet of blue and yellowish gray or brownish shale in which a number of species of fossils were reported, as: *Gryphaea Pitcheri*, *G. versicularis*, *Trigonia Emoryi*, *Ostrea Franklini*, *Pholadomya Sancta-sabae*, *Cardium Hillanum*, *C. Kansasense*, *Idonearca vulgaris*, and several forms not specifically identified. He also states that the base of this section, No. 4, is composed of dark shales in which no fossils were found.[1] The Big Basin sandstone, or Cheyenne sandstone is well exposed along the western branch of Bear creek. The color is frequently mottled bright red and gray, the latter color not being as predominant as in the exposures of this sandstone in

1 Ibid., pp. 77, 78.

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the Big basin. A little farther down the creek, the Day creek dolomite appears and may be followed as a conspicuous stratum that rises higher and higher along the bluffs for several miles.

The high, narrow, and steep divide separating West Branch Bear and Little Sandy creeks, extends in a nearly north-and-south direction for six miles when its southern end is divided by the headwaters of Red Hole creek. The Kiowa shales follow the eastern slope of this divide and around its southeastern prolongation, which is about three and one half miles northwest of Ashland; then around the headwaters of Red Hole creek, turning north again on the eastern side of Little Sandy creek until near its upper part. On the Fares ranch, perhaps four miles northwest of Ashland, near the southeastern limit of the Kiowa shales of this region, the following section was measured.

Section of Hill on Fare's Ranch four miles northwest of Ashland.

No.		Feet.
5.	Upper part of hill Tertiary marl which has an apparent dip of about 3 deg. to the southeast. Plenty of loose flint in the soil at base of the Tertiary sandy deposit of grit. Base of Tertiary 64 feet. (Perhaps this is an overestimate on account of dip of upper part.)	64 —349
4.	Yellowish shales containing some shaly layers of limestone in which are specimens of *Ostrea*. Thickness 53 feet.	53 —285
3.	Mainly black fine argillaceous shales. This division of the section is well shown in several small buttes near the end of the high part of the divide. In these black shales exposed around the sides of the small buttes, vertebrate remains were found.	46 —232
2.	Light gray massive sandstone varying to coarse shaly sandstone. Represents Big Basin sandstone of Cragin.[1]	1½—186

1 Professor Cragin referred the sandstone on the Fares ranch on West Bear creek to his Big Basin sandstone. See Colorado College Studies, Vol. VI, p. 46.

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No.		Feet.
1.	Red sandy shales and red sandstones 22 feet to the level of small run south of the bluff. From the top of the red shales to the level of Red Hole creek on the highway 3 miles west of Ashland, 185 feet.	185 —185

The heavy dip noted in the Tertiary marl on top of the bluff was also noticed in the light gray sandstone near the foot of the hill; but it is thought that the dip does not continue for any considerable distance.

At the southeastern end of the ridge and steep divide between Little Sandy and Chapman creeks, the line of contact between the Red-Beds and the Kiowa, as well as the line between the top of the Kiowa and the Tertiary are both clearly shown. This locality is on section 11, township 32 s., range 24 w., and in a direct line about 10 miles northwest of Ashland.

Section of Southern End of Hill between Chapman and Little Sandy Creeks.

No.		Feet.
4.	Top of point, light gray calcareous grit of the Tertiary in which are blocks of dark-brown sandstone apparently Dakota. Some of these blocks are of large size weighing 100 pounds or more. At first they were thought to show an outcrop of Dakota on this hill; but later it was seen that in all cases they had been imbedded in the Tertiary grit, being more or less thoroughly coated by calcareous material of the grit, while at the northern end of the butte they are finely shown imbedded in the grit capping the hill. Total 13 feet.	13—258
3.	Mainly arenaceous yellowish shales of the upper part of the Kiowa containing fossils. Slope partly covered. 107 feet.	107—245
2.	Near the base of the steep butte, mainly black thin shales with occasional layers of yellowish arenaceous shales. These shales contain vertebrate fossils and beautiful crystals of selenite.	38—138

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No.		Feet.
1.	Light gray sandstone, part of the exposure mottled with red at top, then Red-Beds. From top of the Reds to the junction of Chapman and Little Sandy creeks 100 feet.	100—100

About a mile and a half northwest of the section just described, on the west bank of Chapman creek is a perpendicular ledge of Red Bluff sandstone, which rises from the creek level some 50 feet and carries above it a sloping bank of Kiowa shales which in turn are capped by Tertiary. This locality is probably on section 3, township 32 s., range 24 w.

Section of Cliff on Chapman Creek.

No.		Feet.
5.	Tertiary on ridge above; junction with Kiowa not sharply marked.	
4.	Yellowish shales alternating with pinkish shaly limestone containing *Ostreas*. 43 feet.	43—141
3.	Black argillaceous shales containing vertebrate remains. 43 feet.	43— 98
2.	Brownish sandstone to coarse arenaceous shales....	55— 55
1.	Red arenaceous shale varying in thickness as exposed in the side of the cliff from 2 to 5 feet. Prominent stratum of Day creek dolomite. Below this red sandstones to creek level. From top of brown sandstone to creek level 55 feet.	

The above section gives 86 feet of Kiowa. In the section of the hill between Chapman and Little Sandy creeks, a mile and a half southeast, the thickness of that formation was determined as 145 feet. In the section just described, perhaps the Kiowa shale has a greater thickness than indicated, since the top is not sharply marked. However, it is considerably thinner than in the section to the southeast. In the bluffs, the dolomite forms a conspicuous stratum which may be followed along the creek for some distance. Higher is the stratum of red, sandy shale which near each end of the cliff is thicker than in the central part, being 5 at the ends and perhaps 2 feet near the center. This varying thickness is apparent evidence of unconformability by erosion. Perhaps it may be explained as due to varying thickness in the original deposition of the

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shales, though this position is hardly tenable on account of the increased thickness at each end. By other observers it has been considered as evidence of unconformability due to erosion preceding the deposition of the Comanche series. Between the red shales and the base of the black Kiowa shales is a brownish stratum consisting of either shales or sandstone. This occupies the position of the Cheyenne sandstone and also agrees in character with the Big Basin sandstone of Cragin. The unconformability below seems to unite this sandstone with the Kiowa rather than with the Red-Beds. Along the slopes of the bluffs on the opposite side of the creek are also excellent exposures of black argillaceous shales forming the lower part of the Kiowa. From these black shales as well as from those on the opposite side, remains of vertebrates were collected and described by Doctor Williston. Prefacing his description of the forms is a brief description of the geology of this region, in part as follows: "Suffice it to say here that in the region which we examined—upper Bluff Creek and Sand Creek with its tributaries—I found the beds in which the vertebrates occur, Cragin's No. 4, lying unconformably on the rocks of the Trias and surmounted by a thin stratum of the characteristic Dakota sandstone, and the thicker Tertiary sandstones of the uplands. The material is a dark blue shale, so strongly impregnated with iron that the fossils are always more or less injured after exposure. On moderately inclined slopes the bones, where found at all, were always disintegrated and incrusted with sulphate of lime. For this reason, they can be successfully sought only on steep slopes, and such are infrequent. Furthermore, the bones have always been found isolated, never together, so that it is hardly to be expected that even a tolerably complete knowledge of the fauna will be obtained in many years. The bones are found throughout the whole thickness of the shale, for fifty or seventy five feet. The remains, meagre as they are, are of great interest, because they represent the oldest marine cretaceous fauna of America thus far discovered."[1]

From the above locality the Kiowa shales follow the line of the bluffs west of Little Sandy creek, five miles to the south, where the

1 S. W. Williston, Kansas University Quarterly, Vol. III, July 1894, pp. 1, 2, Lawrence.

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high part of the divide terminates in the buttes known as Mounts Pisgah and Nebo. In the upper part of the Red-Beds along the bluffs west of the Little Sandy are numerous conspicuous outcrops of the Day creek dolomite, that frequently contains nodules of quartz. Professor Cragin mentioned irregular nodules of limonite as occurring in this dolomite but did not mention chert. He, however, stated that the "cherty hardness and fracture are not due to the presence of silica, as one is tempted to infer, but are characters belonging to it as dolomite."[1]

Mounts Pisgah and Nebo are located on the southwest quarter section 35, township 32 s., range 24 w., seven and one half miles west of Ashland and one and one half miles north. They form conspicuous buttes visible from the southeast for a long distance.

Section of Mount Nebo.

No.		Feet.
5.	Top of butte, upper part marly rock, which is sandy at base. Base of Tertiary.	21—274
4.	Yellowish, sandy shales containing Kiowa fossils..	27—253
3.	Black, argillaceous shales in the lower portion of the steep western part of the butte. A small ravine at this part of the butte shows a small synclinal fold, the axis of which is about on a north and south line.	47—226
2.	Stratum of yellowish, sandy shale..............	1—179
1.	Red shales and sandstone to level Little Sandy creek.	178—178

Loose on the upper part of Mt. Nebo specimens of volcanic rock were found. Similar specimens have also been noticed in some other localities in the central and western part of Clark county. These two buttes are west of the house of Mr. Lackey, whose ranch extends along the upper valley of Little Sandy creek for a number of miles. A view of *Mt. Pisgah a Tertiary butte* as seen from the front of Mr. Lackey's house is given as Plate No. XXII. It is quite typical of the high, isolated buttes of central and western Clark county, especially when capped by Tertiary rock which gives to their summits a more or less rounded shape. Not far to the south of

1 F. W. Cragin, Colorado College Studies, Vol. VI, p. 44.

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these Tertiary-capped buttes, and near the left hand side of the picture, is a flat-topped mound not covered by Tertiary, but showing only the Red-Beds.

To the northwest of Mount Nebo where the top of the Reds is exposed on Spring creek, is a massive, light gray sandstone 4 feet in thickness resting on the Reds. This sandstone is supposed to represent the heavy-bedded stratum called the Big Basin sandstone. At this locality there is a decided dip to the southeast, as shown by the outcrop of the sandstone in question along the west side of Spring creek. The Comanche runs around the edge of the high prairie to the northwest of Mt. Nebo and Spring creek crossing Kiger creek considerably farther north than the Big basin. On this part of Kiger creek some years since, the black shale of the Kiowa was mistaken for coal, and a well was drilled which according to Mr. Funk began near the top of the black shales, passed through from 35 to 40 feet of the same and stopped in the Red-Beds at a depth of 80 feet fom the surface. On the west side of Kiger creek at Mr. Funk's about one half mile northeast of St Jacob's well, the base of the Kiowa shales is shown about 30 feet above creek level and have a thickness here of between 35 and 40 feet. Higher are prominent ledges of Tertiary rocks, the lower part consisting of coarse sandstone.

On reaching the upland to the northwest, the prairie appears to be comparatively level for a long distance. A short distance, however, to the westward a marked depression is reached, resembling an immense sink-hole. On the northern side of this depression is a large and deep spring known as St. Jacob's well. This locality is noted on the Ashland topographic sheet near the center of its western edge. The depression is known as Little Basin on account of its basin-like form and seems to be in the axis of a synclinal fold. On the eastern side of Little Basin the rocks belong to the Tertiary. On the western side the Tertiary with steep easterly dip forms the upper part of the cliffs, having below it 28 feet of Kiowa shales that in turn are underlain by 10 feet of sandstone resting upon the subjacent Red-Beds.

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Section of Little Basin at its Southwest Corner.

No.		Feet.
4.	Tertiary sandstone forming upper part of wall of cliff which rises considerably higher to the south. 25 feet exposed in the Basin.	25—63
3.	Yellowish shales containing some fossils............	15—38
2.	Thin black argillaceous shales representing the lower part of the Kiowa. Base of Kiowa.	13—23
1.	Yellowish coarse-grained, friable, sandstone, Big Basin sandstone of Cragin.	10—10

The Big Basin sandstone as exposed in Little Basin, and especially in the draws between Little and Big Basins, closely resembles in its lithologic characters the Cheyenne sandstone, the characters being similar to those noticed on Bluff creek above Messing's, and at other localities in the northern and eastern parts of Clark county.

A short distance west of Little Basin is the very much larger depression known as Big or Great basin. This is an oblong, sunken valley surrounded by steep walls, which on the eastern and northern sides are nearly perpendicular and from 130 to 150 feet in height. The floor of the basin is almost perfectly level, grassed over and without exposures of rock. The walls of the basin are composed in part of rocky cliffs, those of the western and northern sides belonging mostly to the Tertiary, which also forms the upper part of the eastern wall below which is the heavy-bedded sandstone, named Big Basin sandstone that rests upon the top of the Red-Beds. The Big Basin sandstone as exposed in the eastern side of the Big basin is a massive yellowish, brownish and whitish, friable, sandstone which in all its general characters agrees closely with the Cheyenne. In places above the sandstone is a thin remnant of the Kiowa shales, the remainder of the upper part of the wall being Tertiary. Below the Big Basin sandstone are the Red-Beds the line of separation being at times quite sharp, but here and there the colors of the two blend. This is especially noticeable in the southern part of the eastern side of the Basin where the top of the Red Beds changes gradually into the Cheyenne. At one place there is a wall of Red Beds several feet in thickness covered by yellowish sandstone, followed by a band of red, in turn succeeded by the main

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mass of the Big Basin sandstone here 10 to 12 feet in thickness. This sandstone is also frequently streaked with red and shows a somewhat gradual passage from the physical conditions of the Red Beds to those prevailing in its own case. In places it is fase bedded. Plate XXIII. of the *Big Basin sandstone in the Big Basin* represents clearly the massive stratum and conspicuous outcrop of this sandstone in the eastern wall of the Big Basin. The ledge shown in the upper part of the picture is the one from which large blocks of sandstone have fallen.

This is the typical locality for the Big Basin sandstone of Cragin who described it as a "Massive, blocky, red and grayish-white sandstone."[1] He regards it as forming the upper number of the Red-Beds or Cimarron series. As has been already stated it seems to the writer that this sandstone might more properly be correlated with the Comanche series and regarded as representing in Clark county the Cheyenne sandstone of Kiowa and Comanche counties. Professor Cragin has considered the transitional nature of the passage from the Big Basin sandstone to the Comanche which he stated might be regarded as reinforcing "the earlier generally accepted view that the 'Red-Beds' were Jura-Trias, or at least partly so; but the bond of continuity which has already been referred to as apparently existing between the Cimarron series of Kansas and the paleontologically proven Permian of northern Texas outweighs any argument of that sort, and indicates rather that the upper and here lighter-colored zone of the Big Basin sandstone was softened by the invading waters of the Belviderean sea, and its sediments partially and then wholly rearranged as the (for this point) initial deposits of the latter, only gradually becoming supplanted by sediments conveyed from other sources."[2]

Of course if the Big Basin sandstone be regarded as the stratigraphic equivalent of the Cheyenne, then its continuity with the Kiowa shales of the Comanche is exactly what would be expected. This explanation seems more satisfactory, especially when the great similarity of the lithologic characters of the Great Basin sandstone

1 F. W. Cragin, Colorado College Studies, Vol. VI, p. 46.
2 F. W. Cragin, Colorado College Studies, Vol. VI, p. 648, Colorado Springs, Col.

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to those of the Cheyenne is considered, together with the fact of their correspondent stratigraphic position.

The explanation of the formation of Big and Little Basins is a matter of great difficulty. Recently Professor Haworth has accurately described the general features of these basins and suggested an explanation of their formation. His description of Big Basin is as follows: "A broad and level valley more than a mile across and nearly circular in outline seems to have been dropped vertically for about one hundred and fifty feet. This is locally called the great basin. On the east of it a hundred yards is a similar valley a fourth as large, which likewise seems to have been dropped a like distance. In the northern part of this latter valley a sink hole, about seventy five feet across now holds fresh water with a maximum depth of twenty seven feet. This is locally called St. Jacob's well, and is so marked on the U. S. topographic sheets.

"These two areas are so large that it is difficult to understand how they can be classed as ordinary sink-holes as the Meade salt-well may be. Their origin should be looked upon as due to some greater movements, possibly similar in character to that which produced the artesian valley near Meade, although no connecting fault has yet been located."[1]

In comparing the thickness of the Kiowa shales on Mt. Nebo, on the bluffs west of Kiger creek and in Little and Big Basins, it will be seen that their thickness decreases rapidly in going west. This is especially marked from the region of the Basins, no considerable thickness of the Kiowa having been found west of this locality. On the bluffs about three miles east of Cash City and Indian creek, loose shells belonging to the Kiowa are found near the line of junction between the Tertiary and Red-Beds. On the map, Plate XLIV., the Kiowa has been represented by a mere band as extending to this point. Beyond this to the southwest no evidence of the Kiowa was seen, and so far as known to the writer the Comanche series is not represented between the Tertiary and the Red-Beds in the southwestern part of Clark county and southeastern part of Meade. The Basins are located in Vesta township Clark county and the formations of this portion of Meade were briefly described by Case

1 E. Haworth, American Journal Science, 4th series, vol. II, p. 371.

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in 1894 in his paper entitled "A Geological Reconnaissance in Southwest Kansas and No Man's Land."[1] Mr. Case stated that "Following the line of the Tertiary northward we find in the neighborhood of Ashland and Vesta, in Clark county, that the Cheyenne or Comanche Cretaceous separates very indistinctly the Tertiary from the Triassic. It is represented by a yellow sandstone growing thicker towards the east and filled in places with shells. Above this is a layer of clayey soapstone, so called, also thickening towards the east. This increases in thickness from a few feet at Vesta to nearly 30, a mile east. The outcrop of the Cretaceous is nowhere more than a quarter of a mile wide and is continually obliterated both by the Triassic and the Tertiary."[2]

DISCUSSION OF THE SECTIONS.

An examination of the general sections accompanying this report conveys a graphic idea of the broken nature of the country in Barber, Comanche and Clark counties. They also clearly illustrate the thickening and thinning of the Comanche series in this region, and show in a striking manner the erosion following the close of the Red-Beds before the deposition of the Comanche, and the second great erosion after the deposition of the Comanche and before the Tertiary was deposited. This erosion has been described by earlier writers in a general way, particularly by Professors Hay and Hill but probably it has never been as markedly shown for any part of Kansas as in the region just described.

On referring to the section across southern Kansas, Plate XXXVIII., it will be seen that the top of the Medicine Lodge gypsum is almost horizontal from the top of the Gypsum hills, six miles southwest of Medicine Lodge, to the bluff west of Sun City. On the Gypsum Hills it is 1800 feet A. T. according to the Medicine Lodge topographic sheet of the U. S. Survey, and on the hill west of Sun City, nearly twenty two miles northwest of the former place, it has about the same elevation, 1805 of our section which agrees closely with the topographic sheet. In the Walker creek four miles to the northwest of the Sun City bluffs, the top of the gypsum is some 15 to 20

1 E. C. Case, Kansas University Quarterly, Vol. II, pp. 143-148. Lawrence.
2 Ibid., p. 146.

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feet below the 1800 foot line, while some five miles northwest of the Sun City bluff the gypsum disappears in the Medicine Lodge valley at an elevation of 1744, according to Professor Cragin.[1]

The above shows that there is scarcely any dip to the southeast from Sun City for twenty miles, while from this place to the northwest, providing the altitudes be correct, there is a decided dip reaching the amount of twelve feet per mile. In reference to the last statement, I cannot yet say positively that there is such a heavy dip to the northwest. The profile section shows that Stokes Hill, west of Sun City, is composed entirely of Comanche, where it has a thickness of 165 feet; while in crossing the Tertiary prairie to the east branch of Sand creek, twenty four miles southwest of Stokes Hill, the Comanche has thinned to a mere line. On the northern side of Bluff creek valley the base of the Comanche is somewhat irregular; but it rises as it is followed somewhat to the south of west. This is very marked when the position of the Comanche in the bluff south of Bluff creek at Messing's is compared with its position to the east in the creeks north of Bluff creek. This decided irregularity in the base of the Cretaceous in the Bluff creek region was first noticed by Professor St. John who said that: "On Sand creek, three miles northeast of Lexington, the latter formation appears at a level near 120 feet lower than its base on Cat creek, seven miles to the west."[2] I am not quite sure which creeks were meant by Prof. St. John, but it was found that the base of the Comanche is approximately 140 feet higher on the creek east of Messing's than it is eight miles to the southeast on the creek northeast of Lexington. Crossing the high prairie to the north of Ashland, from Bluff creek to the Big basin, the profile shows a small anticline with broad base. This corresponds with a number of local observations made in the high lands of central Clark county.

The section across Mule and Walker creeks (Fig. 6) in eastern Comanche county, and the Medicine Lodge river in southeastern Kiowa county brings out clearly the decided thickness of the Comanche in the high bluffs south of Walker creek, and shows the rapid thinning toward the north on the bluffs north of the Medicine Lodge river, as

1 F. W. Cragin, Colorado College Studies, vol. VI, p. 81.
2 Fifth Biennial Report Kansas State Board of Agriculture, Pt. II, p. 142.

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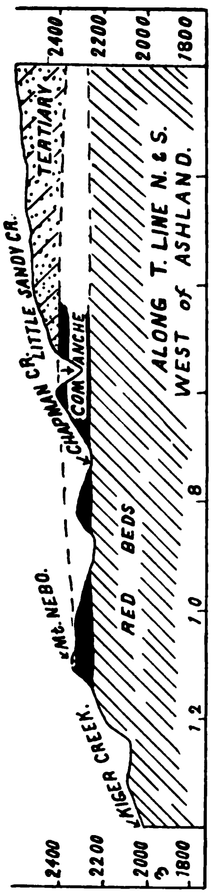

Fig. 6.
A Geologic Section North and South, west of Ashland.

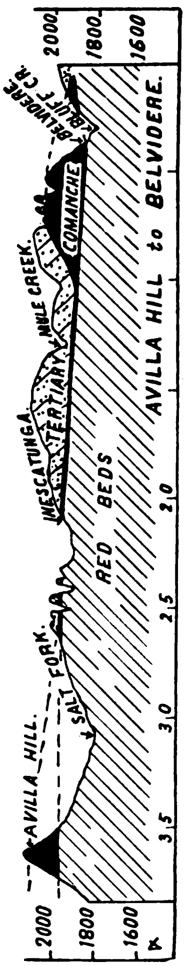

Fig. 7.
A Geologic Section from Avilla Hill to Belvidere.

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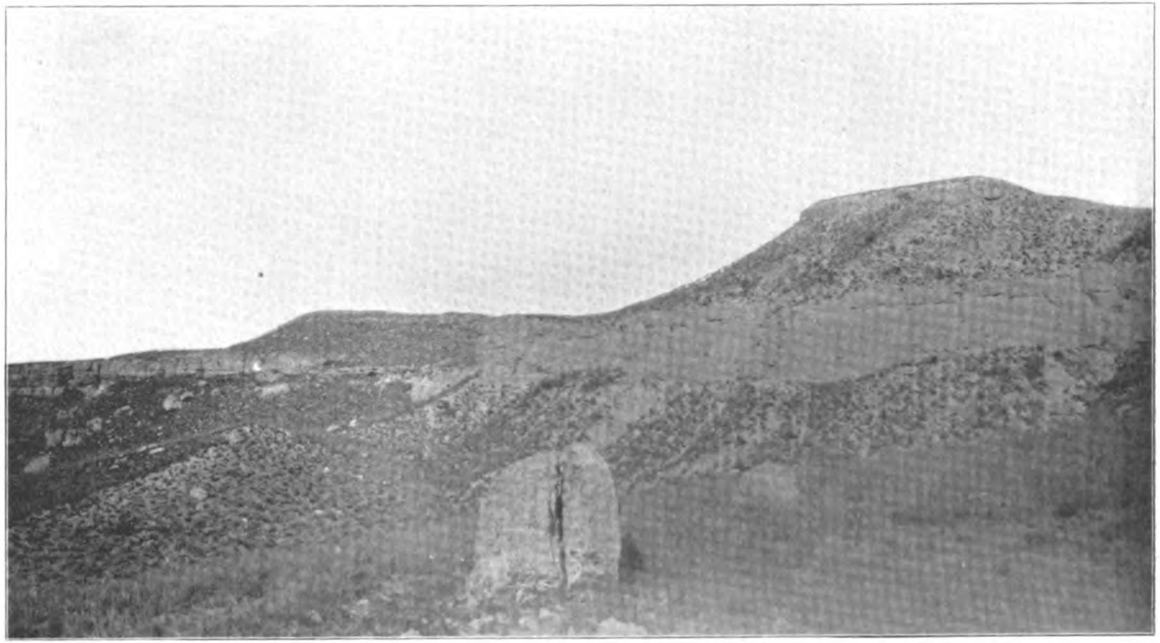

TERTIARY CLIFFS NORTH OF ASHLAND.
(Photographed by Prosser, 1896.)

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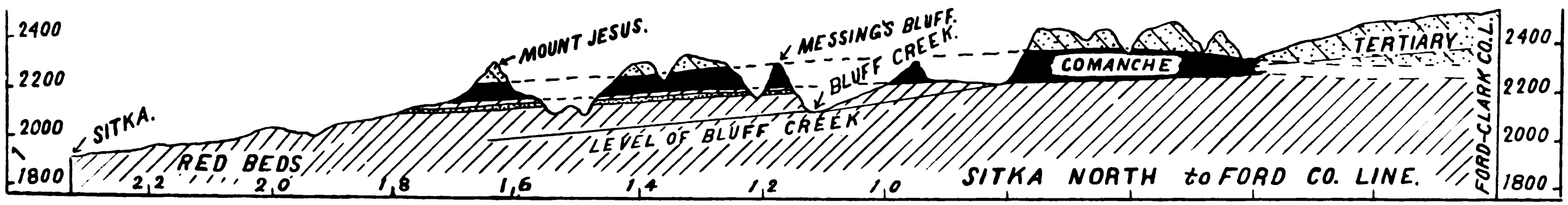

Fig. 8.

A GEOLOGIC SECTION FROM SITKA NORTH TO FORD COUNTY LINE.

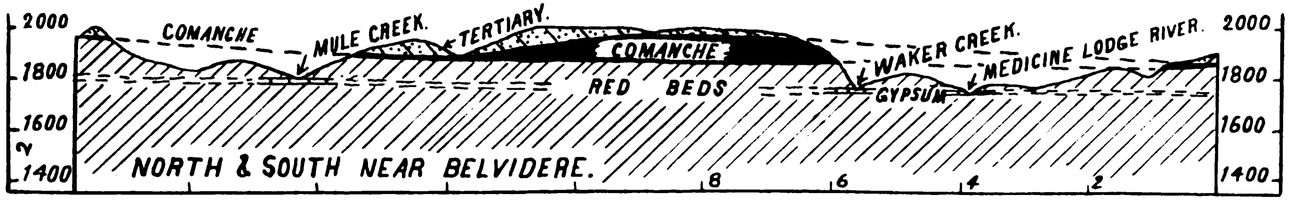

Fig. 9.

A GEOLOGIC SECTION NORTH AND SOUTH NEAR BELVIDERE.

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well as toward the south on the southern side of the high prairie in the banks of Mule creek. It will be noticed that the lower line of the Comanche is quite regular, but that the upper runs down rapidly both to the north and south. This indicates the extensive erosion previous to the deposition of the Tertiary, which had left a country of diversified topographic features, composed of hills and valleys. In even a more striking manner the section farther west from Avilla Hill northeast to Belvidere across the central part of Comanche county and southeastern part of Kiowa, shows the local thick beds of the Comanche, thinning out in a short distance to almost nothing. This is very conspicuous on the big hills southwest of Belvidere, where the Comanche is 163 feet thick; while on the southern side, the upper surface descends very rapidly toward Mule creek, so that from there to the edge of the bluffs north of Salt Fork the Tertiary has nearly replaced the Comanche. On the south side of the Salt Fork the Comanche again appears with nearly its greatest Kansas thickness. This section affords an excellent example of the great plains pre-Tertiary erosion, and the unconformity by erosion of the Cretaceous and Tertiary.

The next section to the west, Fig. 7, in the eastern part of Clark county, from Sitka northwest over Mt. Jesus, Messing's Bluff and up the eastern bank of Bluff creek, shows the Comanche as thickest in the Bluff creek region and thinning to the north and south. The general direction of this section is from the northwest to the southeast and the dip was determined with reference to three stratigraphic lines, showing it to be southeasterly. The elevations of these horizons are as follows on Mt. Jesus, Messing's bluff and the Amphitheatre:

	Base of Tertiary.	Base of Comanche.	Thickness of Comanche.	Top of Day creek dolomite.
Mt. Jesus..............	2220	2135	85	2127
Messing's Bluff.........	2300	2194	106	2174
Amphitheatre	2370	2230	140	....

The distance from Mt. Jesus to Messing's Bluff is five miles, from Messing's Bluff to the Amphitheatre five and one half miles or from Mt. Jesus to the Amphitheatre ten and one half miles. The dip per mile of the top of the Day Creek dolomite, base of the

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Comanche and base of the Tertiary was found to be as in the following table:

	Mt. Jesus. to Messing's Bluff. Feet.	Messing's Bluff to Amphitheatre. Feet.	Mt. Jesus to Amphitheatre. Feet.
Top of Day Creek dolomite....	$9\frac{3}{5}$	....	....
Base of Comanche............	$11\frac{4}{5}$	$6\frac{1}{2}$	9
Base of Tertiary..............	16	$12\frac{1}{2}$	14

The Day Creek dolomite is the most constant line of those used in the above table and the 9 feet per mile may be regarded as a close approximation to the amount of southeast dip along the line of this section. The base of the Comanche is somewhat irregular due to the pre-Cretaceous erosion, for on Messing's bluff there are 20 feet of the Red-Beds between the base of the Comanche and the top of the Day Creek dolomite; while on the bluff farther southeast the dolomite in places was cut away, and on the south side of Mt. Jesus there are 8 feet of intervening Reds. This increased the amount of dip for the base of the Comanche between Messing's bluff and Mt. Jesus. Again, the erosion of the upper part of the Comanche from the Amphitheatre to Mt. Jesus explains the much greater dip for the base of the Tertiary.

Finally, in the section for Kiger creek over Mt. Nebo to the prairie west of Letitia, in the western part of Clark county the thinning of the Comanche to the south is well shown. This section is along a north and south line and the dip is not nearly as great to the south as it is to the southeast in the previous section. The elevations of the base of the Comanche and Tertiary were determined in this section on Mt. Nebo and on the hill between Chapman and Little Sandy creeks. The data are given in the following table:

	Mt. Nebo. Feet.	Hill between Chapman and Little Sandy creeks Feet.
Base of Tertiary.....................	2323	2405
Base of Comanche....................	2248	2260
Thickness of Comanche...............	75	145

The distance between the two sections is five miles and the dip to the south for the base of the Comanche is two and two fifths feet per mile and for the base of the Tertiary sixteen feet per mile. The much greater dip for the Tertiary is due to the erosion of the

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upper part of the Comanche to the south making the latter 70 feet thinner on Mt. Nebo than on the more northern hill.

KIOWA OF CENTRAL KANSAS.

To the north of the Arkansas river the Kiowa shales have been found in a number of isolated localities. They were first reported in 1889 by Professor Cragin from "the western part of McPherson county,"[1] and in the following year he published an account of this outcrop "On the west line of McPherson county" as follows: "This locality has been insufficiently examined, but is characterized by yellow to blue-gray shales with layers of *Ostrea Franklini* breccia and other stony layers in which *Cardium Kansasense* occurs, together with *Turritella Marnochii*, var. *Belviderei*, and a species of Neritina (apparently identical with that from Belvidere), and one *Dentalium*. With others of the normal form, occur frequent specimens of the *Turritella*, in which the apical region is remarkably produced and attenuated. Bands of red and yellow ochre occur here. One or two similar outcrops occur in the east part of Rice county."[2]

Later in discussing the stratigraphic relation of the Mentor beds to the Kiowa shales Professor Cragin said: "While the Mentor beds generally rest upon the Permian in Saline county, they rest in part upon the Kiowa shales further southward, as shown by the occurrence beneath them of black shales amongst some of whose fossils, submitted to the writer from a few miles west of Lindsborg by Prof. J. A. Udden, are *Modiola stonewallensis*, nob., and *Sphenodiscus* pedernalis, Roem."[3] These are the only published references to the occurrence of the Comanche series in central Kansas, as far as the writer is aware.

In South Sharps Creek township in the western part of McPherson county, Mr. J. W. Beede found typical specimens of the coarser, very fossiliferous Kiowa shales. The locality where best exposed is in the "Natural corral" on the northwest quarter, section 5, township 18, range 5 w. Mr. Beede measured a section at this locality which

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1 F. W. Cragin, Bulletin Washburn College Laboratory Natural History, vol. 2, p. 37. Topeka.

2 Ibid., p. 80.

3 J. A. Udden, American Geologist, vol. XVI, 1895, p. 165.

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is important in that it gives the stratigraphic position of both the Mentor and Kiowa.

Section of the Natural Corral, by J. W. Beede.

No.		Feet.
8.	Sandstone to top of hill........................	40(?)—106
7.	Hard brownish sandstone containing *Lamellibranchs* and *Gastropods*. Mentor.	7— 66
6.	Yellowish and blue arenaceous shales and sandstones.	20— 59
5.	Yellowish, very friable, sometimes variegated sandstone, 6 to 8 feet thick.	8— 39
4.	Argillaceous and arenaceous shales and sandstones that contain an abundance of iron pyrites.	30— 31
3.	Layer with structure similar to cone-in-cone, 2 to 4 inches thick.	
2.	Shaly limestone and shales containing abundant specimens of Kiowa fossils.	1— 1
1.	Red and blue shales of the Wellington.	

Mr. Beede states that the Kiowa occurs at about the 1600 foot contour line and may be found frequently at this elevation throughout the township. Blocks of a shaly limestone from between the northeast and northwest quarter of sections 8 and 9 South Sharps Creek township show excellent specimens of *Turritella*. The Kiowa extends from the "Natural corral" south to the vicinity of Windom, and three miles east of Windom, Mr. Beede found an outcrop showing both the Mentor and Kiowa, below which are gypsiferous shales.

Mr. W. N. Logan has also sent me specimens of Kiowa fossils from section 27, South Sharps Creek and section 29 Sharps Creek township, McPherson county. Mr. Logan writes that: "This shell bed rests between layers of shale about 25 feet above red shales. At a distance of about 25 feet above the shell bed is unmistakable Dakota sandstone. These shells occur in a line almost directly west in Ellsworth county, near the eastern border." The specimens from the latter locality are pinkish shaly limestones, filled with *Ostrea*, similar to the shaly limestones found in the upper part of the Kiowa shales in southern Kansas.

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From the hills south of the Smoky Hill river, three and one half miles east and one half mile south of Lindsborg, Mr. Beede collected specimens of brownish, arenaceous shales containing *Turritella*, that resemble the Mentor more closely than the Kiowa.

In the eastern part of McPherson county, on section 23, Delmore township, Mr. C. N. Gould found numerous specimens of the shaly, *Ostrea* limestone of the Kiowa. Later, this locality, which is on Mr. Stark's farm, four miles south of the Twin hills, was visited by the writer. The pieces of shaly limestone are loose near the top of a small ridge between Gypsum creek and a western branch. None of the shales were found in place, though there is no doubt but that they once formed a part of the hill. On the ridge east of Gypsum creek, at this locality, is a ledge of light gray quartzitic sandstone, similar to that on the highway between sections 24 and 25 Bonaville township. Some of the sandstone shows irregular bedding and it is apparently near the base of the Dakota formation.

The farthest north the Kiowa shales are known is in Saline county on the hill east of the Smoky Hill river. This locality is on the southwest corner section 27 and southeast corner section 28 Walnut township where, at least, a foot of the shaly *Ostrea* limestone is clearly exposed along the highway. Above is brownish sandstone containing Mentor fossils. In the field to the west are numerous blocks of the Kiowa *Ostrea* limestone. The fossiliferous shales of this locality were first noticed by Prof. A. W. Jones of Salina who wrote me in regard to it. The Kiowa shales where exposed in McPherson and Saline counties consist of the calcareous shales to shaly limestones, which in southern Kansas are found in the upper part of the formation. Apparently, the black, argillaceous shales that form the lower part of the formation in southern Kansas do not occur in central Kansas.

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THE DAKOTA SANDSTONE.

THE MENTOR BEDS.

DESCRIPTION.

In eastern-central Kansas, in the lower part of what has generally been called the Dakota sandstone, are occasional outcrops of very dark brown fossiliferous sandstone so friable, as a rule, that it does not form a ledge, but its presence is shown by loose blocks on the slopes of the hills. For this terrane, Professor Cragin has proposed the name, Mentor beds, the typical exposure being on the eastern side of the Smoky Hill river about three miles east of the Union Pacific R. R. station of Mentor.

Mentor is in the Smoky Hill valley on the western side of the river seven miles south of Salina and is apparently underlain by the Wellington shales. Professor Cragin has described the lithologic characters and stratigraphic position of these beds and says they are composed "of variegated, earthy-textured marine shales, with intercalated beds of brown sandstone, resting in part conformably upon the Kiowa shales and in part unconformably upon the drab and purple-red laminated shales and impure limestones of the Permian, and succeeded above by the more heavily arenaceous fresh-water sediments of the Dakota. * * * The shales of the Mentor beds are chiefly argillaceous, but they contain a greater or less admixture of sand, to which, as soft sandstones, they locally give place in certain horizons. * * * Being little consolidated, they weather into gentle slopes and broad, low, rounded eminences scarcely worthy the name of hills, and present few conspicuous outcrops. Such outcrops of the shales as do occur present themselves either as limited, more or less steep-faced banks of marly-appearing clay, of white, ferruginous-yellow, red or blue color, or parti-colored with two or more of these. * * *

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"The sandstone of the Mentor beds occurs in thin, local strata. While these are of slight consequence judged by the space they occupy, they are nevertheless of great stratigraphic importance, since it is from these alone that our knowledge of the geological age of the Mentor terrane has been derived."[1]

DISTRIBUTION.

The typical locality, as already stated, is the one in the hills east of Mentor and the Smoky Hill river in Saline county. Beginning three fourths of a mile east of the Berwick schoolhouse, or three and a fourth miles east of Mentor, loose, irregularly-shaped blocks of the dark brown very fossiliferous sandstone occur along the east and west highway, and in the adjoining fields where sections 16, 21, 22 and 15 of Walnut township corner. As shown on the Berwick diagrammatic section, the first of the Mentor occurs about 60 feet above the river level and continues along the road until an altitude 70 feet higher is reached. As the blocks are not in place, the writer does not intend to say that the sandstone containing the Mentor fossils has a thickness of 70 feet at this locality, though he is of the opinion that a stratum of the fossil-bearing sandstone occurs not far from where it was first noted in the highway.

Two miles directly south of the Berwick Hill locality just described, the Mentor fossiliferous sandstone occurs, above a thin ledge of the Kiowa shales, along the north and south highway at the S. W. Cor. Sec. 27, Walnut township. At this locality the Mentor is from 150 to 160 feet above the level of the Smoky Hill river.

On the hills 2 miles north of the Saline river or 5 miles north of the eastern side of Salina, on the western side of a draw in the S. W. Quar. Sec. 18, Cambria township, is an interesting occurrence of the Mentor sandstone which, as usual, is in loose blocks, some of them quite large. The rock is of brownish-red color containing numerous specimens of fossils although fewer species than were found in some of the other Mentor exposures. Below are yellowish-gray to buff shales and buff, friable sandstone, while higher is brownish, unfossiliferous sandstone. The Mentor stratum is between 90 and 100 feet above the level of the Saline river and not much

1 American Geologist, Vol. XVI, Sept. 1895, pp. 162, 163.

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above the base of the so-called Dakota and its position may be considered an important one on account of its proximity to one of the areas where Professor Lesquereux obtained "a large number of fine specimens of fossil leaves," a locality mentioned as covering about three acres of ground which in part of the work is given as about 8 miles from the Salina station, and again apparently the same locality is given as 8 miles above the mouth of the Salina river.[1] Professor Lesquereux's failure to indicate accurately the localities from which the fossil plants described by him came, even when as in this case he visited the place himself, is well known. If this locality be 8 miles above the mouth of the Saline river, it is probably not more than 2 miles above the Mentor outcrop just described and nearly in the same part of the terrane. This conclusion is apparently supported by the later statement of Professor Lesquereux that at this locality he "found the same species of vegetable remains distributed from the base to the top of the hills, the altitude being about 75 feet above high-water mark of the river."[2] If again, it be 8 miles from the Salina station it is also probably in the lower part of the Dakota sandstone. If these Mentor shells and part of the Dakota fossil plants occur at the same horizon then the position of that part of the Dakota sandstone in the Cretaceous system will need reconsideration.

The greatest number of the Mentor fossil shells were found on the divide between Spring and Dry creeks to the southwest of Salina. In this region the outcrop nearest Salina is 11 miles to the southwest on the S. W. Cor. Sec. 10, Washington township, on the northern side of the ridge 3 miles south and ½ mile west of Bavaria. Mentor fossils were found in very dark brown sandstone fragments by the road-side and the yellowish shales of the Wellington were exposed only a short distance below them. On the ridge some 5 or 8 feet above the loose Mentor fossils a single loose specimen of a fossil leaf was found which by its angularity indicates that it had not been carried far and it probably came from the rock composing the ridge which in lithologic appearance it closely resembles.

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1 Report U. S. Geological Survey Territories, Vol. VI, Cretaceous Flora; see pp. 28, 58, 71, 105.

2 Mon. U. S. Geological Survey, Vol. XVII—The Flora of the Dakota Group—1892, p. 22.

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MT. PISGAH, A TERTIARY BUTTE, EIGHT MILES NORTHWEST OF ASHLAND.
(Photographed by Prosser, 1896.)

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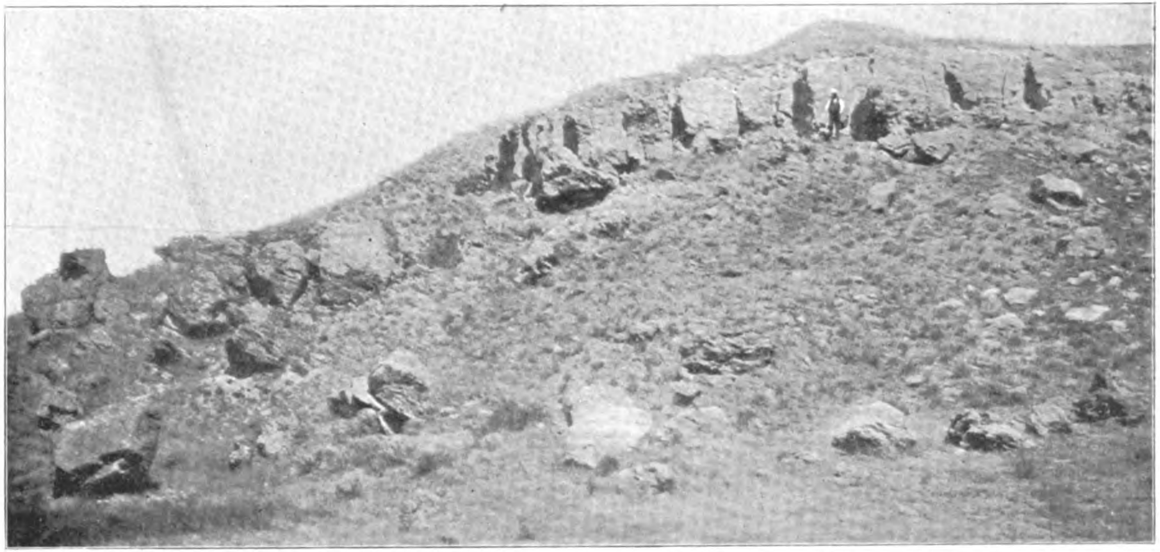

BIG BASIN SANDSTONE, IN THE BIG BASIN, WESTERN SIDE CLARK COUNTY.
(Photographed by Prosser, 1896.)

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One mile south of the above locality and 4 miles west of Smolan on the N. W. Cor., Sec. 22, Washington township is the best exposure of Mentor seen. The rock which varies from brownish-red to almost a black color and contains large numbers of fossils is shown along the highway just south of the four corners though it can scarcely be said to form a ledge. Below are yellowish shales apparently in the Wellington. From specimens collected at this locality, Mr. T. W. Stanton has identified the following species:

1. *Ostrea quadriplicata* Shum.
2. *Gervillea Mudgeana* White.
3. *Trigonia Emoryi* Con.
4. *Cardium Kansasense* Meek.
5. *Protocardia salinaensis* Meek.
6. *Arcopagella mactroides* Meek.
7. *Tapes belviderensis* Cragin (?)
8. *Turritella* (*Mesalia?*) *Kansasensis* Meek.

The brownish-red sandstone with the lithologic characters of the Dakota was first seen on the road, over 3 miles west of Smolan and not much farther west loose pieces of the fossiliferous Mentor sandstone were found.

Five miles west and ¼ mile north of Smolan is another interesting exposure of the Mentor. The fossiliferous nature of the sandstone is quite well shown in a small draw on the western side of the road in the S. E. Quar., Sec. 17, Washington township. Fossils are abundant here and below exposed in the side of the draw is a light gray to buff soft sandstone, 3 feet thick. To the northwest is a low hill, the sides mostly covered, capped by a stratum of fairly thick brownish-red sandstone. The rocks forming the greater part of the hill above the Mentor sandstone are quite well shown, however, in an arroyo on its northwestern side where they are found to be mainly yellowish shales. In this draw, at about the same altitude as on the eastern side of the hill, loose blocks of the fossiliferous Mentor sandstone were found in abundance. An approximate section of the hill appears on the following page.

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Section of hill five miles west of Smolan.

No.		Feet.
4.	Ledge of brownish-red sandstone forming top of hill. Similar in lithologic appearance to the Dakota.	2—55
3.	Mainly yellowish, bluish and slightly reddish argillaceous and arenaceous shales.	50—53
2.	Dark brownish-red sandstone with Mentor fossils. Thickness undetermined.	
1.	Light gray to buff soft sandstone..................	3— 3

The above section shows positively that above the Mentor sandstone at this locality there is a considerable thickness of soft shales that in lithologic appearance differ but slightly from those found below the Mentor. Mr. Hall, a resident of the northern part of Washington township, informed the writer that this lot was known as the John M. Danielson pasture and from this locality Professor Mudge collected the Mentor fossils locating it as "in the vicinity of Bavaria."[1] Meek also spoke of the locality as "twelve miles southwest of Salina."[2]

We are indebted to Prof. A. W. Jones of the Kansas Wesleyan University at Salina, who accompanied us on our trip to the Mentor beds, for directing us to the Berwick Hill, the locality four miles west of Smolan and the one north of the Saline river five miles north of Salina. The writer understands that since that time Professor Jones has discovered new localities of Mentor fossils and that he is preparing a paper describing their occurrence.

Near the four corners one mile south of the locality, four miles west of Smolan, on the northeast corner section 28, Washington township, the Mentor fossiliferous sandstone was found. This is not as favorable a locality for collecting as the one a mile to the north. One mile southwest of the above locality on the southwest quarter section 29, Washington township is a solitary butte, known as Soldier Cap mound, rising 150 feet above the general elevation of the eastern part of the divide. This sentinel gives a clear idea of the erosion that has occurred over the central part of Saline county. The mound is capped by coarse-grained brownish sandstone that

1 First Biennial Report State Board Agriculture of Kansas, 1878, p. 67.
2 Rept. U. S. Geol. Surv. Territories, vol. IX, 1876, pp. 171, 174, etc.

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forms a ledge 15 feet thick on its western side. Some of the rock is really a grit containing numerous small quartz pebbles. The top of the mound is between 170 and 180 feet higher than the Mentor locality one mile to the northeast. There can be no question but that the sandstone on top of this mound is stratigraphically as high as the leaf-bearing Dakota sandstone, for three impressions of the Dakota fossil leaves were found in it. There is a beautiful view from its top—the Smoky Hill Buttes forming a conspicuous ridge to the southeast. A view of the western side of the ledge is given in the picture of the Dakota sandstone at top of Soldier Cap mound on Plate XXIV.

In the northern part of Falun township between West Dry and Middle Dry creeks are two buttes, between which is the hamlet of Falun. The upper part of the buttes is composed of coarse brownish sandstone, while a well at the foot of the northeast mound shows rather coarse bluish and yellowish shales, apparently Wellington, containing gypsum. No Mentor fossils were found; but on the mound southwest of Falun at about 1400 feet A. T., the approximate altitude of the Mentor fossils, four miles north on the northeast corner section 28, Washington township, parallel and netted-veined fossil leaves like the Dakota fossil plants were found. This locality is on the line between sections 9 and 16 of Falun township. On the mound, to the northeast of Falun, composed of dark-brownish coarse sandstone like the Mentor, fragments of fossil plants were also found. There seems to be no doubt but that these fossil leaves are very near the bottom of the deposits usually termed the Dakota sandstone and also in about the same stratigraphic position as the Mentor fossils four and five miles to the north.

Three miles directly east of Falun, on the southwest corner section 7, Smoky Hill township,[1] Mentor fossils were found loose on the surface of the ground at an elevation of 1380 to 1390 feet A. T., and not far from that of the fossil plants on the butte southwest of Falun. A well near the base of the western slope of the Smoky Hill Buttes, at their northern end, shows bluish and yellowish argillaceous shales with some of a reddish tint, and in some of the

1 Called Smoky Hill township on the U. S. topographichal sheet, but Smoky View township on the Saline county map.

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shale a little gypsum. A small draw above the well shows yellowish, blue and slate-colored shales for 70 feet, above which the slope is covered for 40 feet when a stratum of coarse brownish sandstone is reached that probably continues to the top of the buttes which are capped by prominent ledges of Dakota sandstone; see figure 10.

Section of Smoky Hill Buttes, at their northern end.

No.		Feet.
3.	Brownish sandstone at the top, probably 200 feet thick though the greater part is covered. At the base a stratum of coarse brownish sandstone. Dakota sandstone.	200—310
2.	Covered, but perhaps shales similar to those exposed in the draw below.	40—110
1.	Yellowish, blue and slate-colored shales, exposed along a small draw to the mouth of the well.	70— 70

Meek and Hayden in their early exploration of the Kansas valley made a section of the Smoky Hills which is as follows:

No.		Feet.
"1.	Red, brown and yellowish, rather coarse grained sandstone, often obliquely laminated, and containing many ferruginous concretions; also, fossil wood and many leaves of dicotyledonous trees, some of which belong to existing genera, and others to genera peculiar to the Cretaceous epoch. Locality, summit of Smoky Hills	60
"2.	Whitish, very fine grained argillaceous sandstone, underlaid by bluish purple and ash colored clays. Locality same as preceding	15
"3.	Long, gentle slope, with occasional outcrops of ash colored red, blue and whitish, more or less laminated clays, with thin beds of sandstone. Locality same as preceding, and extending down to places nearly or quite to the bluffs of Smoky Hill river; thickness about	200
"4.	Red sandstone, with some layers of hard, light gray calcareous, do., and both containing ferruginous concretions. Locality, bluffs Smoky Hill river, five or	

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Feet.

six miles above Grand Saline river. Probably local, thickness seen about .... [1] 15"

The locality given for No. 4 of the above section is probably the bluffs to the southeast of the present city of Salina. The rocks below No. 4—No. 5 of this section—were regarded by Meek and Hayden as probably belonging in the Permian, but "between No. 5, and the Cretaceous above, there is still a rather extensive series of beds in which we found no organic remains; these may be Jurassic or Triassic, or both, though as we have elsewhere suggested, we rather incline to the opinion that they may prove to belong to the former."[2]

Mr. Beede has sent me typical Mentor fossils collected on the south side of the Smoky Hill river in the "Natural corral" on section 5, South Sharps Creek township, McPherson county, which he says were in the upper part of a stratum of hard, brownish sandstone, 7 feet thick. Mr. Beede also reported Mentor shells from farther south in McPherson county, three miles southeast of Windom. Mr. W. N. Logan has also sent me Mentor fossils from the "Natural corral" in McPherson county, supposed to be the same locality studied by Mr. Beede, among which are specimens of *Trigonia Emoryi* Con. Mr. Logan wrote me that he "had found fossils in the upper and middle horizons of the Dakota which seem to be identical with the Mentor fossils." From a sandstone at the extreme upper limit of the Dakota near Beloit, Mr. Logan has also collected Lamellibranch shells that have not been identified specifically, and may possibly belong in a different fauna from that of the Mentor. Professor Jones reported shells from wells near Brookville, that were from 50 to 60 feet below the leaf-bearing Dakota. Again, on the Townsend place, thirteen miles southeast of Salina are Mentor fossils which the Professor thinks occur above a leaf-bearing stratum. It is also reported that Prof. S. C. Mason of the Kansas State Agricultural College found fossil shells in the Dakota sandstone near Tescot in the southwestern part of Ottawa county; while Professor Mudge in his "Geology of

1 Proc. Acad. Nat. Sci., Phil., Vol. XI, 1859, p. 16.
2 Ibid., p. 21.

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Kansas" gave a second locality of molluscan fossils "in the western portion of Clay county,"[1] in addition to the one near Bavaria.

CORRELATION.

Professor Cragin has identified 25 species of marine mollusca from the Mentor beds and shown that part of them are identical with species that occur in the Denison beds and Kiowa shale of the Comanche series. The Professor's conclusion as to their age is shown in the title of his article, viz., "The Mentor beds; a central Kansas terrane of the Comanche series." This is also clearly expressed at the conclusion of his discussion of their fauna where it is stated that the Mentor beds are "characterized by a fauna related to that of the Denison beds and still more closely to that of the Kiowa shales. Their fauna is, in fact, especially related to that of the upper part of the latter."[2]

After examining a portion of the fossils collected at the locality four miles west of Smolan, Mr. T. W. Stanton of the U. S. Geological Survey wrote me as follows: "I have no doubt that Professor Cragin was right in referring this fauna to the Comanche series rather than to the Dakota. All of the Saline county marine beds that have furnished the supposed Dakota invertebrates apparently go together in the Comanche series and it may even be questioned whether the leaf-bearing beds of that region should not go with them since Mr. Hill and others have found 'Dakota' species of plants in the Cheyenne sandstone beneath invertebrates that belong to the Comanche fauna."[3] The facts appear to strongly support the above conclusions and the writer fully agrees in referring the Mentor beds to the Comanche Cretaceous of the Lower Cretaceous. It is of interest in reference to the correlation of the Dakota to call attention to the fact that Professor Cope has provisionally referred teeth found in the Kansas Dakota to Lepidotid fishes and stated that he has "never found Lepidotid fish remains in the Upper Cretaceous of North America, while they are characteristically Lower Cretaceous and Jurassic in Europe."[4]

1 First Biennial Report State Board Agriculture of Kansas, 2d ed., 1878, p. 67.

2 American Geologist, Vol. XVI, Sept. 1895, p. 165.

3 Letter of Nov. 24, 1896.

4 Proc. Acad. Nat. Sci., Phil., 1894, Pt. I, p. 65. See also the further statement in Jour. Acad. Nat. Sci., Phil., 2d ser., vol. IX, pt. 4, 1895, p. 443.

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Professor Cope also described the remains of a crocodile, *Hyposaurus vebbii*, which was found in a bluish stratum in digging a well at Brookville, Saline county.[1] The age of the formation was incorrectly given as the Benton; it is either the Wellington or Mentor and probably the latter as it was referred by Professor Mudge to the Dakota.[2]

It is a well known fact that the dicotyledonous leaf-bearing part of the Dakota is referred to the Upper Cretaceous and usually regarded as forming its lowest subdivision.[3] In 1874 Professor Lesquereux stated that the Dakota group corresponded "to the Upper Cretaceous of Europe"[4] which he correlated more precisely in 1883 when he said that "The flora of the Dakota group * * * is considered as relating the formation which it represents to the Cenomanian or Middle Cretaceous."[5] This conclusion was apparently unchanged in his final monograph on "The Flora of the Dakota Group" published after his death.[6]

As has already been mentioned some of the Dakota fossil leaves occur either at the same, or nearly the same, horizon as the Mentor fossil shells. This agrees with the observations of Professor Mudge who was the first extensive collector of both fossil shells and leaves in the Kansas Dakota. Professor Lesquereux was aware of this association of the plants and marine mollusks for in support of his belief that the Dakota was a marine formation he quoted the following statement of Professor Mudge: "They [the marine shells] are in the same strata and in the vicinity of several deposits with the dicotyledonous leaves, and together with the plants, identify this portion of the sandstone as belonging to the Dakota group of the Cretaceous."[7] The supposition that a part of the Dakota flora of

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1 Fifth Annual Report U. S. Geological Survey of Montana and Territories, 1872, p. 327. Also in Report U. S. Geological Survey Territories, Hayden, Vol. II,—Vertebrata of the Cretaceous Formations—1875, pp. 17, 67, 68.

2 Ninth Annual Report U. S. Geological and Geographical Survey Territories, Hayden, 1877, p. 291.

3 Bulletin U. S. Geological Survey, No. 82; Correlation Papers—Cretaceous—1891, p. 158; where Dr. White gives the classification of the Upper Cretaceous.

4 Report U. S. Geological Survey Territories, Vol. VI,—The Cretaceous Flora —p. 15.

5 Ibid., Vol. VIII,—The Cretaceous and Tertiary Floras—p. 92.

6 Mon. U. S. Geological Survey, 1892, Vol. XVII; see p. 20 where the age of the Dakota group is considered.

7 Report U. S. Geological Survey Territories, Vol. VI, p. 26. The above quotation was published by Professor Mudge in a description of the "Red sandstone of Central Kansas" in Trans. Kans. Acad. Sci., Vol. I, 1873 (?) reprint 1896, p. 39.

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Kansas belongs in the Lower instead of the Upper Cretaceous is also supported by the fact that Professor Knowlton of the U. S. Geological Survey has identified from the Cheyenne sandstone of Stokes Hill, near Belvidere, three species as identical with lower Dakota plants of Saline county. The locality for one of these, *Rhus Uddeni* Lx., is given as "from the west slope of the Smoky Hill Buttes, near Salemsburg post-office" which indicates that its horizon is below or near that of the Mentor shells to the west of the Smoky Hill Buttes as well as in the same general part of the terrane as the buttes near Falun where fossil leaves were found, and the Mentor fossil shells four miles west of Smolan. The other two species, *Sassafras mudgei* Lx. and *S. cretaceum* var. *obtusum* Lx. came from the bluffs along the Saline river, the locality that has already been considered as near the horizon of the Mentor shells in the western part of Cambria township.[1] Professor Knowlton evidently recognized that perhaps these species belonged in strata older than those containing the greater part of the Dakota flora, for he said: "If more were known of the chronologic sequence of the Dakota flora, it would possibly be found that the plants identified above belonged to lower or older beds."[2]

Prof. Lester F. Ward has recently shown from a study of fossil plants that the lower part of the so-called "Dakota Group" of the Black Hills in South Dakota belongs in the Lower Cretaceous, and he expressed this opinion: "It would seem probable that a considerable portion of the deposits underlying the marine Cretaceous of the Rocky mountain region which have heretofore been referred to the Dakota Group on purely stratigraphical evidence may really be much older."[3]

When examining the upper Permian and Lower Cretaceous of Saline county it was not practicable to study the exposures of the middle and upper Dakota. The writer is not able to say whether the coarse brownish sandstone forming the upper part of Soldier Cap Mound and the Smoky Hill Buttes belongs in the Upper Cretaceous or not. In the diagrammatic sections this sandstone has been

1 American Journal Science, 3d Series, Vol. L, pp. 212, 213.
2 Ibid., p. 214.
3 Journal Geology, Vol. II, May, '94, p. 265.

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DAKOTA SANDSTONE AT TOP OF SOLDIER CAP MOUND, SALINE COUNTY.
(Photographed by Prosser, 1896.)

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considered typical Dakota and as of probably Upper Cretaceous age. If this supposition be true then the Mentor beds or Lower Cretaceous will correspond approximately with those beds which Meek and Hayden thought at first belonged in the Triassic or Jurassic. On the accompanying geological map the Mentor beds and the higher Dakota are mapped as belonging to the "Dakota," using that name in the sense in which it had formerly been used for the lower subdivision of the Upper Cretaceous of central Kansas. This is done because at present it is not possible to indicate the line of division between the Mentor and the Dakota formations of central Kansas, and not with the idea that all of the so-called Dakota group belongs in the same formation. The above remarks are intended to call attention to a region which promises important results as the reward of careful stratigraphical and paleontological study.

REFERENCES TO DESCRIPTIONS OF THE MENTOR FAUNA.

The earliest published reference to the Mentor fossils is apparently that of Dr. John L. Le Conte in 1868. Doctor Le Conte accompanied the surveying party for the extension of the Union Pacific railway from Salina westward in 1867 and he reported fossils from the Dakota group stating that "near the crossing of Spring creek, about a quarter of a mile south of the road, this rock abounds in fossils." The specimens were sent to Mr. Conrad who reported fourteen species, "all of which seem to be new," and the generic names were given in Doctor Le Conte's Notes. In a foot note Doctor Le Conte states on the authority of Mr. Meek that Professor Mudge had procured specimens at the same locality.[1]

From a paper read by Professor Mudge before the fourth meeting of the Kansas Academy of Science, in 1871, it would appear that he first found these fossils in 1868, for he said "Three years ago, passing from Salina to Harper, when near what is now the town of Bavaria, we picked up in the road some marine fossils. Tracing the specimens to the top of an adjoining hill, we found a few acres covered with a stratum not over two feet in thickness, rich in small

1 Notes on the Geology of the Survey for the extension of the Union Pacific railway, Philadelphia, Feb. 1868, p. 7.

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shells."[1] From the material collected at this locality Mr. Meek described ten species of Lamellibranchs and two species of Gastropods. The descriptions were first published without figures in 1872,[2] and the revised descriptions of fourteen species with illustrations in 1876 in Meek's Invertebrate Cretaceous and Tertiary Fossils of the upper Missouri country.[3] The localities from which the fossils were collected were briefly described by Professor Mudge in his "Geology of Kansas."[4] Later, two additional species of Lamellibranchs were discovered by Professor Mudge in Saline county that were described in 1880 by Dr. Charles A. White.[5] To the above sixteen species Professor Cragin has added nine,[6] and Mr. T. W. Stanton one,[7] making a total of twenty six (26) known species of marine mollusca in the Mentor formation.

Acknowledgments.—The writer cheerfully acknowledges the assistance of Mr. J. W. Beede of Washburn College in studying the geology of central and southern Kansas; also that of Mr. C. N. Gould of the Southwest Kansas College who conducted the writer to many of the typical exposures of the Comanche series in southern Kansas; and to Mr. E. R. Cumings of Union College who has materially aided in the preparation of the maps, sections and text of this report.

1 Trans. Kans. Acad. Sci., Vol. I, reprint 1896, p. 38.

2 Hayden's 2d Rept. Geol. Surv. Wyoming and Territories, pp. 297-313.

3 Rept. U. S. Geol. Surv. Territories, Hayden, vol. IX. See Pl. 2.

4 First. Bien. Rept. State Board Agri. Kans., 2d ed., 1878, p. 67. See 9th An. Rept. U. S. Geol. and Geograph. Surv. Territories, Hayden, 1877, p. 291, for the same account.

5 Proc. U. S. Nat. Mus., Vol II, pp. 295, 296. These last two species were also described in Hayden's 12th An. Rept.

6 American Geologist, vol. XVI, p. 164.

7 Tapes belviderensis Crag. (?) given in this report.

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THE UPPER CRETACEOUS OF KANSAS.

BY

W. N. LOGAN.

With an Introduction

BY

ERASMUS HAWORTH.

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THE UPPER CRETACEOUS OF KANSAS.

INTRODUCTION.

BY ERASMUS HAWORTH.

At the close of the Comanche period, already described by Professor Prosser, the outlines of the North American continent were well formed and were similar to the continent as now known excepting a narrow inland sea reaching from the southern part of the United States to beyond the limits of Canada, and probably connecting with the Arctic ocean. This inland sea separated the eastern part of the American continent from such portions of the great Cordilleras area as were elevated into dry land. The coast lines along the Atlantic coast and the Gulf of Mexico were considerably farther inland than they are at present, leaving a border averaging from a hundred to a hundred and fifty miles in width, which has since been elevated and has become a part of the continent. Plate XXV, a small sized map of the United States, has the approximate areas marked on it which were under water at the close of Comanche time and which subsequently had Cretaceous rocks formed over them. It will be seen that there was an arm of the ocean reaching northward from the western part of the Gulf of Mexico, passing through Texas, the Indian Territory, Kansas, eastern Colorado, Nebraska, the Dakotas, eastern Wyoming, and Montana. The same area probably reached far into Canada, or quite likely connected with the Arctic ocean. Throughout this relatively large area sediments were accumulating from the drainage of the dry lands on either side, and from the accumulation of matter from animal organisms, so that heavy deposits of sandstones, limestones, and shales were formed. These deposits are similar in many respects to those formed during the same time along the ocean borders of the Atlantic and the Gulf of Mexico.

Western Kansas and eastern Colorado represent the great central

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portion of this formation. It would seem that in some way ocean water remained over these areas longer than it did farther to the south, as they have younger rocks than can be found in some of the southern parts. Plate XXVI is a section drawn north and south near the west side of Kansas to represent the relative positions and arrangements of the various Cretaceous rocks which were formed during the time now under discussion. It will be noted that at the extreme southwestern part of the state the Dakota sandstone occurs at the surface. As one passes northward one finds the relatively thin edges of succeeding formations in the order of their deposition, first the Dakota, then the Benton, next the Niobrara, and later the Fort Pierre. Could this section be continued farther northwest it would show succeeding formations, the Fox Hill and the Laramie, belonging to the Cretaceous. So far as the indications in Kansas are concerned, therefore, it would seem that this great inland sea was drained to the north by the elevation of the continent being greatest on the south.

The study of the Cretaceous formations in the great inland area progressed slowly from the first excursions of Meek and Hayden in the '50's until quite recent times. Slightly different systems of nomenclature have been suggested by different ones, each of which has had its advocates. They have more or less been abandoned, however, or combined, until at the present time it is customary to classify the upper Cretaceous rocks in the following manner:

No. 5. Fox Hill Group	Montana Formation.
No. 4. Fort Pierre Group	
No. 3. Niobrara Group	Colorado Formation.
No. 2. Benton Group	
No. 1. Dakota Group	Dakota Formation.

Of these all but No. 5 are found in Kansas and are included in the following description.

The Dakota formation is interesting and peculiar in some respects on account of the strong indications in different parts of America that it is of fresh water origin. By descriptions given of it for both north and south of Kansas, it would seem to represent fresh water deposits, but here in Kansas it furnishes marine invertebrate fossils, and has other properties, such as salt and gypsum

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within it, which strongly imply that it was formed under ocean water. This formation is so largely composed of sandstone that it is frequently spoken of as the Dakota sandstone. It is probably true, however, that less than half of the thickness of the whole Dakota is sandstone, the remainder being different kinds of shales, of which clay shale is the most abundant. Lignite or brown coal is found in place in sufficient quantities to become an article of commerce. Other changes, perhaps equally great, imply that a detailed study would result in the subdivision of the Dakota into a number of groups or formations.

The Benton is largely composed of limestone, and is rich in marine fossils. Whatever may have been the character of the water under which the Dakota was formed it is certain that with the close of the Dakota ocean water covered the whole of the great inland area. The great abundance of shale in the Benton, constituting more than two thirds of the total thickness, shows how a large amount of earthy material was carried from the dry lands into this inland ocean. It is probable that the main portion of it was carried westward from the large continent lying to the east, although it is difficult to make positive statements regarding this. It is known that at this time portions of the Rocky mountain area existed as dry land covered with different forms of crystalline rock. The sediments in the whole of the Cretaceous of Kansas from the beds of the Comanche to the top of the Fort Pierre seems to be entirely free from any fragments of crystalline rock. This strongly implies that the drainage was westward from the Coal Measures of the great interior area.

With the close of the Benton Niobrara time was ushered in. During this period a less amount of sediment was carried oceanward from the dry lands, and a correspondingly larger amount of the Niobrara is composed of different forms of limestone. Why this decrease in the deposition of dry land sediment it is difficult to say. Probably it was due to the climatic change resulting in a less rainfall on the adjacent lands. However that may be, the conditions were such that the character of the limestone formed was very different from that found elsewhere in Kansas, or in America outside of the Niobrara. The great mass of the

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Kansas Niobrara is principally chalk, in some places being perhaps more nearly composed of microscopic organisms constituting true chalk than elsewhere. But all over the state, wherever the upper Niobrara rock occurs, a sufficiently large proportion of such organisms are found to give the limestone a chalky character.

During Fort Pierre time the conditions were again reversed as regards sediments from the dry land, almost all the Fort Pierre formations in Kansas being shales or shaly limestones which must have been produced by the accumulation of sediments brought down from the land areas. The climatology of Cretaceous time in Kansas is an interesting subject, one which might produce valuable results were it studied in sufficient detail.

THE UPPER CRETACEOUS.

BY W. N. LOGAN.

In this Report will be given, first, a general discussion of the Upper Cretaceous of Kansas, and second, a number of sections which will serve to show the principal features of Upper Cretaceous stratigraphy.

GEOGRAPHY.

Approximately the upper Cretaceous occupies in north central Kansas an area of twenty five thousand square miles—nearly one third of the total area of the state. The main portion of this area lies between the 38th and 40th parallels north latitude and the 97th and 100th degrees 30 minutes west longitude. The border lines of the area are very irregular. On all of the principal streams which flow through the formation outcrops occur far beyond the boundaries of the main area. On the Smoky Hill river they extend as far west as the Colorado line. The direction of the longitudinal axis of the group is from northeast to southwest. The eastern and western general boundary lines of each subdivision are nearly parallel. The boundary lines of the Dakota are the most irregular. Narrow arms extend almost through the Benton area in many places. South of Great Bend a probable northward movement of

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the Arkansas river has cut into and eroded away the Dakota rocks, making a great southern bend in the Dakota area.

There are many small Cretaceous outcrops lying in the great Tertiary area south of the Arkansas river that usually occur along the streams which have cut through the overlying Tertiary formation. Outcrops of the Comanche, a member of the Lower Cretaceous, occur along the border of the Red-Beds in the southwestern part of the state.

The width of the lower Cretaceous area is only a few miles in extent. The formation extends from near the northern part of Barber county along the western border, thence across Comanche and Clark counties to Meade county. These outcrops form narrow borders along the northern tributaries of the Cimarron in the above-named counties.

The outcrops of the Upper Cretaceous are found farther to the west. A small Dakota area occurs on the Cimarron river in the southwestern part of Morton county. A much larger area is found along the Little Cimarron in the northern part of the same county. A small area of Dakota occurs on a tributary of the Cimarron in the extreme southern part of Stanton county. A similar outcrop is found a few miles north on Bear creek in the same county. The largest Dakota exposure occurs on a tributary of Bear creek, in the southern part of Hamilton county. The three outcrops last named extend into Colorado. They occupy a narrow strip on the banks of the streams.

The Benton is represented south of the Arkansas by a few small outcrops. A small area occurs in the southern part of Gray county. This is entirely isolated from the main body of the Cretaceous, being surrounded by the Tertiary formation. A similar outcrop is found about midway between Bear creek and the Arkansas river in Hamilton. Along the Arkansas river from Hartland, in Kearny county, beyond the western line of the state into Colorado, the Benton outcrops are almost continuous. They occupy here, as elsewhere in this part of the state, however, but a narrow belt along the banks of the river.

On the northern tributaries of the Arkansas in the same region, Niobrara exposures rest conformably on the Benton rocks. No

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outcrops of Niobrara are found south of the Arkansas, but a few isolated outcrops occur in the great Tertiary area north of that river. Two such instances are found in the southeastern portion of Scott county, which are probably the ones referred to by Hay as belonging to the Fort Pierre.[1] A larger Niobrara area is found in the western part of Greeley county, which is Fort Hays limestone and extends across into Colorado. Another small exposure of Fort Hays limestone is found along the tributaries of the Arkansas a few miles north of Coolidge on both sides of the state line.

TOPOGRAPHY.

There is a marked similarity in general topographic features of the Cretaceous and the Carboniferous formations in Kansas. Between the Cottonwood Falls limestone of the Permian and the Lower Coal Measures we find four great limestone groups which serve to produce marked changes in topographic features. In the Cretaceous and the Tertiary areas above the Cottonwood Falls limestone we also find four rock formations which serve a similar purpose. The four members of the first group are, beginning with the lowest, the Erie limestone, the Iola limestone, the Garnett limestone, and the Oread limestone. The members of the upper group are, the Dakota sandstone, the Benton limestone, the Fort Hays limestone, and the "Mortar beds." Throughout the state wherever there is an exposure of any one of these groups, similar irregularities of surface have been produced. Along the eastern border of each exposure mounds of shale protected by the more durable rock are found. Above the point where the limestone or sandstone disappears under the surface, a comparatively level but gradually ascending plain extends westward until the next limestone or sandstone group is reached, where nearly the same topographic features are repeated. Therefore in passing from the eastern part of the state to the west north of the Arkansas river, we ascend a number of terraces, each one having a very irregular border. Of these upper terraces, the Dakota presents the greatest diversity in topographic features, a condition due largely to the varying texture of the sandstone. The sandstone hills of the Dakota group are

1 See Doctor Williston's report on the Niobrara, in this volume.

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composed usually of thin bands of sandstone with intervening shale beds capped with a heavy thickness of sandstone. See Plates V, VI, XII, and XXIV.

The Benton area is more regular in topographic features. It contains a single chain of hills which extends from northeast to southwest through the central portion of the area, and are composed of the upper Benton shales, the Blue Hill shales, capped with the Fort Hays limestone. On account of the peculiar bluish appearance which they present when seen from a distance, they are called the Blue Hills. Their color is due to the dark blue shales of which they are composed.

The Fort Pierre shales in the northwestern part of the state are protected by the "Mortar beds." Many mounds similar to those in the Dakota and Benton areas are found.

DIP.

The direction of the dip of the Cretaceous bed is toward the northeast. The altitude of the lowest Fort Hays limestone of the Niobrara on the Hackberry in Trego county is 2200 feet. The same stratum rests upon the Blue hills to the northeast in Mitchell county at an elevation of 1800 feet. This makes a difference of 400 feet in elevation for a distance of eighty miles, or a dip of five feet to the mile. A continuation of the same section from Ionia to Scandia produced relatively the same result. The altitude of Wallace in Wallace county, eighty five miles west of the Hackberry, in Trego county, is 3300 feet. Allowing 400 feet for the Niobrara and 100 feet for the Fort Pierre at Wallace, we have a difference in altitude of 600 feet, making a dip of seven feet per mile. Taking the elevation of Otego, in Jewell county, 1792 feet, and using the above data for Wallace, we find a difference in altitude of nearly 1000 feet in a distance of 170 miles, or a dip of six feet to the mile. The elevation of Beloit, in Mitchell county, at the extreme Upper Dakota is 1350 feet. The elevation of Santa Fe, in Haskell county, is 2950 feet. A well at Santa Fe passes through 324 feet of Tertiary and 13 feet of Fort Benton, giving an elevation for the upper surface of the Dakota at that point of 2611 feet. The difference in elevation of the Dakota at Beloit and at Santa Fe is therefore 1261 feet. The

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distance between the two points is one hundred ninety miles. Thus the dip is a little more than six feet to the mile for the upper surface of the Dakota in this direction. The Septaria horizon is found near Laird, in Ness county, at a height of 2300 feet. At Tipton, in Mitchell county, the same horizon occurs at an elevation of 1800 feet. Tipton is one hundred miles northeast of Laird and the difference in elevation is 500 feet, consequently the dip for the Fort Benton upper beds is five feet per mile.

These comparisons of elevation are sufficient to show that the dip of the Cretaceous beds does not exceed seven feet to the mile in any part of the state when measured over long distances. In different places, however, locally a much greater dip is found.

DIVISIONS.*

Three principal divisions of the upper Cretaceous are represented in Kansas. These divisions are: the Dakota, not divided; the Colorado, divided into two groups, namely, Benton and Niobrara; and the Montana, represented by a single group, the Fort Pierre. The vertical position of these divisions is shown by the accompanying vertical section, Plate XXVII. Beginning with the Permian, upon which the Cretaceous beds rest, the order of stratigraphic sequence is as follows: first Dakota, second Benton, third Niobrara, fourth, Fort Pierre. These groups will now be considered in the order in which they have been named and a few facts in regard to the geography, stratigraphy, economy and paleontology of each will be given.

THE DAKOTA.

The Dakota occupies a narrow belt along the eastern border of the Cretaceous area. It extends from Washington county on the northeast to Ford county on the southwest in one continuous area, and has a number of small outlying areas farther to the southwest, as already mentioned. Its greatest width is a line extending from the confluence of Big creek and the Smoky Hill river to the western line of Morris county. The narrowest portion of the belt

* For a discussion of the divisions of the Cretaceous see introduction to this article.

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is in Clay and Cloud counties. In the northern portion the Dakota beds rest upon the Permian gypsiferous shales, and in the southern upon the Red-Beds of the Permian.

The Dakota formation may be subdivided, but there are no well defined separating lines. For convenience of discussion, however, it will be divided into two groups; first the ferruginous or lower group; and second the saliferous shale group, or upper group. The layer of sandstone which underlies the upper shales will be considered the line of separation.

THE LOWER GROUP.

The lower group consists of alternate layers of red and white sandstone, and argillaceous and arenaceous shales. In the southeastern part of the Dakota area these shales rest upon the Permian limestone; in the northeastern part upon a thin bed of gypsiferous shales which probably belong to the Permian. The shales of the lower bed are chiefly argillaceous, but near the sandstone layers they are frequently found to be highly arenaceous. In many places, especially in the strata adjoining the lignite veins, they are very bituminous. They are of many colors, but the color usually prevailing is a light blue. An outcrop in the Smoky Hill Buttes shows three bands of color, red, mottled and white. Small traces of lignite are found in the lower bed of shales, as are also thin layers of sandstone. Gypsum crystals are found usually near the middle of the bed. The maximum thickness of this lowest bed of shales is in the neighborhood of one hundred feet. The remainder of the lower group consists of alternate layers of shale and sandstone with the sandstone layers far exceeding the shales in thickness. The thickness of each layer of sandstone varies, however, in different parts of the Dakota area. Near the middle of the sandstone group is a layer from which many fossil leaves have been taken, but they are not always found at exactly the same horizon, their position varying as much as fifty or sixty feet. The best specimens have been collected in the eastern part of Ellsworth county, none having been found thus far in the northern part of the Dakota area. The sandstones of the ferruginous group rest on the lower beds. They probably reach their maximum thickness in the northern part of the area, and thin out

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toward the southern. They are highly ferruginous in character, and curiously shaped ferruginous nodules are of common occurrence. They vary in texture from the loosely cemented sand to the very coherent sandstone.

The Dakota sandstone is used for building purposes to only a limited extent. Representing approximately both extremes in the scale of hardness, they are either too hard to be dressed or too soft to withstand weathering. Another objection urged against their use as building stone is that of their color. Owing to the constantly varying amount in the quantity of iron oxide in the stones of the same quarry even, many shades of color exist.

Many peculiar effects of erosion are to be seen in the sandstone area. Standing on the hillside a few miles east of Ames, in Cloud county, is a single escarpment which has weathered into a form resembling an ancient castle. At Pawnee Rock, in Barton county, a similar outcrop stands sentinel over the Arkansas valley. Both owe their preservation to a protecting covering of the Benton limestone. The natural fortifications of Pete creek, in Washington county, are only equaled by those at Fort Riley. Soldier Cap Mound, in Saline county rises 140 feet above the surrounding country and consists of a single point of shales protected by a layer of sandstone. See Plate XXIV. The Smoky Hill Buttes are similar mounds in the southwestern part of Saline county, Plates V and VI. At Rock City, in Ottawa county, the sandstones have been eroded into peculiar rounded forms, resembling glacial boulders. The intersecting channels, with their inclosed forms, give to the group the appearance of a city, hence the name. With the exception of the spherical forms, similar groups occur in Lincoln, Ellsworth and Russell counties. In the majority of instances, the white sandstone rests upon the red; but in a number of instances they occur in the same horizon. East of Bavaria both were found in the same horizon, the one color passing gradually to the other.

THE UPPER GROUP.

Lignite Horizon.—Resting upon the gray or white sandstone, in the last upper layer of the sandstone group, is a thin bed of lignite which is entirely wanting in certain localities. The lignite varies in

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thickness from 6 to 26 inches. In Republic county it occurs from 80 to 100 feet below the Benton limestone. In Lincoln county it is only 60 feet below that horizon, and in Russell county it is 90 feet. The thickest vein occurs in the mines on Little Timber creek in Lincoln county where the lignite rests between beds of shale and gray sandstone, the shale adjacent the coal being extremely bituminous in character. In Republic county near Minersville, two 9 inch veins are intercalated with shales which are argillaceous, and not bituminous in character. Above the lignite bed in Mitchell county rests a thick bed of bituminoous shales which seem to pass conformably into lignite. In Coal cañon thin layers of lignite are intercalated with sandstone and shale. The lignite is mined in this locality by tunneling into the drift of the creek bed. Shafts have been sunk to a depth of 80 feet in Republic county and 50 feet in Lincoln county. Lignite is mined and used for fuel in Republic, Mitchell, Lincoln, Russell and Ellsworth counties. The lignite contains much ash in the form of pyrite, shale, etc. The principal mines are located on Wolf creek and Coal cañon in Russell county; on Coal creek and Elkhorn in Ellsworth county; on Spillman creek, Little Timber creek, Bacon creek, Rattlesnake creek and Elkhorn creek in Lincoln county; on Rock creek and Solomon river in Mitchell county; on West creek in Republic and Cloud counties.

The strata adjacent the lignite vary with the locality. In some localities the lignite rests between beds of shale, in others between layers of sandstone, and still in other localities it is found resting upon sandstone and covered with shale. In many places it is entirely wanting. Its place, however, may be occupied by a thin bed of bituminous shale.

Salt Marsh Horizon.—Resting upon the lignite is a bed of shales which are, in the majority of instances, highly saliferous in character. They vary in thickness from 15 to 30 feet. By the disintegration of these shales salt marshes have been formed in many localities along the exposure of the upper Dakota horizon. The marshes occur on the Rattlesnake creek in Lincoln county; on Rock creek and Salt creek in Mitchell county; on Marsh creek in Cloud county; on West creek, Marsh creek and Salt creek in Republic

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county, and on Marsh creek in Jewell county. The saline properties of the Great Spirit spring, which is located in an outlier of the Dakota near Cawker City, are due to these shales. Salt springs occur in this horizon in Mitchell, Jewell and Republic counties, and the water of the wells which pass through the shales is invariably saline.

Gypsiferous Horizon.—Above the saliferous shales is a bed of shales varying in thickness from 10 to 20 feet. These shales are thin, laminated and of loose texture. They contain quantities of gypsum crystals.

The gypsum shales are more numerous in the southern part of the district. Outcrops occur a few miles west of Lincoln Center, and near Buel, in Mitchell county. Gypsum is also found in the Little Timber and other mines. Above the gypsiferous shales a thin layer of sandstone occurs. This sandstone varies in thickness from 8 to 12 inches and occurs in from one to six layers. In some outcrops the sandstone rests between thin beds of gypsum, and is very fossiliferous. This sandstone marks lithologically as well as paleontologically the separation of the Benton from the Dakota.

DAKOTA STRATIGRAPHY.

The following records of outcroppings will serve to show the relative positions of the different layers of the upper horizon.

Salt Creek Section:

1st outcrop—

5. Soil, 5 feet (top).
4. Black shale with red sandstone in thin layers 8 feet.
3. White sandstone 6 feet.
2. Sand, 4 inches.
1. Saliferous shale? (bottom).

2d outcrop—

5. Soil, 3 feet (top).
4. Shale 4 feet.
3. Sandstone 6 inches.
2. Black shale, gypsiferous, 15 feet.
1. Saliferous shale? (bottom).

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3d outcroop—

7. Soil 5 feet (top).
6. Sandy shale, 10 feet.
5. Gypsum, 3 inches to 2½ feet.
4. Red sandstone 8 inches.
3. Gypsum 1½ inches.
2. Gypsiferous shales, 10 feet.
1. Saliferous shale? (bottom).

4th outcrop—

3. Soil, 5 feet (top).
2. Gypsiferous shale, 10 feet.
1. Saliferous shale? (bottom).

Rock Creek Section:

1st outcrop—

4. Alluvium, 10 feet (top).
3. Lincoln marble and shale, 5 feet.
2. Red sandstone, 5 feet.
1. Saliferous shale ? (bottom).

2d outcrop—

4. Soil, 6 feet (top).
3. Gravel rock, 1 foot.
2. Sandstone in thin layers, with sand 10 feet.
1. Saliferous shale ? (bottom).

Little Timber Section:

1st outcrop—

8. Soil, 15 feet (top).
7. Red sandstone, sand and shale, 10 feet.
6. Shale, gypsiferous, 15 feet.
5. Shell bed, Leptosolen conradii, 6 inches.
4. Blue shale, 8 feet.
3. Bituminous shale, 4 inches.
2. Lignite, 26 inches.
1. Gray sandstone? (bottom).

2d outcrop—

4. Soil, 10 feet (top).
3. Shale?

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2. Coal, 24 inches.
1. Gray sandstone?

PALEONTOLOGY.

The lower Dakota horizon is noted for the number and variety of its fossil plants, but with the exception of a few fresh water mollusks and the tracks of birds, no animal remains have been found. Among the plants the following genera are represented: *Cessites* (three species); *Ficus* (six species); *Sassafras* (four species); *Diospyros* (three species); *Plantanus* (? species); *Leguminosites* (one species); *Juglans* (species); *Protophyllum* (? species); *Laurus* (one species); *Aurus* (species); *Rhanus* (species); *Liriodendron* (three species). Many pieces of fossil wood, and, in some instances the trunks of trees, have been found in the lower Benton. These undoubtedly belonged to the upper Dakota horizon.

In the upper Dakota group fossils have been found in three horizons. In the thin sandstone layers of the first shale bed the following fossils were found: *Corbicula subtrigondis*, *Trigonarca salinaensis*, *Yoldia microcodonta*, *Crassatellina oblonga*, *Arcopagella macrodonta*, *Tellina subscitula*, *Corbicula?*, *Protocardia salinaensis*, *Cardium kansasense*, *Cyrena dakotensis*, *Margaritans nebraskacenses*, *Mactra siuxensis*, *Tellina modesta*, *Tellina?* besides several other forms not yet determined.

In the saliferous shale horizon was found a bed of fossils of which the following have been determined: *Leptosolen conradi*, *Pharella dakotensis*, *Pharella?*, *Cardium kansasensis*, also a number of forms not yet determined. Altogether more than twenty five species have been found in the Upper Dakota.

DAKOTA WATER-BEARING STRATA.

There are two principal water sources in the Upper Dakota. Resting upon and beneath the saliferous shales are thin layers of sand or loosely cemented sand rock. It is through these layers that the so-called sheet water of the Dakota flows. Every where along the line of exposure of the Upper Dakota, from Washington county on the north to Ford county on the south, water flows from these sand beds, lying immediately above or below the shale hori-

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zon. In some places on account of the local dip of the underlying sandstone, the water is forced through the shales and comes to the surface in the form of salt springs. In one of the Republic county salt marshes an artesian flow was obtained with sufficient pressure to lift the water 12 feet high. The line of exposure may be traced by such local terms as "Willow Spring," "Spirit Spring," "Round Springs," "Salt Spring," "Marsh Spring," etc.

A number of views have been advanced to account for the source of the Dakota water. One is that it follows the Dakota from its position on the eastern slope of the Rocky Mountains. Another is that it is from the Tertiary sheet water. It is not improbable, however, that the source of a large part of the water is much nearer at hand than even the Tertiary formation.

The Dakota sandstone is capable of storing a great quantity of water and of retaining it for a long period of time. The North Smoky Hill Butte, figure 10, furnishes an excellent example of this. This butte consists of a mound of shale rising one hundred feet above the neighboring surface and capped with layers of sandstone, forming with the intervening layers of shale an additional thickness of 125 feet. The upper surface of the Mound presents an almost level exposure of twelve or fifteen acres. At the point of contact between the lower shale bed and the sandstone the water flows out in the form of springs. The water from the springs flows the year round. The springs are located at the northeastern point of the mound, showing that the dip of the rocks is in that direction. It is clearly impossible for the water which supplies these springs to have come from a horizon below the sandstone; hence its source must have been the rain which fell on the surface. That capping of sandstone absorbed the water from the clouds and it trickles out from the upper surface of the shale as its own weight brings it to that level. Some idea of the amount of water stored may be gained from the fact that during three extremely dry years the supply of water in these springs did not fail once.

Terra Cotta Mound, figure 11, is another excellent example of the storing power of the Dakota. This mound consists of a bottom layer of 100 feet of shale with 30 or 40 feet of sandstone resting above. Although its upper surface is only a few acres in extent, yet

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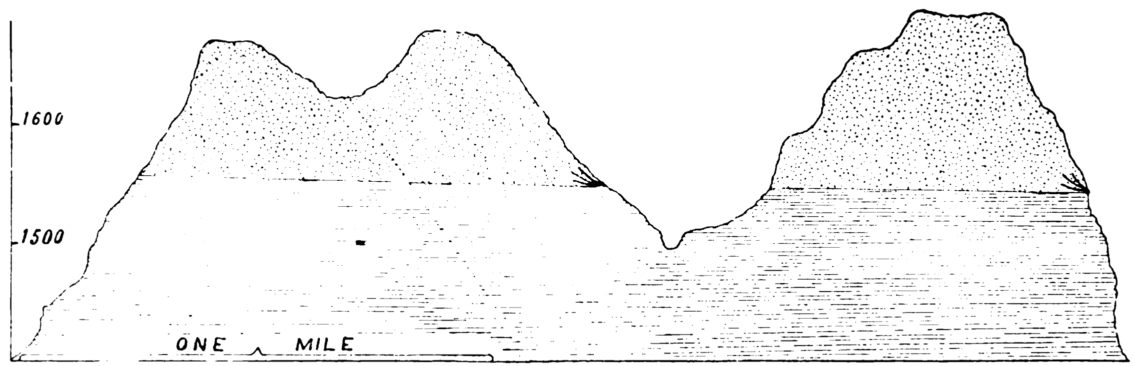

Fig. 10.
Smoky Hill Buttes; Upper Part Dakota Sandstone, Lower Part Shale.

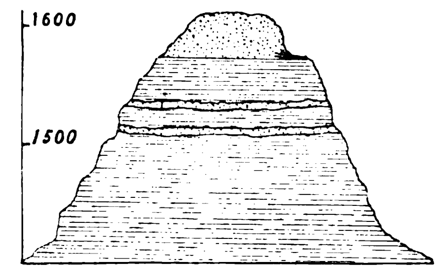

Fig. 11.
Terra Cotta Butte; Upper Part Dakota Sandstone, Lower Part Shale.

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a never failing spring of water is found at the eastern extremity of the sandstone and shale conjunction.

The sand grains of the Dakota sandstone are rarely so closely cemented together as not to permit the free circulation of water. A few mounds of shale in Ellsworth county, however, are surmounted by a layer of sandstone the grains of which cohere so closely that the water is shed and very little, if any, stored.

THE BENTON.

The dividing line between the Dakota and Benton is marked lithologically by the change from sandstone to shale, or from bitumenous to argillaceous shale.

GEOGRAPHY.

In geographical extent the Benton is the largest of the Cretaceous groups. It extends from the north line of the state in Republic county to Ford county on the southwest. With the exception of two small outcrops, one in Hamilton and one in Gray county, the Benton area lies north of the Arkansas river. It seems to be conformable with the Upper Dakota, and the dip of its strata is toward the northeast.

STRATIGRAPHY.

Lithologically the Benton[1] may be divided into two groups, viz., the lower, or limestone group,[2] and the upper or shale group.[3] The lower group includes all the limestone and the interbedded and underlying shale. The upper group includes all the shales above the limestone group and below the Fort Hays limestone of the Niobrara.

THE LOWER GROUP.

The lower group contains five principal horizons, namely:

1, Bituminous shale; 2, Lincoln Marble;[4] 3, Flagstone; 4, Inoceramus; 5, Fence-post.[4] The entire thickness of this group is from

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1 For reasons that will be evident from the discussion of the Benton, the nomenclature of that group employed by Prof. F. W. Cragin in his paper, "On the Stratigraphy of the Platte Series," has been somewhat changed.

2 Russell Formation—Cragin.

3 Victoria clays—Cragin.

4 On stratigraphy of Platte series—Cragin.

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90 to 130 feet. The indications are that the group thins out toward the south.

The Bituminous Shale Horizon.—The shales comprising this horizon vary in thickness from 20 to 40 feet. They are dark blue in color and somewhat slaty in structure. Upon weathering they present a laminated appearance. In many places they extend upward toward the next horizon gradually changing color from blue to yellow. Very few fossils are found in this horizon, *Inoceramus liabatus* being the most abundant.

The Lincoln Marble Horizon.—Resting conformably upon the bituminous shales is the Lincoln Marble horizon. This group consists of from two to five layers of hard flinty limestone intercalated with shales. The maximum thickness of the group is 15 feet. The maximum thickness of the individual layers is 6 inches. The Lincoln Marble is of a bluish gray color, contains many impurities, is porous, hence weathers easily. It contains abundant evidence of vertebrate fossil remains. Fossils not yet fully identified, but what seem to be remains of *Plesiosaurus* and tracks of other saurians, have been found. Squaladont selachin shark teeth abound, as many as a dozen having been found under a single square foot of surface. The invertebrate forms are numerous. *Inoceramus umbonatus*, *Inoceramus undabundus*, and other forms, as yet undetermined, have been found.

The Flagstone Horizon.—The Flagstone horizon rests conformably upon the Lincoln Marble. It consists of three or four layers of limestone with intervening shale. The maximum thickness of the group is 10 feet. The maximum thickness of the individual layers is 8 inches. The fossil forms in this horizon are not numerous. Remains of fish, shark teeth and invertebrates, of the genus *Inoceramus*, have been found. The limestone is white in color and fine in texture. It is used throughout the Benton area for flagstone, hence the name.

The Inoceramus Horizon.—The Inoceramus horizon is nearly midway of the limestone group, and rests conformably upon the Flagstone horizon. The average thickness is from 4 to 5 feet, and consists of from one to three layers of limestone separated by argillaceous shale. The average thickness of the individual layers is 6 inches. The limestone is composed almost wholly of *Inoceramus*

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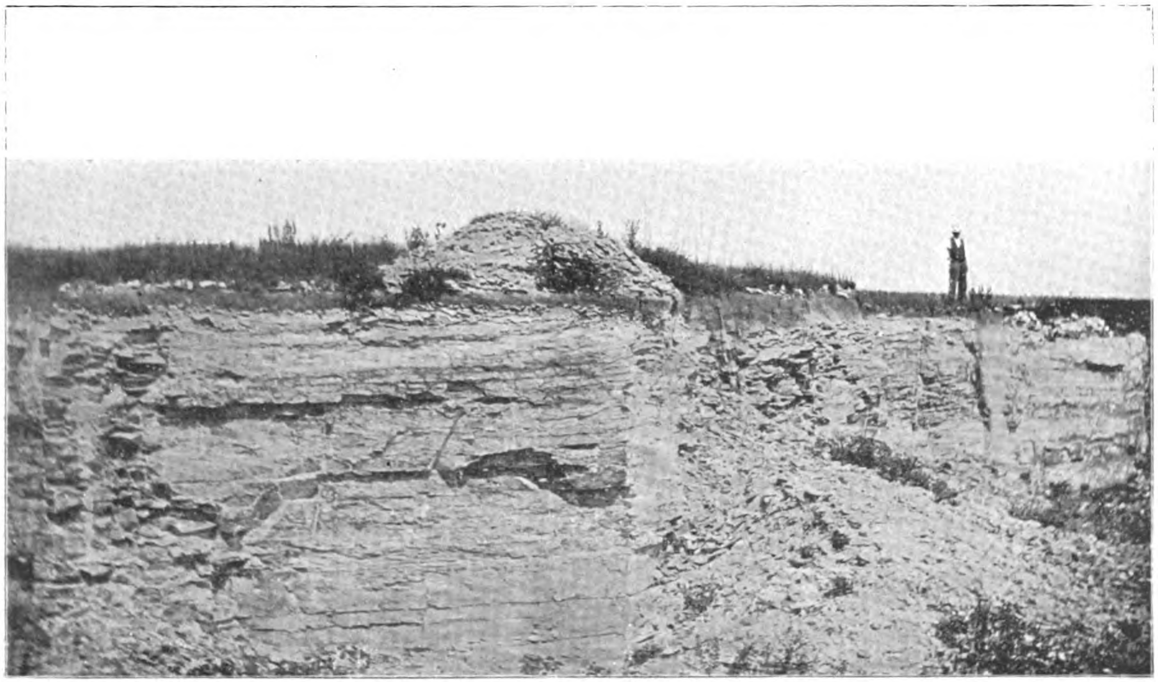

QUARRY IN NIOBRARA CHERT, ONE MILE NORTHEAST OF NORTON.
(Photographed by Haworth, 1896.)

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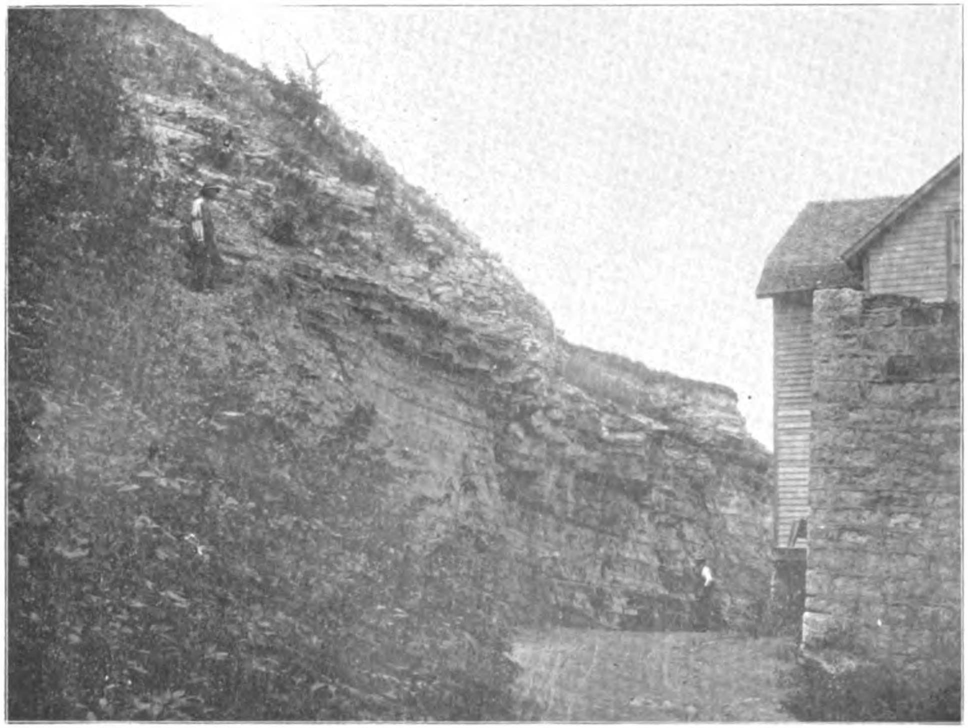

NIOBRARA BLUFF CAPPED WITH CHERT, AT OLD MILL, NORTON.
(Photographed by Haworth, 1896.)

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problematicus, and resembles a mortar bed into which shells have been thrown. The Inocerami casts are well preserved, and, although found throughout the upper limestone group, are most abundant in this horizon. For this reason the name Inoceramus has been given to the horizon. The shell rock, or lime rock as it is called locally, is used to a limited degree in the manufacture of lime.

The Fence-Post Horizon.—Near the top of the limestone group is the Fence-post horizon, so named because the limestone is used very extensively for making fence-posts. It is estimated that there are at least fifty thousand of these posts in use in Mitchell and Lincoln counties alone, five thousand being used in a single township. Their use is becoming general throughout the Benton area. The average thickness of the fence-post limestone is 9 inches. A ferruginous seam passes through the center of the layer and by splitting the limestone along this seam excellent flag-stones are produced. The fossils found in the Fence-post horizon are chiefly invertebrates. Species of the genera *Aspidorhynchus* and *Osmeroides* have been found. With the exception of the *Inoceramus* group the limestone from each of the horizons is used for building purposes.

THE UPPER GROUP.

The upper group contains two horizons, namely, the Ostrea shales, and the Blue Hill shales. This group represents a total thickness of 250 feet.

The Ostrea Horizon.—The Ostrea shales rest conformably upon the Fence-post horizon of the lower group. They consist of a bed of argillaceous shales of variegated colors, from 100 to 150 feet in thickness. The characteristic fossil of this horizon, from which it has been named, is the *Ostrea Congesta*, beds of which occur throughout the horizon. These shells are usually found adhering to the bivalve *Haploschapa capax*. Remains of squaladont selachians and sestrationt selachians have also been found. In certain localities the shales are somewhat saliferous, forming wherever exposed, salt pans or licks. These pans are never of very large area and are usually recognized by their whitish appearance. In the extreme upper horizon the Tennuicarinata serpula is the chief fossil form.

It is the disintegrated Ostrea shales that form the soil for the

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major part of the Benton area. The soil so formed on account of the great quantity of Ostrea shells is very productive. The shales as a rule, however, are closely textured, so that there is a tendency to the formation of a subsoil which bears among agriculturists the name of "hard-pan." The hard-pan not only prevents the disintegration of the shales below, but becomes almost impervious to water, so that when water falls upon the surface of the ground and sinks through the stratum of soil to the surface of the hard-pan it flows along this surface until it reaches some neighboring outlet. Hence, instead of being stored up in the soil it is drained away and in a short time, the soil not being very deep, that part which remains has evaporated and the crops suffer as a result.

The Blue Hill Horizon.—The Blue Hill shales, unlike the Ostrea shales, are very loosely coherent, and easily removed by erosion. Wherever they have covered the surface they have formed a very unproductive soil which is called locally "gumbo." The unproductiveness of the soil is due to the unfossiliferous character of the shales. The Upper Benton shales are preserved from erosion in the central portion of the Benton area by the massive Fort Hayes limestone of the Niobrara. Shales not protected in this way have been eroded away leaving the protected shale beds with nearly perpendicular walls.

The maximum thickness of the Blue Hill shales is 100 feet. They are dark blue in color and nonfossiliferous. Williams Butte, a single isolated point among the Blue Hills, forms an excellent example of the erosion of the upper shale beds. It is 120 feet in hight, and is protected by the Fort Hayes limestone.

The Salt Creek Gravel Beds.—The Salt Creek gravel bed, or conglomerate gravel stones, were at first difficult to account for. Chiefly owing to their resemblance to the grit rock of the Tertiary, they were thought to belong to that formation. They belong more probably, however to a later period. This gravel horizon is about 15 feet above the saliferous shales of the Upper Dakota, which form the bottom of the creek bed. The beds dip under the soil towards the bluffs, which are protected by the Benton limestone. An examination of the rock showed it to be composed of gravel, ferruginous nodules, etc., from the shales and limestone beds of the

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upper horizon. Herein, undoubtedly, lies the explanation of the origin of the gravel beds. By the disintegration of the shale, and the dissolving of the limestone, the gravels accumulated along the bed of the stream. Subsequently the stream changed its course, and the detritus from the bluffs filled up the old bed of the stream. After cutting down to a lower level the stream again changed its course, and exposing the old gravel beds which had, in the meantime, been cemented into firm rock.

THE NIOBRARA.

Septaria.—The Niobrara group occupies a narrow belt along the border of the Tertiary area and overlies the Benton. Its total thickness is between 350 and 400 feet. Lithologically it has been divided into two groups: the lower, or Fort Hayes limestone; and the upper, or Pteranodon[1] beds, or Smoky Hill chalk.

Resting upon, and often embedded in the black shales of the upper Benton horizon, is a layer of shale containing many calcareous concretions to which the name Septaria has been given. It marks the dividing line between the Benton and Niobrara. This zone reaches entirely across the Benton-Niobrara area from Jewell county almost to the Arkansas river. The nodules are usually in the shape of flattened spheres, and their surfaces are either smooth or seamed. Some of them are solid, others are hollow, and the cavity lined with a crystalline substance, usually calcite. The calcite crystals vary in color, from a dark wine color to transparent. At the base of Williams' Butte, in Mitchell county, a field more than ten acres in extent is covered with the concretions, some of which are more than four feet in diameter. Many tons of them have been hauled away for museum specimens, or lawn ornaments. Some fine specimens of ammonites and scaphites have been found in them. Testudinates have also been found in that horizon.

Fort Hays Limestone.—The Fort Hays limestone forms a continuous line along the bluffs of the Smoky Hill river, from the mouth of Hackberry creek to the western line of Ellis county. Here it dis-

1 Since Pteranodon has been shown to be synonymous with Ornithostoma, some think the latter name should be used.

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appears, but reappears as a capping for the Blue Hills in Russell, Mitchell and Republic counties. Its total thickness is 50 or 60 feet. A single escarpment on the Hackberry measures 45 feet. It rests upon the Septara and upper shale bed of the Benton. The Fort Hays limestone is used to a limited extent for building purposes. When taken from the quarry it is very soft, therefore, easily cut, or sawed into any desired form. Under exposure it hardens somewhat, but is considered too soft to be very valuable as a building stone.

The Pteranodon Beds.—The Pteranodon beds, or Smoky Hill chalk, rests upon the Fort Hays limestone. These beds represent a total thickness of more than 300 feet. They vary in color from a light blue, through lavender, yellow and buff, to light red. Under fresh exposure the chalk, in many instances, presents the appearance of a blue shale, and sometimes has been taken as such by persons doing geological work in western Kansas. These freshly exposed beds, however, under the weathering influnces of air and water, soon change their shale-like appearance and their blue color to red, yellow or buff, due probably to a change in the character of the iron compounds in it. In an exposure of chalk northeast of Lebanon, in Smith county, the chalk had a laminated appearance, and was blue in color in all parts except along the borders of five vertical fractures where it was the ordinary buff. The action of the surface water, as it passed along these crevices, probably accounts for the bleached appearance of the chalk along the border of the fractures. In passing up the Smoky Hill river to the state line the exposures near the river bed are found to be blue in color, while those back on the bluffs are variegated. Wells which pierce the Tertiary deposit, lying immediately above the Pteranodon beds, usually strike blue chalk. That they do not always do so is easily explained when we remember that there was a period of erosion preceding the deposition of the Tertiary formation, which may have resulted in the bleaching out of much of the chalk.

In a few places the chalk beds carry large amounts of chert which seem to be interstratified with the chalk. This is well represented at Norton, along the Prairie Dog creek. Northwest of the town about a mile the chert is quarried to a considerable extent. Plate

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XXVIII shows this, and Plate XXIX shows the same chert capping a chalk bluff at the old mill, Norton.

Some excellent mineral pigments have been taken from the chalk beds near Wa-Keeney to be used in the manufacture of paints.

Erosion has produced many peculiar forms in the Smoky Hill chalk beds. Near Hackberry creek, in Gove county, is a mound of chalk 70 feet in hight, known as Castle Rock, and shown in Plate VII. It stands on an open terrace a few rods from the bluffs. In form it resembles an ancient castle, hence the name. Near Elkader is a group of these chalk forms which because of their pyramidal shapes, are called the Pyramids; see Plate XXXV. "Castle City" is the name of a group which is situated near the western line of Gove county. The highest of these chalk mounds is nearly sixty five feet. Erosion within the chalk area is rapid and large quantities of chalk are carried away by each freshet.

The chalk beds of Kansas are particularly rich in fossil remains, a synoptical review of which by Doctor Williston follows this paper.

THE FORT PIERRE.[1]

Resting upon the Pteranodon beds in northwestern Kansas is a bed of shales which belong to the Fort Pierre group of the Montana Cretaceous. Outcrops of these shales occur on the Beaver in Rawlins county, the Prairie Dog, in Norton, and on the Hackberry, Republican and Arickaree in Cheyenne county. The upper shales are dark blue in color, argillaceous, chaffy and loosely textured. The next band is variegated in color, but usually of a rusty yellow. These shales contain nodules of a flat, disc-like shape. The freshly fractured surface of these nodules presents a bluish gray color, but the outside is like the shales, of a yellowish color. These nodules sometimes contain invertebrate fossils.

The maximum thickness of the Fort Pierre shales in Kansas does not exceed 200 feet. The principal invertebrate fossils of the Fort Pierre group are:[2] *Avicula fibrosa*, *Inoceramus cripsii*, and *Lucina occi-*

1 In his paper, "On the Stratigraphy of the Platte Series" Colorado College Studies, 1896, Prof. F. W. Cragin classes the Arickaree shales as Fox Hill. They were first called Fort Pierre by Prof. Robert Hay in his paper on: "Water Resources of a Portion of the Great Plains," published in the Sixteenth Annual Report of the Director of the U. S. Geological Survey.

2 Mr. T. W. Stanton, of the U. S. Geological Survey, kindly determined these species for the University in the Autumn of 1896.

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dentalis, and *Baculites ovatus.* Undetermined species are from the genera *Ostrea, Corbula* and *Scaphites.*

A SECTION THROUGH THE CRETACEOUS FROM CLIFTON TO THE COLORADO LINE. PLATE XXX, FIGURE 1.

Beginning at Peach creek a few miles east of Clifton, we find a bed of blue shales resting upon 6 feet of Permian limestone. Above a bed of sandy gypsiferous shales rests conformable with the blue shales. On the east side of Peach creek a line of Dakota sand hills rise to a height of 125 feet. These hills are composed of alternate layers of shale and sandstone and are invariably capped with from 10 to 25 feet of sandstone. The surface west of Peach creek rises gradually to a height of 50 feet above the creek bed. The sandy character of the soil indicates that the formation is Dakota, but there are few outcrops. The wells of this locality pass through sand and shale to the upper surface of the Permian limestone, along the surface of which the water flows.

Passing westward from Clifton to Clyde there are found a few outcrops of sandstone. The individual layers vary in thickness from 2 to 3 feet. The sandstone is of a brown color and loosely textured. In a railroad cut east of Clyde the following condition of stratigraphy was exposed, numbering from the bottom of the cut:

5th, Soil, 1½ feet.

4th, Red sandstone, 10 feet, friable.

3d, Blue clay, shale, 10 feet.

2d, White sandstone, 2½ feet, compact.

1st, Blue clay, 1 foot, nonfossiliferous.

The valley of the Republican from Clyde to Concordia is bounded by the Dakota sandstone bluffs. These bluffs are composed of alternate layers of red or white sandstone and shale, and owe their preservation to the sandstone layer which rests upon them. West of Concordia the Upper or Lignite division of the Dakota is reached. The bluffs on each side of the river are capped with Benton limestone. The coal shafts at Minersville pass through 70 feet of gypsiferous and saliferous shale, and reach two 9 inch veins of lignite, intercalated between beds of shale. On the bluffs above the mouths of the shafts, the Benton limestone rests, the intervening distance

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being occupied by the lower Benton shale. North of Minersville, on West creek, the overlying shales of limestone have been removed by erosion, leaving the saliferous shales exposed. The latter, by weathering, have formed a salt marsh of several hundred acres in extent. An upward pressure of the water in the underlying Dakota strata has caused, in many parts of the marsh, the shales to assume the character of muck. A well was bored in this marsh to a depth of 150 feet. The water, owing to a local dip of the underlying strata, rose above the surface to a height of 12 feet. A salt marsh twelve hundred acres in extent occupies the same horizon on Buffalo creek, northwest of Jamestown.

Benton.—In passing up the valley from Concordia to Jamestown, the last Dakota outcrop toward the southwest occurs a mile east of Jamestown. But farther toward the west, on Buffalo creek, outcrops of Dakota sandstone are of frequent occurrence. The surface of the country from Jamestown to Scottsville rises gradually, passing through the lower Benton formation. The Benton limestone is found everywhere capping the hills south of Jamestown, but disappears under a gradually thickening bed of the Ostrea shales as Scottsville is neared. All of the horizons of the Benton limestone are marked, but the Lincoln marble is less distinctly marked here than elsewhere, and in some outcrops seems to be wanting altogether. One outcrop shows seven layers of limestone varying in thickness from 2 to 9 inches, and intercalated with yellow rather closely textured shales, which contain the Ostrea congesta. From Scottsville to Beloit the slope of the country is toward the east and south. The Ostrea shales cover the surface, but many of the streams have cut down to the lower Benton, or the Upper Dakota. On West Asher creek in an exposure of 37 feet, are fourteen layers of Benton limestone, intercalated with shales. This limestone disappears under the Ostrea shales farther to the north. The limestone layers vary in thickness from 2 to 6 inches, and the shale beds from 6 inches to 2 feet. The most characteristic fossil of the limestone is the *Inoceramus liabatus.*

The Upper Dakota appears on the Solomon river at Beloit in a layer of sandstone from 2 to 3 feet in thickness, resting on a bed of blue colored shale. The sandstone strata is very fossiliferous.

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Over the surface of the shale and through the sandstone flows the water with which the city is supplied. The thin stratum of sandstone contains many of the fossil forms described by Meek as belonging to the Dakota, and later by Cragin as to the Mentor beds. The bluffs on each side of the Solomon river are covered with layers of Benton limestone. Near Solomon Rapids the following section may be observed, numbering from the bottom:

4th, Alternate layers of limestone and shale, 20 feet.

3d, Limestone, ½ foot, *Inoceramus liabatus.*

2d, Limestone (Lincoln Marble), 5 feet. Shark's teeth abundant.

1st, Bituminous shale, 40 feet.

The Lincoln marble contains abundant remains of shark's teeth, and is about the same thickness as that found fifteen miles south on Salt creek.

In a railroad cut at Glen Elder the following order of stratigraphy may be observed, numbering from the bottom:

10th, Soil, 2 feet.

9th, Limestone, 8 inches.

8th, Shale, 2 feet, yellow color, Ostrea congesta.

7th, Shale and limestone, alternate layers, 20 feet.

6th, Limestone, 4 inches, *Inoceramus* horizon.

5th, Shale, 6 feet.

4th, Limestone, 3 inches, white.

3d, 2 feet of shale, light blue, with *Inoceramus.*

2d, 4 inches of blue colored limestone resembling shale in texture.

1st, 10 feet of black shale closely textured.

Passing north from Glen Elder the Benton limestone which is found on the bluffs at that point rapidly disappearing under the gradually thickening Ostrea shales. These, in turn, disappear under the Blue Hill shales, which, twelve miles north, in the vicinity of Iona, are capped with the Ft. Hays limestone of the Niobrara. Farther toward the north, in the vicinity of Burr Oak, the Pteranodon beds rest on the Ft. Hays limestone.

South of Glen Elder the Benton limestone disappears under the Ostrea beds and outcroppings are seen only along the streams. The country is comparatively level, with a gradual slope, until the hills are reached, when there is a rapid ascent of from 100 to 200

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feet. The Blue Hills rest upon the Ostrea beds and are composed of the Blue Hill shale, capped by a layer of Ft. Hays limestone. The surface rises gradually from Glen Elder westward and the principal exposures are of the Ostrea shales. The Niobrara is reached near the confluence of Oak creek and the Solomon river numerous nodules of the Septaria horizon being found along its bed. In the neighborhood of Kirwin Pteranodon outcrops become more numerous. These Pteranodon beds contain *Inoceramus deformis* and *Ostrea congesta*. The plains marl of the Tertiary is also found to the north and south, but there are no outcrops of the mortar beds. Along the Solomon river the outcrops of the Pteranodon beds are numerous, but disappear under the Tertiary formation in Norton county.

The Tertiary.—The thickness of the Tertiary formation is measured by the depth of the weels. The mortar beds are found resting upon the chalk beds of the Niobrara in the eastern and central portions of the Tertiary area, and toward the western line of the state upon the shales of the Ft. Pierre formation. The mortar beds consist of coarse sands cemented by a calcium carbonate cement. The plains marl is composed principally of clay, mixed with calcium carbonate. The maximum thickness of the Tertiary is about three hundred feet. The composition of the water-bearing stratum differs with this locality. In many places it is a fine grained sand, while in other localities it is found to be either coarse gravel, or gravel and sand mixed. The mortar beds are wholly wanting in some places. In Jewell county a narrow tongue of the plains marl extends between the White Rock and the Republican to the eastern border of the county, but the mortar beds are not found in the county. The sheet water here flows over a stratum of the impervious shale, or chalk, the dip of the surface of which is toward the northeast and, consequently, the flow of water is in that direction. In many places where the streams have cut down below the level of the shale bed, the sheet water flows out in the form of springs.

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SECTION THROUGH THE CRETACEOUS FROM ABILENE TO THE COLORADO LINE. PLATE XXX, FIGURE 2.

On the bank of the Smoky Hill river, a few miles west of Abilene is the last westward outcrop of the Permian limestone. The formation above is sand from the disintegrated sandstone of the Dakota. It is very probable that the shales which did overlie the Permian limestone have been eroded away and the valley filled in with sand from the surrounding sandstone. Sheet water from the Dakota flows over the surface of the Permian limestone, and is reached in the valley at a depth of from 12 to 30 feet. Toward the west the surface rises gradually, and the outcrops are sand or loosely cemented sandstone. Between Solomon City and Salina, along the Smoky Hill valley, the soil presents the appearance of disintegrated Permian shale, but no outcrops occur. West of Salina, in the neighborhood of Mentor, small outcrops of sandy shale, intercalated with thin layers of sandstone occur. These sandstones contain, according to Meek, the following invertebrate forms: *Corbicula subtrigondis*, *Trigonarca salinaensis*, *Cardium kansasense*, *Cyrena dakotensis*, *Margaritans nebrasacenses*, *Mactra siuxensis*, *Tellina modesta*, *Pharella dakotensis*, etc.

Southwest of Mentor, in the vicinity of Salemsburg, is a row of hills called "The Smoky Hill Buttes." The Buttes are from 200 to 240 feet high, and consist of almost equal thicknesses of shale and sandstone. The sandstone occurs at the top. The shales are bluish white and contain iron ore nodules and traces of lignite. The character of the shales do not differ in any respect from those found in the Upper Dakota. A well one fourth mile north of the Buttes, reaches the Permian limestone after passing through a bed of red shale, which undoubtedly belongs to the Permian. On the hills west of Salina the red and white sandstone occur in the same horizon. Farther to the southwest, on Sharp's creek, in McPherson county, the red beds are overlaid by a bed of shales which contains a shell bed of undoubted Kiowa fossils. The cone in cone structure, so common in the Dakota area, lies above this shale bed. At Brookville a well 38 feet deep passes through 26 feet of blue shale and 12 feet of Permian limestone. Above the blue colored shales, on the surrounding hills, the Dakota sandstone occurs. In passing up the

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creek from Brookville to Arcola, we notice a narrow valley, bordered on each side by shale banks, capped with sandstone. One of these shale banks measured 100 feet, being composed of 80 feet of shale, overlaid by 20 feet of sandstone. No fossils were found, but gypsum crystals, so characteristic of Upper Dakota shales, were abundant. One mile west of Terra Cotta a 10 foot outcrop of white sandstone is covered by a 25 foot bed of yellow to purplish shales intercalated with thin layers of red or yellow sandstone, containing fossil leaves. A few rods to the south a hill 120 feet high is composed of alternate layers of sandstone and shale. Beginning at the top we find

4th. 25 feet of sandstone, yellowish brown.

3d. 25 feet of shales, with thin layers of sandstone.

2d. 10 feet of white sandstone, compact.

1st. 60 feet of shales and sandstone.

The country from Terra Cotta to Ellsworth is very broken and the land is used chiefly for grazing purposes. A well one and a half miles west of Terra Cotta passes through 40 feet of shale and sandstone to a layer of white sandstone through which the sheet water flows. A hill rises 60 feet above, and is capped with brown sandstone. A well one half mile south passed through a 6 inch vein of lignite in the same shale horizon.

Benton.—On the divide between Lincoln Center and Ellsworth, the first Benton limestone is found. It covers the Dakota sandstone hills along this divide and gradually approaches the Smoky Hill river. In Russell county it is found capping the first bluff of that river. South of the Smoky Hill river the line of contact between the Benton and Dakota passes off toward the southwest through the northern part of Barton county and across Pawnee county into Ford county to its southern limits. It passes toward the north through Lincoln, Mitchell, Cloud and Republic counties. The last Dakota outcrop on the Smoky Hill river is found near the confluence of Big creek in the western part of Russell county. From the mouth of Big creek to the mouth of the Hackberry, we pass through the divisions of the Benton, in their order, from lowest to the highest.

The Limestone Group.—The Benton limestone is found in many outcrops in the eastern part of Ellis and the western part of

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Russell counties. The Benton area may be recognized by the stone fence posts which are used in these localities. These fence posts are taken from the Fence-post horizon of the Benton group. The majority of the houses in this area are built of the Benton limestone.

The Ostrea Shales.—The Benton limestone is superseded by the Ostrea shales. These shales contain here, as elsewhere, the characteristic *Ostrea congesta*, and gypsum veins. Many outcrops occur along the river west of Mungor, and the surface of the country lies within the Ostrea horizon.

The Blue Hill Shale.—The Blue Hill shales which overlie the Ostrea shales occur in banks along the river from White Rock to the mouth of the Hackberry. They everywhere underlie a bed of Ft. Hays limestone. At Cedar Bluff, a 50 foot bed of Blue Hill shales is overlaid by a 30 foot bed of Fort Hays limestone. At the mouth of the Hackberry a 45 foot ledge of Ft. Hays limestone rests upon a bed of Blue Hill shales in which the Septaria concretions are embedded. The Septaria marks the dividing line between the Benton and Niobrara. Passing up the Hackberry we find the Ft. Hays limestone overlaid with chalk cliffs, varying from a few feet to 100 feet in thickness.

The Niobrara.—These chalk beds with the underlying Fort Hays limestone belong to the Niobrara formation. The outcrops of the chalk, or Pteranodon beds are almost continuous from a few miles above the mouth of the Hackberry to the western line of the state. The famous Castle Rock, see Plate VII, a single chalk mound 70 feet high, is located on the Hackberry about seven miles from its mouth. The Pteranodon beds occupy the country along the Smoky Hill river a distance of from one to three miles on each side from near the mouth of the Hackberry to Russell Springs. The hills back from the river are covered with the Tertiary formation. From Russell Springs to the state line the outcrops occur only at the river's banks and become less and less frequent as the line is neared.

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THE BENTON SECTION FROM BELOIT TO TIPTON. PLATE XXXI, FIGURE 1.

Starting at Beloit and passing to the southwest a distance of twenty five miles, we cross the exposed surface of each of the Benton divisions. The altitude of the Upper Dakota stratum at Beloit is 1350 feet, and the altitude of the highest Benton stratum on the Blue Hills is 1850 feet, making a difference in altitude, for the twenty five miles, of 500 feet. About 50 feet above the Upper Dakota horizon appears.

The Benton Limestone Group.—The Benton limestone group here consists of layers of compact white limestone, intercalated with bands of yellow shale. On the bluffs south of Beloit the Benton limestone appears and disappears a few miles back under the Ostrea shale. The surface soil rests upon the Ostrea shales from this point to the base of the Blue Hills.

The Ostrea Shales.—The Ostrea shales underlie the surface soil of the greater part of Mitchell, Jewell, Cloud, Lincoln and Russell counties. The upland areas of these counties have almost as fertile a soil as the bottom lands, a condition due largely to the Ostrea shales.

The Blue Hill Shales.—Near the base of the Blue Hills we find the lower horizon of the Blue Hill shale, and at the top the upper horizon containing the Septaria. A rather heavy deposit of Ft. Hays limestone rests upon the shales and prevents their erosion. The shales here do not differ from those found in other localities.

THE FORT PIERRE SECTION FROM ST. FRANCIS TO THE ARICKAREE RIVER. PLATE XXXII, FIGURE 1.

At St. Francis the Fort Pierre shales are very near the surface. St. Francis is located in the valley of the south fork of the Republican, which has cut down into the Tertiary a distance of from 150 to 200 feet. The surface of the Fort Pierre bed is very uneven at this point as indicated by the records of the wells. One well pierced the shale at 8 feet without reaching water, but another one only a few feet to the west, passed through 16 feet of sand and gravel without striking shale, and found abundance of water. Another well was dug, one half passing through shale the other half through sand.

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Water was found in this well but it was rendered brackish by contact with the shale. Another well pierced the Fort Pierre shales to a depth of nearly 200 feet. On passing from St. Francis towards the northwest we find the surface rising at first rather abruptly for 150 feet, then gradually to 250 feet above St. Francis. This difference in altitude is occupied by the Tertiary formation and the wells measure its thickness, for the sheet water flows over the surface of the Fort Pierre shales. At a distance of fifteen miles from St. Francis, on Hackberry creek, there is an abrupt descent of nearly 300 feet. Along the bank of this creek are numerous outcrops of Ft. Pierre shale. These shales are of a rusty yellow color and contain *Lucina occidentalis.* Here again the surface of these shales seems to present unevenness. For in several different sections of land the shales extend above the water level so that no water has been obtained. Six or eight miles to the northwest of the Hackberry, on one of the tributaries of the Arickaree, is a mound of shale upon which rests a single pinnacle of Tertiary grit rock. This mound has received the name "Chimney Rock." Similar mounds are called the "Barracks," "Devil's Cap" and "Fortification Hill." The shales of these mounds contain *Avicula fibrosa, Inoceramus crispii,* and *Baculites ovatus*, besides forms of *Ostrea*, *Corbula*, and *Scaphites*. The shales are of a brownish yellow color and contain rusty colored argillaceous nodules.

Devil's Cañon, which is a southern tributary of the Arickaree, descends by almost perpendicular banks a distance of 100 feet, the major part of which distance is occupied by the Ft. Pierre shales. The shales vary in color from a light yellow to black and the characteristic fossil is *Baculites ovatus.* The record of a few outcrops will serve to show the relative position of the Tertiary and Ft. Pierre strata.

East Cañon Section, numbering from the bottom:

4th, Plains marl, 6 feet (top).

3d, Mortar beds, 20 feet.

2d, Sand, 2 feet.

1st, Shales, 40 feet, *Baculites ovatus*, (bottom).

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Devil's Cañon Section:

3d, Shale, 100 feet, *Baculites ovatus*, (bottom).

2d, Mortar beds, 10 feet.

1st, Plains marl, 3 feet (top).

Hackberry Section:

3d, Plains marl, 20 feet (top).

2d, Sand, 3 feet.

1st, Shale, 30 feet, *Lucina occidentalis*, (bottom).

DAKOTA SECTION FROM BROOKVILE TO LITTLE TIMBER CREEK, Plate XXXI, Figure 2.

Resting on the Permian limestone at Brookville is a stratum of light blue colored shale. The shales appear in consecutive outcrops along the creek to Carneiro and westward. They are succeeded above not unfrequently by beds of red or yellow shale of much the same texture. The shales are entirely argillaceous, but above are of arenaceous shales intercalated with thin layers of sandrock. The hills northwest of Brookville are crowned with layers of sandstone. The following outcrops serve to show the stratigraphy:

First outcrop:

6th, Sandstone, 10 feet.

5th, Shales, 6 feet, yellow.

4th, Sandstone, 6 inches.

3d, Shales, light yellow, 4 feet.

2d, Sandstone, 4 inches.

1st, Blue shale, 30 feet (bottom).

Second outcrop:

6th, Sandstone, 6 feet (top).

5th, Shale, 3 feet, yellow.

4th, Sandstone, 3 inches.

3d, Shale, 4 feet, yellow to red.

2d, Sandstone, 5 inches.

1st, Shale, blue, 20 feet (bottom).

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Third outcrop:

4th, Sandstone, 4 feet.

3d, Shale, red, arenaceous.

2d, Sandstone, 1 foot.

1st, Shale, 22 feet, argillaceous, blue (bottom).

The stratigraphy of the Upper Dakota is given in the Little Timber section.

CORRELATION OF KANSAS AND COLORADO SECTIONS.

EASTERN COLORADO SECTION.

By G. K. Gilbert.*

Dakota.—Yellowish gray sandstone, some lower members nearly white, some upper members almost black, surface colors of lower, beautiful tints. Upper layers close textured, the lower beds more open. Lower layers sometimes approach conglomerate in character. Intervening shales usually light or dark gray, somewhat arenaceous. Contain shreds of vegetable tissue changed to coal. Some shales of a greenish brown color. Four fifths of formation sandstone, near mountains. Upper sandstone layers thin and alternate with shale. Average thickness, 300 feet.

Benton.—I. A laminated argillaceous or clayey shale with very little admixture of limy or sandy material. Exposure causes to form in small flakes. The middle third dark gray, some parts apparently bituminous, the lower and upper parts medium gray. Rows of calcareous concretions found at various levels. Thickness from 200 to 210 feet.

II. Consists of strata of limestone from 3 to 12 inches thick, separated by somewhat thicker shale beds. Limestone, pale bluish gray, fine grained and compact. Shales have a light gray color, laminated, contain more lime than the formations above or below. ***Inoceramus labiatus*** abundant. Thickness, 25 to 40 feet.

III. Shale, medium gray, the dominant color, the middle third darker. Finely laminated and argillaceous, arenaceous west, passing into sandstone, replaced farther east by purplish limestone, with

*Grove Karl Gilbert: The Underground Water of the Arkansas valley in Eastern Colorado. Seventeenth Annual Report of the Director U. S. Geological Survey, Washington, 1896.

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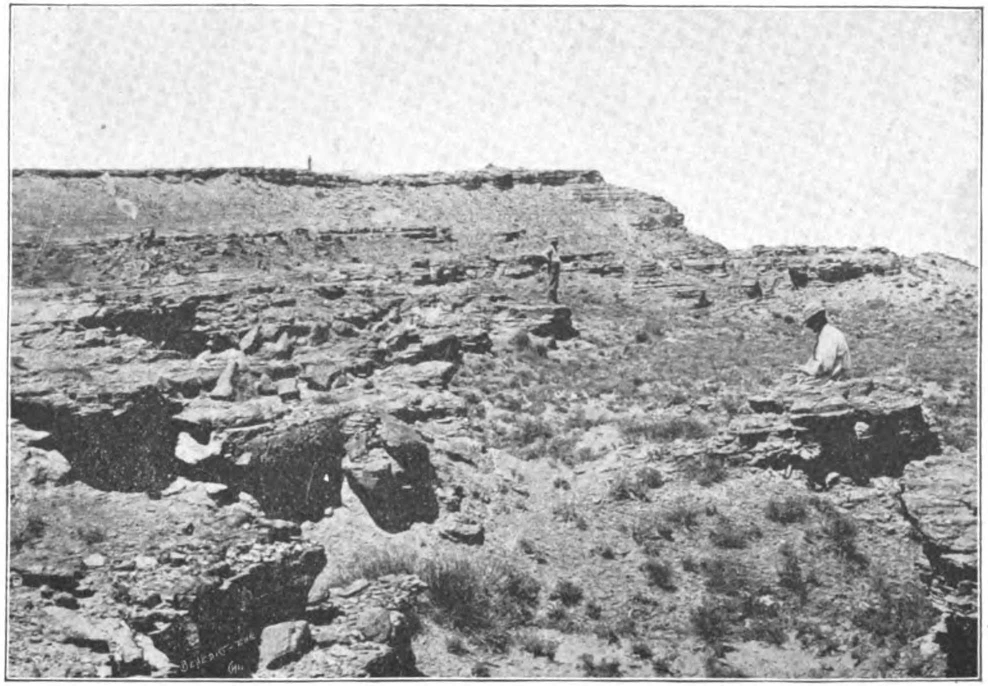

OUTCROPPING OF NIOBRARA CHALK, PLUM CREEK, GOVE COUNTY.
(Photographed by Williston.)
From Kan. Acad. Sci., vol. XIII.

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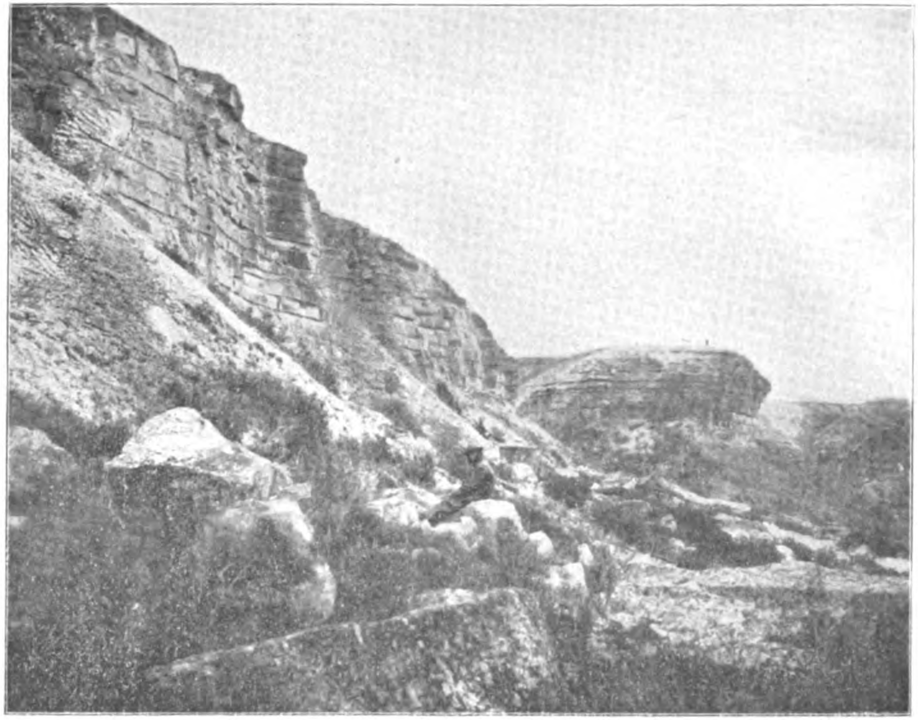

NIOBRARA BLUFFS, GOVE COUNTY.
(Photographed by Williston.)

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Prionocyclus wyomingensis somewhat abundant. From 20 to 50 feet from top of formation, many calcareous nodules ranging from a few inches to 5 feet in diameter, having a cone in cone structure and well formed calcite crystals on the inside. Thickness, 175 to 200 feet. Total thickness of Fort Benton, 400 to 450 feet.

Niobrara.--I. A series of limestones and calcareous shales with prevailing blue colors. Limestone series at base, 50 feet. Individual beds range from a few inches to 3 feet. Separated by layers of gray shales 1 or 2 inches thick. Limestone light gray color, creamy white on weathered surfaces, compact, rather fine grained. Lower layers contain nodules of iron sulphide. Characteristic fossils, *Inoceramus deformis* covered with *Ostrea congesta.* Upper limit of limestone passes into light gray limy shale, terminating in two layers of chalky limestone. Thicness, 175 feet.

II. Chiefly an argillaceous, laminated shale, dark gray colors, acquiring a yellow color and rougher texture on weathering. Thin plates of gypsum somewhat abundant, and oval fish scales and fish bones. Calcareous concretions at various horizons, broadly ellipsoidal, contain crystals of barite. Total thickness of formation, 500 feet.

Fort Pierre.—Deposits of laminated argillaceous shales not interrupted by sandstone, limestone or other hard layers. A lower zone of medium gray color, texture rough. Barren of fossils. Contains few concretions. Thickness, 400 or 500 feet.

A zone above characterized by abundance of ovoid concretions, carbonate of lime. Contain fossils. Thickness, 600 feet.

A zone above, shale, fine textured, medium gray color, with concretions larger than in zone below, contain fossils. Thickness, 1000 feet.

CENTRAL COLORADO SECTION.

By T. W. Stanton.*

Dakota.—A thin bed of conglomerate, composed of well rounded pebbles, united by a strong silicious cement; hard, usually gray sandstone, in two prominent benches separated by bands of fire clay; fossil plants abundant in some localities. 300 feet.

Benton.—Dark shales with frequent indications of fossilliferous

*T. W. Stanton: Colorado Formation and its Invertebrate Fauna, A. J. S. (4) vol. I, p. —, 1896.

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drab limestone in upper one third, *Inoceramus labiatus* and characteristic species, *Prionotropis* and *Woolgarii* occasional. 400-500 feet.

Niobrara.—Drab white limestone, containing *Inoceramus deformis*, *Inoceramus labiatus*, *Ostrea congesta*. Gray clay and buff siliceo-calcareous shales with *Ostrea congesta* and numerous scales.

CENTRAL AND WESTERN KANSAS SECTION, Plate XXVII.

By W. N. Logan.

Dakota.—Consists of an upper bed of saliferous and gypsiferous shales containing fossils and a thin bed of lignite. Total thickness, 50 feet. A central group of red and gray sandstone in several layers with intervening layers of leaves. Total thickness, 150 feet. A lower group of shales, variegated shales, argillaceous, contains the following forms: *Corbula* (?), *Trigonarca depressa*, *Modolia pedernalis*, *Cardium kansasense*, etc. Thickness of group, 300 feet.

Benton.—A limestone group intercalated with shales. The lower layers of limestone compact. Contain sharks' teeth. The upper layers of limestone thicker, white with yellow seam. Intervening shale argillaceous. Characteristic fossil, *Inoceramus labiatus*. Thickness 100 feet. A central group of variegated shales, argillaceous, contain quantities of *Ostrea congesta*. Thickness 150 feet. An upper group of black chaff-like shales, non-fossiliferous, with Septaria nodules in upper part. Thickness 100 feet. Total thickness of group 300 feet.

Niobrara.—A group of massive white limestone, thickness 50 or 60 feet. Comparatively soft, hardening somewhat on exposure. Almost devoid of fossils except minute organisms of which it is composed. An upper bed of chalk of variegated colors. Fossils, invertebrate and vertebrate, abundant. *Ostrea congesta* and *Inoceramus deformis* abundant, also pyrite nodules. Contains the minute organisms of true chalk. Thickness 250 to 300 feet. Total thickness of group 350 feet.

Fort Pierre.—Laminated argillaceous shales containing disc-like, argillaceous nodules. Nodules containing fossils. *Inoceramus* (Sp.). Shales dark or rusty in color. Shales contain *Baculites ovatus*, *Lucina occidentalis*, etc. Total thickness 200 feet.

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THE KANSAS NIOBRARA CRETACEOUS.

BY

S. W. WILLISTON.

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NIOBRARA CRETACEOUS.

The divisional line between the Benton and Niobrara Cretaceous beds is placed perhaps rather arbitrarily between the Blue Victoria of Cragin and the Fort Hays Beds. These latter strata vary somewhat in thickness—between fifty and sixty five or seventy feet—and are very persistent, both in lithological characters and in extent, reaching from Jewell county on the north to near Coolidge on the west, about ten miles north of the Arkansas river where it enters the state. It is composed of distinctly stratified, massive white chalk, or soft limestone, hardening somewhat on exposure. Its microscopical characters are similar to those of the upper Niobrara. The rocks have yielded a few vertebrate fossils, especially a large Plesiosaur in Jewell county. Mosasaurs and Pterodactyls seem to be wholly wanting. The invertebrate fossils are for the most part, Ostrea and Haploscapha, together with Inoceramus. They are usually, however, in a more or less comminuted condition. The Blue Hill shales beneath them are entirely conformable, apparently, and are very easily distinguished by the large and numerous septaria which they contain. Crystals of selenite are often abundant in the shale, as is so usually the case in the blue shaly deposits of the Cretaceous throughout the succeeding formations.

An escarpment of the Fort Hays beds at the mouth of Hackberry creek in Gove county has above it, and lying conformably, the less distinctly stratified chalk of the Upper Niobrara, which, though nearly barren in fossils, shows some of the characteristic fishes of that formation. The Fort Hays beds disappear beneath the upper beds some miles further west, near the post-office known as Ailanthus.

The thickness of the upper Niobrara beds, the Pteranodon Beds of Marsh, the Smoky Hill Beds of Cragin, are not less than 300 feet, and in all probability are nearly 400. At Elkader, in the valley of the

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Smoky Hill, repeated observations with a good barometer, gave 290 feet as their visible thickness. Wells in the vicinity had penetrated at least 40 feet more without reaching the Fort Hays beds, making in all 330 feet as the total thickness at this place. From this may be subtracted perhaps 25 feet as the amount of dip between the table land and the bottom of the valley, leaving over 300 feet. There are many difficulties in the way of an absolutely correct measurement of the outcrops. The rocks nowhere present clear lines of stratification over extended areas. A slight difference in the coloring or in the effects of weathering is all that can be relied upon. Furthermore, there are no extended areas of denudation where the general dip can be measured, and, in addition, there are numerous local disturbances which interfere with obseravtions on an extended scale.

These local disturbances are of more than passing interest. Nowhere have I seen faults of more than a few inches in extent, but frequently slight anticlinal or synclinal bendings are observable, the strata rarely dipping at an angle of fifteen or twenty degrees for a few hundred yards. The dip is north of east of from 10 to 20 feet per mile. This general dip is evident from the much more sloping banks of the valleys on the south side of all the rivers. The Fort Pierre beds of at least 100 feet in thickness are exposed on the North Fork of the Smoky Hill at McAllister at nearly the same elevation as the Fort Hays beds fifty miles south near Coolidge. For this reason I very much doubt the occurrence of Fort Pierre on the upper waters of Butte creek, and on the White Woman. If they should prove to be Fort Pierre then there must be a considerable non-conformity between the two formations. In the upper part of the Pteranodon Beds, or Ornithostoma beds as they must be called, since Pteranodon is a synonym of Ornithostoma,[1] one can not be unobservant of the numerous seams or veins of calcite standing nearly vertically. They run in all directions, but are usually nearly vertical. Their thickness often varies appreciably within short distances. Often they are not more than two or three inches in thickness, though not rarely reaching a thickness of a foot. In the large

1 Marsh in his latest published scheme of the geological epochs (American Journal Science, Dec. 1896, applies the name Pteranodon beds to the whole of the Colorado epoch!

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veins the calcite crystals are often very pure and perfect, intermixed more or less with crystals of barite. I have never observed foreign material in them. I doubt not that they represent simply cracks from drying, the crystals formed from infiltration. Possibly, however, the numerous local disturbances in the formation may indicate other causes. Plates XXXIII and XXXIV.

The material of which the Ornithostoma beds is composed is true chalk throughout their entire thickness. There is no marl, no sandstone or other material. The color varies, often within short distances from a light blue to a lavender, a white, a buff, a yellow or even a red. This color is, however, not confined to any horizon, save that the lower horizons have the color usually lighter blue or purer white. The yellow color with its varying shades of red where much exposed is confined to the upper beds, and the line of separation is very easily traced from the Smoky Hill east of Monument Rocks to the Saline north of Wa Keeney, and thence to the South Fork of the Solomon near Lenora. Not only is the color line easily traced, but the fossils contained in them are characteristic. For convenience I will call them the Hesperornis beds and the lower strata the Rudistes Beds. The impurities of the chalk vary from less than two to about ten per cent.

It is strange that the diyision into chalk and shale beds should have been persistently adhered to by writers on the Kansas Cretaceous since the time of Mudge. As I have already said more than once there is no such geolcgical distinction. As a usual thing the blue chalk and its weathered blue shales are found lower down in the valleys of the rivers or their tributaries, that is, where it is more or less saturated with water. Almost always borings for wells encounter the blue chalk, not white or yellow. Furthermore frequently one will observe the blue chalk changing to white and yellow as it passes outwards from the water courses, and this change may take place within a few yards distance. Pure white or yellow homogeneous chalk may be traced through every foot of the entire thickness from the Fort Hays to the Fort Pierre. I trust the myth of chalk and shale beds will not be again repeated. Wherever the chalk is of a deep blue color, when exposed it becomes shaly, loose and friable, broken up apparently by the action of the pyrites which such beds

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often contain in large quantities. Nodular concretions of pyrite are found in some localities in great abundance. Near Castle Rock, I remember seeing one such locality years ago, where the small round nodules, like grape shot, could have been gathered up by the wagon load. The decomposition of these nodules in the chalk produces an abundance of gypsum crystals, sometimes appearing on the surface as excellent selenite, but more often loosening the chalk into a friable dusty mass, injuring or destroying fossils that may be contained in it. Water percolating these shales becomes so thoroughly saturated with styptic salts as to be undrinkable.

Weathering has left the exposed chalk in many places eroded into picturesque objects. The famous Castle Rock, in the valley of the Hackberry about ten miles from its mouth is a lone pyramid several hundred yards from the upland. My first knowledge of the Rock dates from October 1874, and since that time I have seen but little evidence of erosion. In various places throughout the chalk beds of the Smoky Hill river I have observed marks scratched by myself eighteen years previously that appeared as clear almost as when they were made. The erosion in general is not nearly so rapid as one would think. The smooth, worn surfaces made on the projecting angles of many low cliffs by the buffaloes are still to be seen nearly as smooth as they were twenty years ago. I have seen buildings made of the chalk more than twenty years ago still remaining with but little indications of wear. One such building is at Manhattan, or was a year or two ago, erected by the Union Pacific Railroad company from blocks that had previously done like service in western Kansas. Its surfaces show but little effects of weathering. Erosion takes place much more rapidly by undermining than by direct abrasion of the surface. Blocks lying in their natural plane of stratification will strongly resist wear, but when once toppled over so as to bring the lines of stratification vertically or obliquely they go to pieces within a year or two.

One of the most famous landmarks of the Niobrara is the Monument Rocks on the Smoky Hill river. See Plate XXXVI. When I first saw them in 1874 the place had been recently abandoned as the stage station of the Overland stage route. A vertical crack in the main rock has deepened very much since that time and it is now

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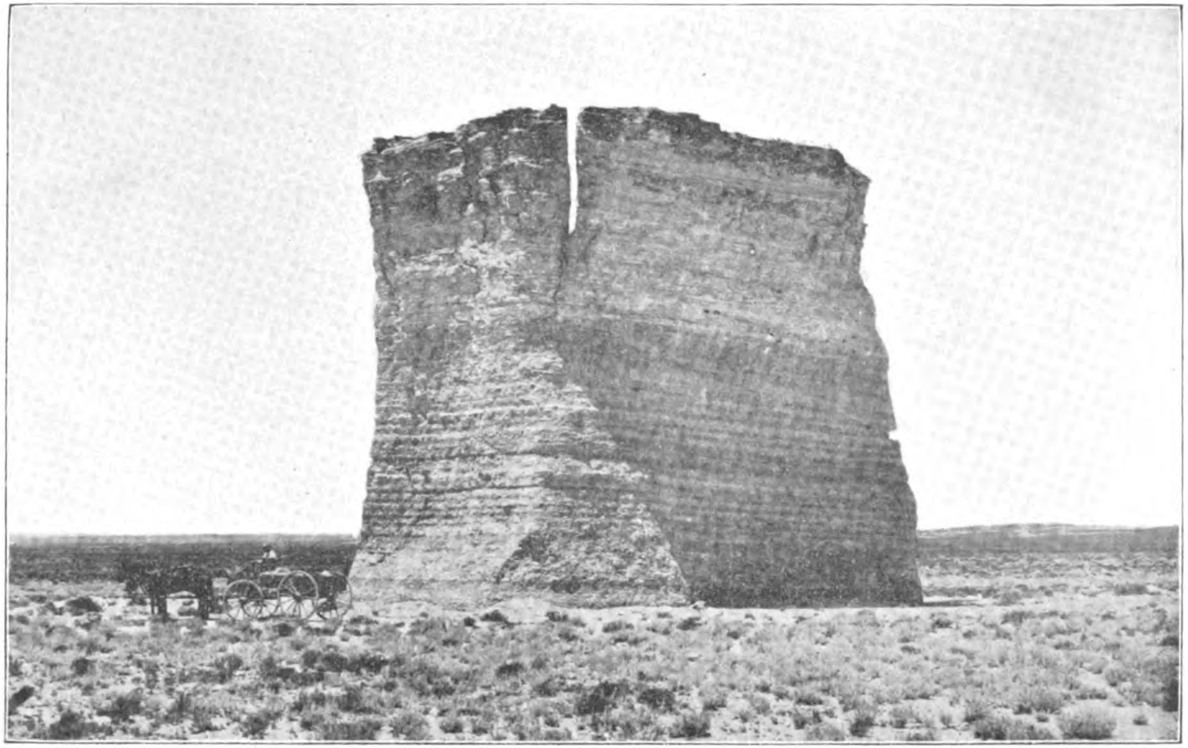

ONE OF MONUMENT ROCKS, NIOBRARA, SMOKY HILL VALLEY, GOVE COUNTY.
(Photographed by Williston.)
From Kan. Acad. Sci., vol. XIII.

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but a question of a few years when it will topple over and be demolished.

A few miles west of Elkader in the Smoky Hill valley there is another conspicuous area of rocks resembling at a distance the ruins of many castles, and known as "Castle City," a name given it by myself twenty years ago.

Notwithstanding the general homogeneousness of the Ornithostoma beds in their lithological characters throughout their whole extent, there is a very distinct difference between the upper and lower horizons in the fossils. I have never made any special study of the invertebrates, and not very extensive collections, but from the thirty or more months of explorations I have become fairly familiar with the invertebrate fauna. But very few collections have been studied by paleontologists, and I am sure that the field is rich for such explorations.

INVERTEBRATES.

Of the mollusca, Ostrea congesta is of very great abundance in the Rudistes beds, but much less common in the Hesperornis beds. They are found attached to other shells, and it may perhaps be in consequence of the fewness of large shells in the upper strata that their comparative rarity may be ascribed. Several species of Inoceramus are apparently found in all horizons, but the Haploscaphas are abundant only in the lower horizons, and I never have found H. grandis or those allied to that species in the upper horizons. On the Smoky Hill river near the mouth of the Hackberry there are places where these shells can be gathered by the wagon load, often distorted, but not rarely in extraordinary perfection. A very thin shelled Inoceramid measuring in the largest specimens forty four by forty six or eight inches is not rare over a large part of the exposures. Invariably where exposed, as they sometimes are in their entirety on low flat mounds of shale, they are broken into innumerable pieces. For that reason, I have never known of one being collected complete, or even partially complete. Notwithstanding their great size the shell substance is not more than an eighth of an inch in thickness. Fragments of Rudistes are not rare

—16

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in some places in the lowermost horizons and I have seen specimens near the Saline river northwest of Ft. Hays into which one could thrust his arm to his elbow. They are totally wanting in the Hesperornis beds.

Of the cephalopods, ammonites occur, though rarely, and almost always only impressions are found, with but little of the shell substance. Once or twice I have seen such impressions a foot in diameter. Belemnites are not common; one will scarcely find a specimen in a day's search anywhere in the beds. I have never observed any difference in their abundance in the different horizons.

One or more forms of chondrophorus dibranchiates are not at all rare, though almost always represented by unrecognizable fragments. The nature of these fragments was for years a great puzzle to me. They are usually but a few inches in length, and are of a glistening fibrous character. Recently a nearly complete specimen collected by Mr. H. T. Martin has shown them to belong to a large cuttle fish, apparently different from any described genus. The gladius measures about six inches in width by at least a foot in length, and has the sepia bag about two inches wide and an inch thick below it. The surface is smooth, lustrous, its material rather shaly and soft. I have observed the shafts most frequently in the Hesperonis beds, but they may be as abundant in the lower strata.

Baculites have never been seen in the Niobrara of Kansas so far as I am aware. The Baculites ovatus deposit at Sheridan, for a long time supposed to be from the Niobrara, I showed several years ago to belong in the Fort Pierre. Echinodermata are represented, so far as I am aware, by a single genus, Uintacrinus, first described from Kansas specimens.

All the specimens of which I have any knowledge have come from the vicinity of Elkader, in the valley of the Smoky Hill, in the horizon just below the yellow chalk. The largest colony hitherto discovered measures about seven feet in diameter and is now mounted in the University of Kansas museum. Another colony that may belong to a distinct species, but is more probably the young of socialis, is of about half the size of the larger colony and contains many hundred calyces of less than a third of the diameter of those of socialis. An examination of these specimens in the two colonies,

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and of another a little less large, shows many variations in the arrangements of the plates. Among them are specimens which can not be distinguished from U. westfalicus, which I believe to be identical with socialis.

It is not at all improbable that various species of crustacea will be found in the chalk. So far, however, I know of but a single one, a species of Cirrhiped figured in the accompanying Plate XXXVI, and which I will call Pollicipes Haworthi, after Professor Haworth, who discovered it near Gove City. I am not quite sure that it belongs in the genus Pollicipes, but I believe the photographic illustration will render its recognition tolerably certain. The specimen is attached to a shell of an Ostrea congesta. Lying close by it are two more specimens, one of them about one-third the linear dimensions of the one figured, the other about one half. Its horizon is the yellow chalk.

Fossil wood is occasionally found in the formation. A tree about thirty feet long was discovered near Elkader a year or two ago. In the bark of fossilized wood fragments of amber have several times been obtained. Near Russell Springs, Mr. H. L. Martin found a mass of pure charcoal imbedded in the chalk. I have never seen impressions of leaves. At several places in the upper part of the formation there occur thin seams filled with fragments of bones, scales, teeth and similar remains much broken up and comminuted. No coal, of any character has ever been discovered in the formation, and from the nature of the beds can not be expected.

VERTEBRATES.

The Niobrara deposits have been famous for the past twenty five years for the abundance, variety and perfection of its vertebrate remains. Many tons of fossils have been collected for various institutions and individuals, among which may be mentioned Yale and Harvard Universities, the University of Munich, and of Kansas, the National Museum, Professor Cope, etc. In his publications, Professor Marsh has stated, or left it to be inferred, that his personal explorations in this as in other fields were extensive and that the larger part of the fossils described by him were the results of these explorations. The actual fact is that since 1875, when my personal

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relations with Professor Marsh began, he himself did no field work, his knowledge of the formations being derived from a few transient and hasty visits to the different fields where his collectors were at work. Mr. Hatcher has already mentioned the extent of his personal explorations of the Laramie Cretaceous, which may be taken as a sample of all the field work done by himself. His reference to the personal dangers encountered from hostile Indians is amusing in the extreme to all those who know the facts. I think that I can say without fear of dispute by those who know the facts that Prof. Marsh never ran any greater danger from Indians than when he entertained Red Cloud at his home in New Haven. This statement I think is called for in justice to his collectors who did expose themselves to real and often imminent dangers from hostile Indians, but who were rarely or never mentioned by him in his publications. And of these mention should especially be made of the late Professor Mudge, the veteran Kansas geologist.

A correct list of the various species and genera of Kansas Cretaceous vertebrates can not yet be given. Many species have been described which will have to be abandoned. Our knowledge of the fishes is the most incomplete and fragmentary, notwithstanding the extraordinary abundance of their remains. I can say but very little regarding their distribution in the different beds, inasmuch as I have collected but few from the lower deposits. In general they are infrequent in the Rudistes beds, though remains are found quite to the Fort Hays deposits. A collection of species of Ptychodus teeth, in which the largest grinders measured three inches in length and which I have not yet succeeded in determining, was obtained some years ago from near the base. There were 140 in the set. The same species in isolated specimens, or in groups of a dozen or more has been obtained more recently from these beds, but the species has never yet been found in the Hesperonis bed.

Six genera of Mosasaurs have been referred to the Kansas Niobrara—Clidastes, Tylosaurus, Platecarpus, Holosaurus, Sironectes and Baptosaurus. The last two I have never seen, but, though Merriam's determination of Baptosaurus is based upon slight material, it seems authentic. The genus must occur very rarely and possibly comes from the Pierre deposits, which have always hereto-

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fore been confounded with the Niobrara. Sironectes I believe to be a doubtful genus, and Holosaurus is not distinct from Platecarpus.

The distribution of these genera is of some interest. In all my collections I have yet to learn of a single specimen of Clidastes being found in the Rudistes beds, or indeed anywhere save near the top of the formation. The other genera extend to within a hundred feet of the base of the Ornithostoma beds, and possibly lower down. An examination of more material may perhaps show a restricted range in the species. I need not call the attention of future collectors to the importance of locating the horizon of specimens more accurately than has been done heretofore. Of the Pterodactyls two genera and eight species have been ascribed to Kansas. In the examination of the extensive material in the University of Kansas I so far find evidence of but five species. The largest is Ornithostoma ingens, of which O. umbrosus is a synonym. This species measured in life eighteen and one half feet from tip to tip of wings. A restoration now completed will shortly be published. This species is by far the most common in the formation, and almost the only one that I have found far down in the deposits. This does not necessarily mean that the smaller species are later than the large one, but rather that the lower deposits mean a deeper sea and more remoteness of the shore line. Nyctodactylus has been found in the yellow chalk only.

The turtles are especially characteristic of the uppermost deposits. Near the upper part of the yellow chalk remains of various species are common; in the lower strata they are rarely or never found.

The Plesiosaurs occur in about equal abundance throughout the deposits. They are at best comparatively rare, but are relatively far more abundant in the lower beds.

Finally the toothed birds are, I believe, confined to the upper beds. The only possible exception is that of the type of Icthyornis which was found by Mudge near Bread-bowl mound in Rooks county.

In general, vertebrate fossils of all kinds are far more abundant, at least ten times so, in the yellow beds than in the white beds

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below them. I believe that this is due to shallower water and nearer shore lines.

The recognition of the Pierre deposits within Kansas was first made by myself in 1891. I recognized then only the deposits on the North Fork of the Smoky Hill, which had previously been considered to be Niobrara. Vertebrate fossils from this locality had been collected by Mudge and Marsh, and it is not at all impossible that some of them have been described as Niobraran. I found in 1891 two species of saurians at this place, both of which are different from any that I know below. Later a specimen of Clidastes, obtained by Mr. Sternberg from this same locality, was described by me as C. Westii. Another species of Clidastes I have since seen from Colorado. So far this is the only genus of vertebrates from the Pierre that is known to occur in the Niobrara, though the turtle Arcalon of Wieland seem *very* closely allied to Protostega. The genus Mosasaurus of the Pierre is closely allied to Clidastes, yet sufficiently distinct to be separated. Tylosaurus is replaced by a peculiar genus, of which a brief description was given by myself in the Kansas University Quarterly, vol. I, p. 10. Further study shows that the genus is entitled to a generic name, for which I propose *Brachysaurus*.

It can not yet be said that the Pierre deposits are conformable in Kansas with the Niobrara. Hay has recorded the beds from Butte Creek and the White Woman, but I believe that he is in error in these references. He also recognized the beds in Cheyenne county as Fort Pierre, a determination confirmed by Mr. Logan in this Report.

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Physical Properties of the Tertiary.

BY

ERASMUS HAWORTH.

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PHYSICAL PROPERTIES OF THE TERTIARY.

CONDITIONS AT BEGINNING OF TERTIARY TIME.

At the beginning of Tertiary time the American continent seems to have had almost the size and shape it now has excepting a narrow border along the Atlantic and Gulf lines and a small area extending up the Mississippi to near the mouth of the Ohio river. The great inland sea area which existed throughout Cretaceous times between the Rocky mountains and the Mississippi valley had been changed to dry land. The accompanying map, Plate XXV, shows the geography of the United States at the beginning of Tertiary time. It was the whole of the United States minus the parts marked as Tertiary lying along the Gulf of Mexico, the lower Mississippi valley, and the Atlantic ocean. The great inland Tertiary area, as will shortly be seen, was dry land, while the Tertiary areas along the ocean boundaries were still under water.

The degree of elevation which occurred in the west central part of America at the close of Cretaceous time is difficult to determine with exactness. It is probable, however, that the Rocky mountain area was elevated permanently above ocean water and to a sufficient hight to give a decided drainage in various directions.

The Tertiary of America may well be divided into two classes; one, which was deposited under ocean water on the Atlantic and Gulf border areas; and another which was deposited by rivers and under lake water on the great inland area, including all of the inland plains Tertiary and the various Tertiary formations in different places in the Cordilleras. The elevation of the mountainous area was therefore sufficient to cause a great spread of mountain debris in many directions. The lesser areas in the valleys of the mountains were occupied probably by fresh water lakes, and as the descent fom the mountain sides was rapid the accumulation of sedi-

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ment was correspondingly rapid and the filling in process carried to a great extent.

Eastward from the mountains the material was likewise carried in vast quantities and spread out over the present plains area. It was not accumulated to such great depths, the thickness rarely exceeding 1000 feet, while over the western part of Kansas we nowhere find it at the present time more than 350 feet thick. The mountainous elevation was probably less during early Tertiary times than at present. The drainage which carried the debris eastward seems to have been fluctuating in character, at times flowing with a strong current, as is shown by the coarseness of the material carried, and at other times moving with a mild current, so that only the finer sediments could be carried and deposited.

The floor upon which the Tertiary material was deposited was principally a Cretaceous floor, one which doubtless had been elevated above the ocean water for a sufficient time over the greater part of the area to have its surface greatly corroded by the weathering agents until it presented an irregular surface. If the corrasion of the Cretaceous surface occurred after the entire inland ocean was destroyed the drainage producing such a corrasion must have been eastward. It is difficult to understand why such a drainage would not carry debris from the mountainous areas the same as a similar drainage did at a somewhat later period. It seems probable therefore that the eastward movement of the debris began about the time the corrasion of the Cretaceous surface began, and that the two processes were carried on to a great extent simultaneously. Possibly the particular character of the surface drainage was such that relatively large areas on the plains received no material from the mountains for a time, corresponding somewhat to the present condition with so many streams rising farther east than the limits of the mountains. In this way sediments may have been forming over certain parts of the plains during the earlier Tertiary or Eocene period, a corrasion of the surface of other portions taking place at the same time. By slight change of elevation in the plains, or in the mountains, at a somewhat later date the conditions could have been changed so that the areas before disconnected from the moun-

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tains were now connected with them, and the debris likewise spread over their surface.

From paleontologic evidence it seems that the northern part of the plains Tertiary, or that in the Dakotas and northern Nebraska, is older than the lowest Tertiary farther south in Kansas and the Indian Territory. It is possible that the explanation for such a condition is that just given. In this way the great corrasion of the surface of the Cretaceous in Kansas could have occurred during the time that the accumulations of the earlier Tertiary materials were forming in northern Nebraska and the Dakotas and possibly elsewhere in the mountainous areas. Near the beginning of the Neocene period changes were brought about in one way or another so that the drainage from the mountains spread sediments continuously from the Dakota-Nebraska area over the western part of Kansas and into the Indian Territory and farther south in Texas, reaching even almost as far as the Rio Grande.

CHARACTER OF THE TERTIARY MATERIAL IN KANSAS.

The Tertiary material in Kansas is composed of gravel, sand, black sand, clay, and silt, with a small amount of material usually called "volcanic ash."

The Gravel.—The gravel is pebbles varying in size from four or five inches in diameter to the finest of pebbles, grading into the sand. Their character is such that no doubt can be entertained regarding their former home. They are composed of granite, syanite, porphyry, andesite, rhyolite, basalt, and not infrequently of pure quartz. In the granite pebbles the feldspars are generally of a reddish hue, but frequently the lighter colored ones seem to abound.

It has been thought that the general character of the pebbles was different in different parts of the state; that those in the northern part differ materially from those in the south with intermediate grades between. During the two summers of active field work in the Tertiary areas of the west the writer has paid considerable attention to this phase of the subject, and at the present can only say that thus far variations in character of the pebbles do not seem to be general, but only local, and probably accidental. He is not familiar with the crystalline rocks of the mountainous area in

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detail. It is possible that if one were a careful study of the pebbles in Kansas might show a corresponding variation in character, so that an estimate could be made regarding this particular part of the mountainous area from which such pebbles were derived. But without such a knowledge of the crystalline rocks to the west it is doubtful if a discrimination between the character of the material in the pebbles found in the different parts of western Kansas will have any considerable value. Reddish feldspar is found along the northern border of the state, and in every county from the north line to the south. Dark colored material, which probably was horneblend or black mica, is associated with the feldspars in every part of the state. Quartz grains also are intimately associated with the feldspars throughout the whole area. Occasional pebbles of basic rock are likewise found promiscuously scattered from the north line of the state to the south. Free quartz, or pebbles composed entirely of quartz, are found here and there lying in the sand and gravel beds beside the granite pebbles.

At different periods of our investigation in the west it almost seemed that such a variation in the character of the gravel could be found. Doctor Adams, who has spent two summers in this country, reported in the autumn of 1895 that he was pretty well satisfied such a distinction between the character of the pebbles north of the Arkansas river and those south of it could be made, and might be of value. But the field work during the summer of 1896 largely dispelled this idea. The individual gravel beds lying to the west and southwest of Meade in Meade county are composed essentially of the same gravel as those on the north bluffs of the Arkansas river, and of those much farther to the north, even almost all the way to the north side of the state. We may therefore dismiss the idea that any one can discriminate between the character of the crystalline gravels in different parts of western Kansas, without a detailed knowledge of the crystalline rocks to the west so that a relatively obscure yet essential distinction might be noticed in the gravels corresponding to similar distinctions in the rocks of the Rocky mountains. Students of petrography will appreciate this point, for they well understand that such distinctions sometimes are important between different classes of rock, distinctions which are

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so obscure in general character that one unfamiliar with them would not be able to make a corresponding distinction between the gravels produced from them.

The Sand.—The character of the sand is similar to that of the gravel. It is much more largely composed of quartz, as sand usually is principally pure quartz. But perhaps it would be difficult to gather a handful of the sand anywhere in the whole Tertiary area of Kansas which did not show minute granules of feldspar and other constituents of the rocks of the mountainous areas to the west. The sand grains are generally rounded to a great extent implying long distances of travel. As regards degree of division the sands vary throughout almost the entire scale. On the one hand they grade into the finer gravel with no line of demarcation between. On the other hand they reach the finest granules microscopic in dimension, and are so intermingled with the fine particles of the clay and silt that frequently one can hardly distinguish between them without washing the mass to get rid of the floating clay particles. The sand is sometimes quite well bedded when found in place, but often is almost structureless. Cross bedding is a common condition to observe, as is shown in Plate XXXVIII taken from a bluff near Dodge City along the Arkansas river.

Black Sand.—Almost everywhere over the Tertiary one frequently finds small accumulations of black sand which have been slightly segregated by the rainwater carrying away the finer materials and leaving these little granules behind. They are composed almost entirely of grains of black oxide of iron, the greater portion of which are granules of magnetite, as can readily be shown by placing them within reach of a magnet. Usually about one third or one fourth of the volume will not be attracted by the magnet, and are doubtless particles of dark colored hematite. These little granules are originally intimately mixed with the clay and the silt in the upper portions of the deposit so that they are entirely unobservable under ordinary conditions. But when the rains come the little rivulets of water on the hillsides carry the lighter and finer clay and silts away and wash the iron oxide grains into little streaks which lodge here and there in the rock or on the hillside or are spread out in the fields and attract attention. Unfortunately the

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general appearance of this material is the same as that of the black sands so frequently found in connection with the placer gold mines of the west. In fact they are probably the same material. But being so much lighter than the gold dust which is associated with them in gold mining localities they have been carried to the east from their original home and have gone far beyond the limits of the gold which is mixed with the sand in gold mining localities. Many a citizen of western Kansas has had his expectations wrongfully excited on account of his superficial knowledge of the association of this black sand with gold dust in placer mines. He has neglected to consider that the higher specific gravity of the particles of gold would cause them to lodge much nearer the mountain side than these granules of iron oxide are found. As the result of this he has expected that the presence of the iron oxide implied the presence of gold.

Many samples of black sand have been sent to the University for examination, not one of which had the slightest trace of gold. Usually it is sufficient to make an examination with the microscope. But different individuals have so insisted on an assay that occasional samples of the black sand from western Kansas have been assayed for gold. Such assays have beeen made in the chemical laboratory of the University, and have invariably resulted in finding no trace of gold.

Clay and Silt.—The clay and silt vary in character from place to place and at different depths. Occasionally almost pure masses of clay are found, beds almost entirely free from admixtures of sand, clay with a high degree of plasticity, and which in every respect resembles the purest character of clay known, excepting sufficient impurities to modify its color. Frequently such masses of clay seem to be colored with decaying organic matter, as though during its accumulation organic matter in one form or another was present at least in limited quantities. Elsewhere the color of the clay seems to indicate the absence of organic matter of any kind.

Volcanic Ash.—In a few localities a material exists in small quantity throughout the Tertiary of Kansas, which for years has been called "volcanic ash." Under the microscope it appears to be composed of irregularly outlined thin flakes of a glass-like sub-

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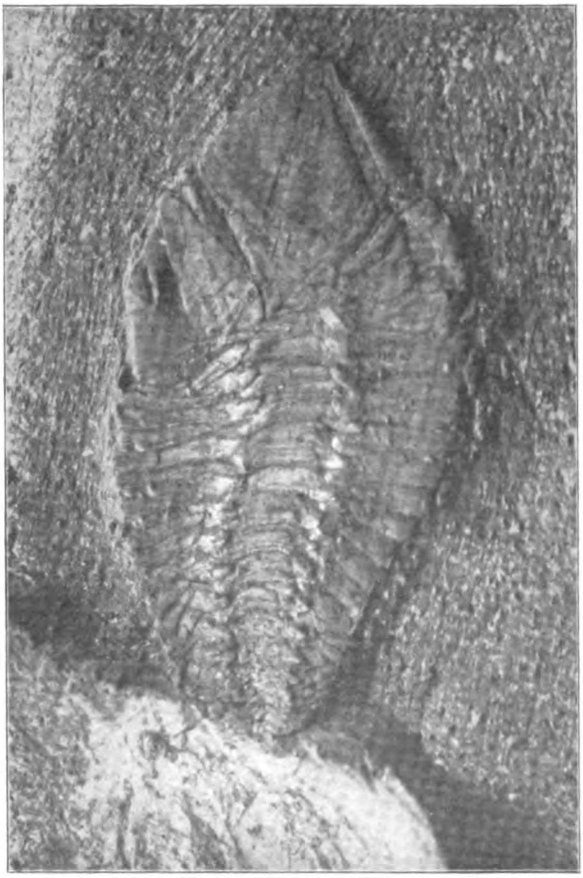

POLLICIPES HAWORTHI WILL. X 3.4.
(Photographed by Williston, 1896.)

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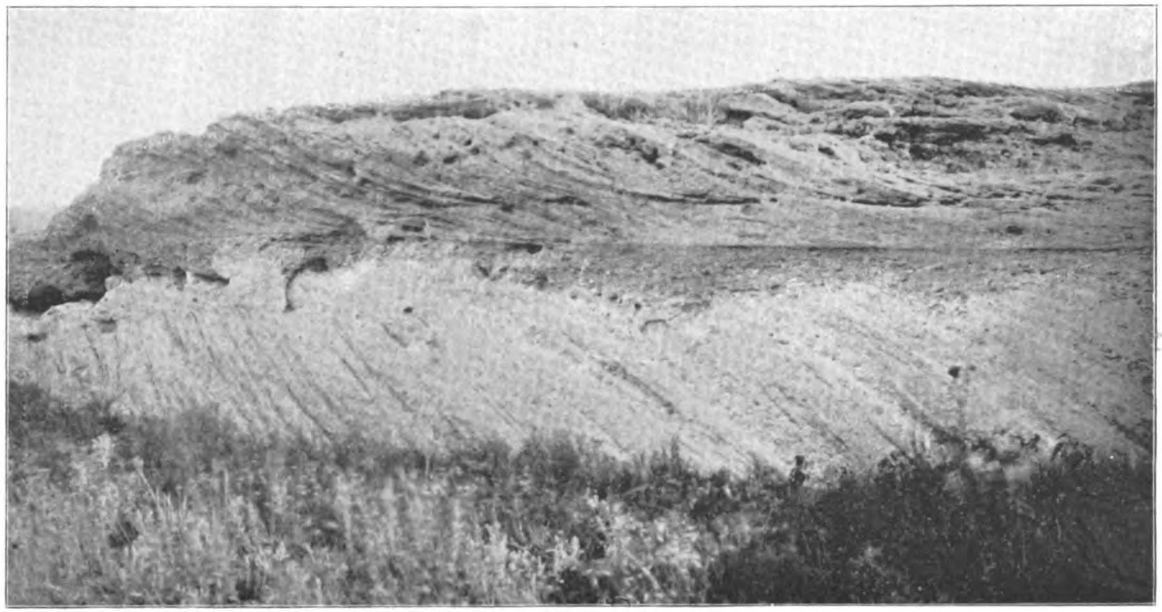

CROSS-BEDDING IN TERTIARY SANDSTONE, THE "MORTAR BEDS," NORTH BANK OF ARKANSAS RIVER, ELEVEN MILES WEST OF DODGE CITY. TOTAL LENGTH ABOUT FIFTEEN FEET.
(Photographed by Haworth, 1895.)

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stance. When examined with polarized light it is almost entirely free from double refraction, in which respect it further resembles glass. The color of this material is variable passing from almost a pure white to various shades of light buff. It is frequently well stratified, sometimes even to minute proportions. The lesser stratification surfaces occasionally have most delicate and beautiful wave lines marked in them, such as might be produced by gentle wave action in water or wind action upon a dry surface of the material. Plate XXXIX represents the ash as it appears well stratified along the south bank of a tributary to Spring creek about a mile west of Meade. The upper layer, 4 feet thick or more, is very weakly cemented, yet it has more firmness than the lower beds which are gradually blown away by the winds leaving a slight projection of the upper and heavier beds. The lower beds gradually disappear to the right, near where the man is standing, and have their stratification lines converging in that direction as is faintly shown in the plate. Elsewhere the ash rarely if ever shows such prominent stratification lines.

The localities at which this volcanic ash is found are relatively numerous, but seem to be entirely disconnected. What seems to be the same material is found in different places in Nebraska, in a dozen or more counties in western Kansas, and westward into Colorado. Sometimes it covers but a few square rods in area, and rarely more than a few acres. Cragin[1] has suggested that these isolated deposits be considered as a definite terrane and has offered the name *Pearlette Ash* for it, the name referring to an abandoned country post-office on the plains of Meade county. There is no evidence of any relation between the different isolated deposits excepting as it seems probable to some that they must have been formed at about the same time on account of their probable origin as implied by the name volcanic ash. As it is yet an open question regarding the true nature of the material, and much more so regarding its mode of deposition, it is hardly desirable to draw many conclusions from their supposed origin. It is correspondingly less desirable to group the little isolated patches together and assign them to a geologic terrane including nothing else.

1 Prof. F. W. Cragin, The Pearlette Ash; Colorado College Studies, Vol. VI, p. 54, Colorado Springs, March 1896.

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STRUCTURAL RELATIONS OF TERTIARY MATERIALS.

The structural relations of the different Tertiary materials are far from regular. It is doubtful if there can be any definite stratigraphic relations established covering a considerable scope of country. A description of the conditions will first be given, and later a discussion of the same.

The gravel and sand are frequently cemented into a moderately firm rock by the presence of a variable amount of a calcium carbonate cement. This is sometimes found in the clay as well, but it is most abundant in the sand and gravel, producing a sort of sandstone or conglomerate to which the name mortar beds or "grit" is generally applied. Some of the varieties of this are the so-called "natural mortar," which is extensively used throughout the west for making a mortar to plaster with and to roof houses. These mortar bed horizons are prominent features in many places, and constitute the only hard and resisting strata in the Tertiary. The idea so frequently expressed that they are located near the base of the Tertiary is correct for some localities, but incorrect for others.

Evidence from Surface Conditions.—Along the Prairie Dog from near its source to the eastern limits of the Tertiary the mortar beds are frequently found, often in a high degree of development. They frequently lie near the tops of the hills. On the south bank of the stream at Clayton they furnish two well defined horizons, the uppermost one near the top of the hill, and often 20 or 30 feet thick. Below these we have 20 or 30 feet of clay and sand which is poorly cemented, and then the second mortar beds horizon which will average 20 feet or more in thickness. There is so much difference between the hard and soft layers that weathering has given the bluffs a terraced appearance. The mortar bed layers contain much gravel and ordinary sand. The exact distance below them to the base of the Tertiary is not known, but it must be 50 feet or more.

On the high divides both north and south of Stockton, in Rooks county, the Tertiary covers the country. The very summits of the highest hills are capped with the mortar beds which in this locality, particularly to the north of Stockton, is cemented with a silicious cement until the rock has been changed almost into a quartzite. The

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thickness of the Tertiary here is not definitely known, but probably is in the neighborhood of 100 feet.

Southward from these localities along the different tributaries of the Smoky the mortar beds are frequently found at the summit of the hills. They are as frequently found, however, in intermediate positions, and possibly at or near the base in many instances. It is certain, however, that in many cases they are found near the uppermost surface of the Tertiary in much greater abundance than near the base. Along the Pawnee and its different tributaries well developed forms of the mortar beds are frequently found, sometimes occupying one horizon, and at other times another.

Along the Buckner in the southwest part of Hodgeman county the sand and gravel are as firmly cemented as at any place known to the writer. Here they form a tolerably solid rock which lies at the top of the bluffs on the south side of the Buckner. They are in beds from 10 to 20 feet thick, varying much more than ordinary sandstone beds do. Below them in this locality the bluffs are composed of a looser and finer material. At other places along the Saw Log near by the mortar beds are found near the bottom of the Tertiary, and not infrequently resting immediately upon the Benton limestone.

The north bluff-line of the Arkansas river from some distance below Dodge City westward almost to Garden City is protected by a well developed mass of mortar beds. Throughout the most of this distance three distinct layers of mortar beds can be traced, while in other places four or more may be found. They are composed of cemented sand and coarse gravel, and are separated from each other by beds of clay and fine sand. The weathering processes wear away the soft clay beds more rapidly than the mortar beds producing a series of narrow terraces along the bluffs similar to those generally observed in places where the limestones and shales alternate with each other, as is so frequently found in the eastern part of the state.

South of the Arkansas river but little of the mortar beds material it to be seen until the vicinity of Crooked creek and the Cimarron is reached. Here we have the same lack of regularity so noticeable elsewhere. The most pronounced form of the mortar beds are often found at the very summit of the bluffs, but by no means always so. In other places they occur midway up the bluff,

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and not infrequently near the base. The bluffs of Crooked creek below Meade are good examples of this. On the eastern side of the creek they are very rugged, with frequent instances of mortar beds being well developed, but by no means do they form a constant stratum continuously along the bluff. On the western side the bluff line is not so abrupt, and consequently there is not so good an opportunity for observing the mortar beds masses. To the southwest of Meade along the upper portion of Spring creek, however, some of the hilltops are very distinct and the erosive forms are significant of hills with a protecting cap of hard material covering softer materials. These can well be studied from the Meade topographic sheet. A few of these hills are particularly noteworthy. On the north bluff of Spring creek about four miles above Crooked creek valley the mortar beds are found lying at the summit of the hill. The sandy clay underneath is worn away so that quite frequently the mortar beds rock projects several feet, forming an overhanging cliff. South of Spring creek a similar condition obtains. Hill point after hill point stands out in the landscape as prominent features, on the top of which a horizontal mass of mortar beds rock serves as a protection to the soft and easily eroded sandy clays beneath.

Along the Cimarron river from some distance above Arkalon to where the river encounters the Red-Beds near Englewood its valley is cut downward into the broad plain to a depth of nearly 200 feet. As one stands on a prominent point on either side of the valley and looks up and down the stream it is easy to see the line of light colored mortar beds lying almost at the summit of the bluffs, with the darker colored shales and sands beneath. A more careful examination shows that for many miles along the stream relatively firm rock covers the topmost part of the bluffs, and is largely responsible for the precipitous character so pronounced on either side of the river around Arkalon. Beneath the mortar beds is found masses of sandy clay which constitutes the main mass of the bluffs. There is strong correspondence between the characters here and that shown in the well at Liberal soon to be described, in that the coarsest gravel is found near the surface.

In summarizing the above observations it may be concluded that

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there is a lack of regularity in the position of any one kind of material, whether gravel, or sand, or clay, or the cemented product called mortar beds.

Evidence from Deep Wells.—During the last two years the Kansas State Board of Irrigation has sunk twenty wells in western Kansas, the greater portion of which are confined to the Tertiary. One of the provisions in the contract for the drilling of each well was that a carefully selected and accurately labeled suite of samples was to be preserved and delivered to the Board, such samples to be taken with sufficient frequency to accurately represent the character of the material passed through. These samples from the different wells were turned over to the writer by the Board of Irrigation and have been carefully examined. This is the first time one has been able to examine the Tertiary materials at any considerable depth below the surface, excepting where they are found along the bluff lines of the various drainage streams. They are therefore of more than ordinary importance, and are worthy of considerable notice in this connection.

It was found that little relation existed between the distance from the surface and the size of the gravel. Gravel beds of a considerable degree of coarseness were frequently found near the surface, and the finest sand, and clay, and silt were not infrequently found near the base of the Tertiary. There was such an irregularity of position shown with reference to any one material, and such a lack of definite relation between the different kinds of material, that it seems as though but little if any dependence can be placed in any older classifications. In order to show what the conditions are the sections of a number of wells will be given.

State well No. 1, Hamilton county, on high uplands about six miles nearly north of Kendall:

No.		Feet.
1.—	8 feet soil and light colored subsoil	8
2.—	6 ft. clay with large amount of calcareous cement	14
3.—	57 ft. sand and gravel, with gravel somewhat irregularly placed	71
4.—	28 ft. sandy clay with much calcareous cement	99
5.—	6 ft. sand and coarse gravel	105
6.—	5 ft. sandy clay with calcareous cement	110
7.—	20 ft. sandy clay	130

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No.	Feet.
8.—12 ft. sand and gravel	142
9.—13 ft. yellow sand	155
10.— 9 ft. sand and gravel	164
11.— 6 ft. clay	170
12.—22 ft. water-bearing sand and gravel	192
13.— 4 ft. yellow clay and fine sand to bottom of well	196

It will be noted in this well that a large amount of gravel was met with at less than 75 feet from the surface below which was a sandy clay cemented with calcareous cement, then another layer of sand and gravel, then again sandy clay with calcareous cement, below these a 20 foot bed of sandy clay, then another stratum of coarse sand and gravel, below which was found yellow sand, again sand and gravel, and then a layer of clay which was almost entirely free of sand. Below all these we have 22 feet of water-bearing sand and gravel with a sandy clay in the bottom of the well. The well is located on the high uplands about 180 feet above the level of the river valley to the south. Along the bluffs on the north side of the river at this place and farther west the Benton formation is exposed to the surface. To the west the Benton is shown along the banks of different ravines entering from the north. The materials of the Tertiary where exposed along the bluff are frequently cemented by calcium carbonate into a relatively firm mass of rock called Tertiary grit, or mortar beds. But when the well itself is reached it is noticed that there was practically no calcareous cement found more than 110 feet from the surface, although the well went to a depth of 196 feet. We therefore have nothing in this well to imply that the coarse material lies at the bottom and the finer at the top.

Well No. 2, located in the sandhills on the south side of the Arkansas river in Gray county, about three miles southwest of Cimarron. Professor Hay, in his section along the 102d meridian, has represented the mortar beds as being very prominent all the way south from the Arkansas river to the south line of the state. This well is a short distance to the east of the line of his section, but is the only well the state has put down in the sandhills. In it we have:

No.	Feet.
1.—17 ft. surface sand	17
2.— 2 ft. clay	19
3.— 5 ft. sand	24

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No.		Feet.
4.—	5 ft. clay	29
5.—	9 ft. sand and gravel	38
6.—	3 ft. clay and gravel	41
7.—	20 ft. water-bearing sand and gravel, in which some of the gravel were 4 in. or more in diameter	61

At this place there seems to be a total absence of any calcareous cementing material which is so abundant in the bluffs on the north side of the river at about the same altitude.

Well No. 3, located in Grant county on the high divide between the two Cimarron rivers, about six miles south of Ulysses. It reached a depth of 231 feet, passing about 12 or 13 feet into the Cretaceous. In it we have:

No.		Feet.
1.—	2 ft. soil	2
2.—	91 ft. sandy clay partially cemented with calcareous cement. Throughout this distance there are a number of changes of color, and slight changes in the degree of coarseness, but the clay is found uninterruptedly throughout the whole distance	93
3.—	31 ft. red sandy clay. This differs from the first in no essential respect excepting in color	124
4.—	20 ft. water-bearing sandy clay. This mass of clay is no richer in sand than the clay in No. 1. It is described by the well driller as joint clay, and produced a considerable amount of water	144
5.—	4 ft. dry sandy clay	148
6.—	5 ft. water-bearing sand. This sand stratum is entirely free from calcareous cement, and is sand of an ordinary degree of coarseness	153
7.—	4 ft. sandy clay which is dry	157
8.—	13 ft. water-bearing sandy clay similar in all essential particulars with the sandy clays mentioned above	170
9.—	3 ft. water-bearing coarse sand	173
10.—	12 ft. red clay which was reported to be dry	185
11.—	27 ft. water-bearing sandy clay	212
12.—	8 ft. sand somewhat cemented with calcareous matter. Here there is a total absence of what is usually known by well drillers as gravel. The samples examined show no material coarser than ordinary coarse sand	220

Well No. 5. This is another deep well, and hence an interesting one. It is located in Logan county in the western suburbs of the

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town of Oakley. It went to a depth of 162 feet, showing the following section:

No.		Feet.
1.— 3 ft.	surface soil	3
2.—21 ft.	yellow sand	24
3.— 9 ft.	light clay	33
4.—11 ft.	sand and gravel cemented with calcareous cement	44
5.—11 ft.	reddish sand and gravel cemented with calcareous cement. These two masses are practically the same excepting in color	55
6.—10 ft.	sand and gravel	65
7.—10 ft.	reddish sand with much calcareous cement	75
8.— 9 ft.	red clay mixed with sand	84
9.— 6 ft.	sand and gravel	90
10.— 5 ft.	sand with calcareous cement	95
11.— 7 ft.	water-bearing sand	102
12.—10 ft.	clay and sand with enough clay to make the whole mass exceedingly plastic	112
13.— 7 ft.	water-bearing sand	119
14.— 4 ft.	clay and sand	123
15.— 3 ft.	water-bearing sand and gravel	126
16.— 2 ft.	clay and sand	128
17.— 9 ft.	water-bearing sand and gravel	137
18.— 8 ft.	sandy clay	145
19.— 3 ft.	water-bearing sand	148
20.— 7 ft.	clay	155
21.— 7 ft.	water-bearing sand	162

It will be seen from these that no more gravel is found during the last 60 feet than there is during the second 60 feet, while the clay is interbedded here and there, or is mixed with the sand entirely regardless of depth from the surface.

Well No. 6, in Wichita county, near Leoti:

No.		Feet.
1.— 1 ft	soil	1
2.—26 ft.	clay with calcareous cement	27
3.— 6 ft.	coarse white sand	33
4.—42 ft.	sand with calcareous cement very abundant	75
5.— 3 ft.	water sand	78
6.—26 ft.	sand with calcareous cement	104
7.— 3 ft.	water sand	107
8.—22 ft.	sand	129
9.— 5 ft.	water-bearing sand and gravel which rests upon the Niobrara chalk	134

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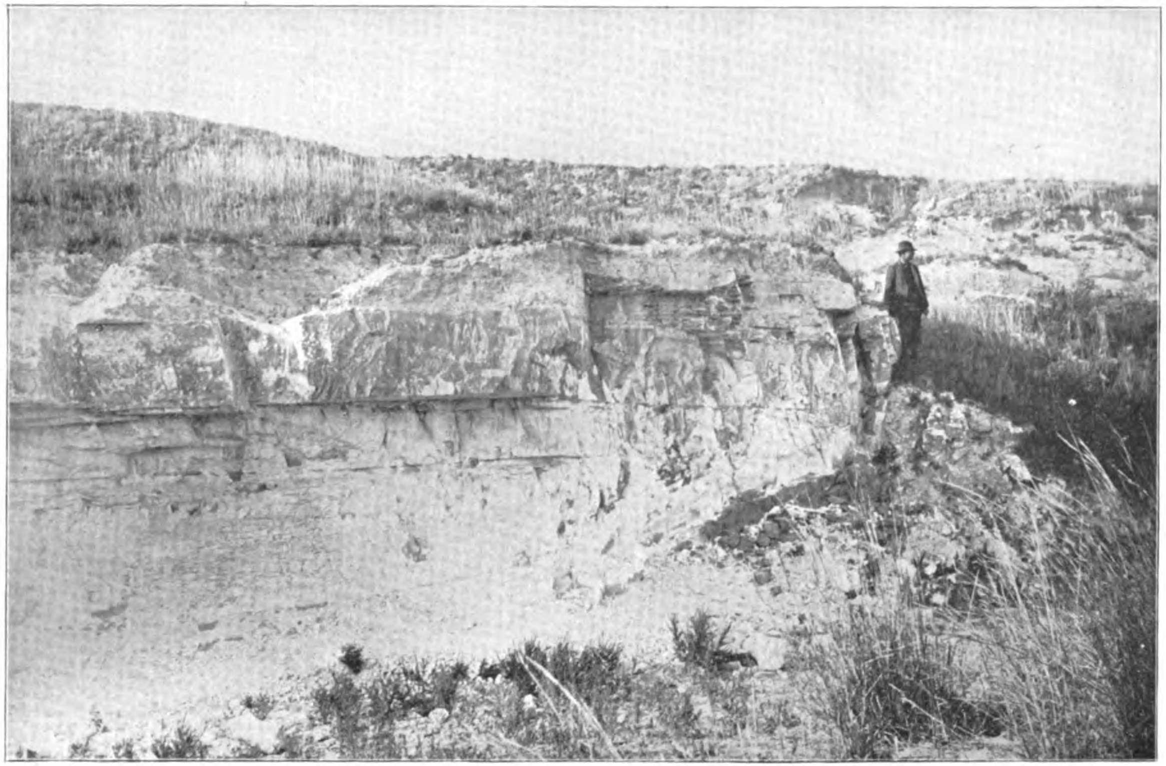

STRATIFIED "VOLCANIC ASH" IN THE TERTIARY NEAR MEADE.
(Photographed by Haworth, 1896.)

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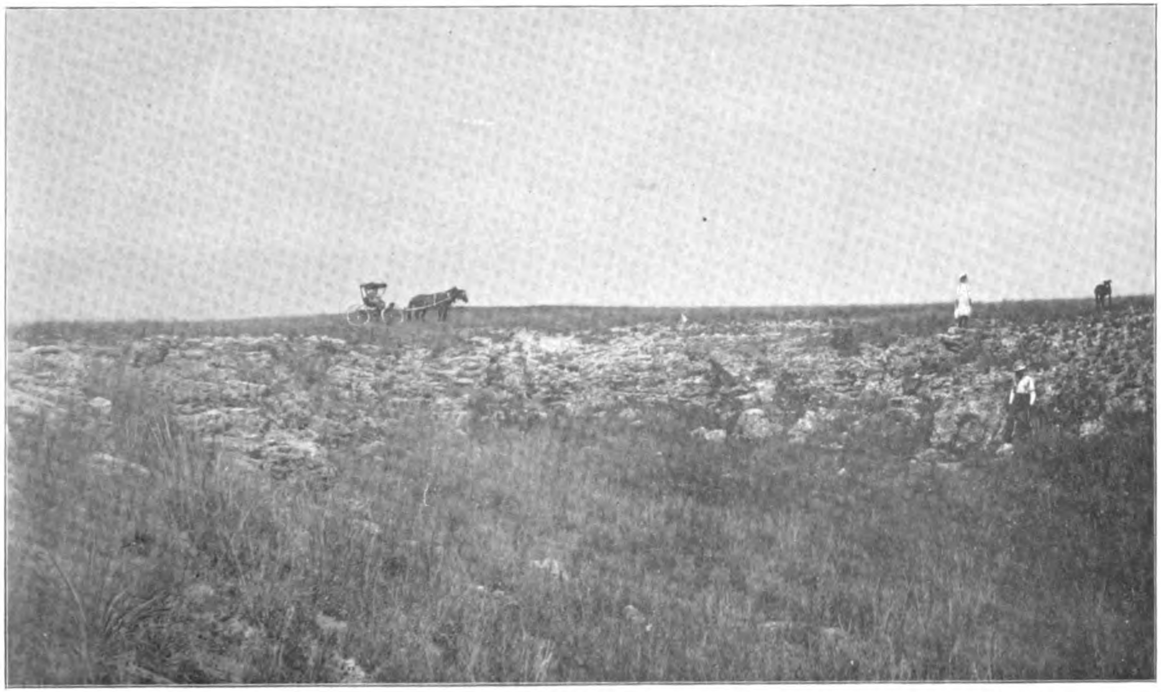

"MORTAR BEDS" ON THE UPLANDS AT HEAD OF ARROYO IN NORTHWESTERN CLARK COUNTY.
(Photographed by Haworth, 1896.)

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In this case we find the coarsest gravel near the base of the Tertiary.

Farther north in Rawlins county near the town of McDonald a well was sunk to a depth of 213 feet, with the following section:

No.	Feet.
1.—32 ft. soil and light-colored subsoil	32
2.—66 ft. red clay	98
3.—30 ft. sand and gravel with large amount of calcareous cement	128
4.—10 ft. sand and gravel	138
5.—26 ft. dry sand	164
6.—6 ft. sand and gravel	170
7.—20 ft. water-bearing sand	190
8.—23 ft. water-bearing sand and clay tolerably evenly mixed	213

Here it will be seen that there is a stratum of sand and gravel beginning near 100 feet below the surface, and also that we have a mass more than 20 feet thick carrying considerable clay lying at a depth of nearly 200 feet. The well stops before the base of the Tertiary was reached, so that it is not known what lies beyond.

Going back southward to Ford county, another well was put down on the high uplands about two and a half miles north of Dodge City. The bluffs for miles along the river near Dodge City have three distinct strata of sand and gravel strongly cemented with calcium carbonate into a more or less firm rock. They are separated from each other by beds of clay carrying a smaller amount of relatively fine sand. In places below these other beds of gravel likewise cemented are found.

Well No. 13, Ford county, near Dodge City:

No.	Feet.
1.— 2 ft. surface soil	2
2.—70 ft. yellowish clay and sand with calcareous cement	70
3.—26 ft. sand strongly cemented with calcium carbonate	96
4.— 4 ft. coarse gravel strongly cemented with calcareous cement	100
5.— 2 ft. ordinary sand cemented with calcium carbonate cemented into firm sandstone	102
6.—14 ft. sand strongly cemented	116
7.—13 ft. water-bearing sand and gravel. Here the contractors were changed and there is a slight discrepancy in the samples saved and in the records. The second contractor began at a depth of 122 feet, and records 13 ft. fine sand	129
8.— 6 ft. gravel	135

No.	Feet.
9.—10 ft. clay	141
10.— 2 ft. sand and gravel	151
11.— 7½ ft. clay	153
12.— 2 ft. clay	160½
13.— 5 ft. coarse gravel, in which the digging was stopped, as a large amount of water was obtained, the object for which the well was dug	162½

It will be noticed here that in general the coarser material is at the bottom and the finer material at the top of the well.

The state well at Liberal is of considerable interest on account of so great a lack of coarse material. It is located about two miles northwest of Liberal on the high uplands south of the Cimarron river. The character of the material immediately below the surface soil may be described as a coarse sand with large quantities of gravel, some of which are from two to three inches in diameter. In making the excavations for erecting the windmill tower several wagon loads of this material were thrown to the surface, from which bushels of coarse gravel could have been screened. Intimately mixed through the gravel was clay and sand of all degrees of coarseness, so that probably no more than a fourth or a fifth of the volume of the whole material was gravel. Below this the material is relatively fine, until a depth of about 100 feet is reached when more coarse gravel was found. Below this much more fine material was passed, and near the bottom of the well a clay mixed with fine sand constituted a heavy layer. The calcareous cement was present in this well in an unusual amount and was about as uniform in location as has been seen from other wells.

These well sections may be taken as a type of all the state wells and of several hundred private wells examined with more or less detail during the past two summers. By carefully studying them it will be seen that there is altogether a lack of any definite regularity in kind of material passed through, no matter whether we regard the sand, or gravel, or clay or the calcareous cementing material. The mortar beds of Hay which have been so generally described as lying near the base of the Tertiary are composed essentially of sand and gravel cemented with calcium carbonate. There is no limit to the degree of coarseness or fineness of the sand, and

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consequently the only essential feature to produce the mortar beds structure is to have a sufficient amount of the cementing material to hold any mass of sand or gravel, or a mixture of the two, together with relative firmness. In fact it frequently happens that the clay carried but little sand and no gravel whatever, but is cemented together in a more or less firm mass so that it too has been generally designated by the term mortar beds. These records show that the cementing material is exceedingly irregular in its distribution. Generally it is most abundant some distance above the underground water, frequently near the top of the well. In no instances known to the writer is the cement found in the same horizon with the ground water. In a few instances only, such as Grant county well No. 3, is there any of the cementing material below the water. If we use the presence of the calcareous cement as a criterion for judging the mortar beds, from the well records the same as from surface exposures, we must conclude that they are in general as near the surface as they are its base.

In studying the physical properties of the Tertiary it is necessary to emphasize the conditions already stated, that the so-called mortar beds are simply the sand and gravel and clay materials cemented usually with calcareous cement. The real stratigraphic conditions probably do not depend upon the presence or absence of cementing material, but rather upon the continuity of beds of like material. A stratum of gravel which is not cemented should be considered as important as though it had chanced to have its individual constituents held together by a cementing material of some kind. Yet in our study of the subject we are usually inclined to regard the beds which are cemented into a firm rock as more important than softer materials. It is necessary, therefore, to look with considerable care at the character of the cementing material, and to determine if possible its origin and the manner of its formation.

THE CEMENT.

The cementing material of nearly all the Tertiary sands and gravels which appear in the form of sandstones or conglomerates is calcium carbonate. A few exceptions are known to this rule. There is a sandstone near Long Island, in Phillips county, which is

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so firmly cemented with silica that a rock similar to quartzite has been produced. On the uplands north of Stockton likewise a silicious cement has been deposited between the grains of sand producing a rock which is quite like quartzite. Near the Saint Jacob's well in western Clark county silicious cement has been deposited between the grains of sand, forming a close-grained rock.

But throughout the Tertiary area of the state, with these few exceptions, wherever the sand and gravel are held together by any kind of cement it seems to be calcium carbonate. The firm mortar beds near Dodge City and elsewhere crumble to grains of sand and gravel when acted upon by an acid which will dissolve the calcium carbonate.

The degree to which this cementation is carried is astonishingly great. In an examination of materials from the different state wells as already referred to it was found that with scarcely an exception the whole of the materials taken from them and at a distance more than 3 or 4 feet below the surface retained enough carbonate to effervesce strongly when placed in acid. Every pinch of clay or loose sand, with the exception of the sand which is water-bearing, would effervesce vigorously.

The amount of cement is exceedingly variable, even in the same kind of material. There are horizons in most parts of the state at which the clay and silt are heavily charged with calcium carbonate. Sometimes this will be a thin layer not exceeding 12 to 20 inches in thickness. Other times it will be a mass 20 to 40 feet in thickness. Occasionally a layer of such fine calcium carbonate is near the surface and plowed fields frequently have a light color as a result which in the distance looks almost like snow.

The arrangement of the cement in the mortar beds is more regular than elsewhere, but not infrequently here even it is quite irregular. It almost always shows an approach to concretionary forms. In different places along an exposure of the mortar beds a careful examination will show that the first deposition of the cement was in the form of granular masses. A later deposit cemented these together into larger masses or concretions and in many instances a third or fourth period of deposition is plainly marked so that the larger fragments previously formed are included in one concretion

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frequently of from four to six or even eight to ten inches in diameter, and possibly much larger. In the beds of clay and in sand beds where the supply of cement seems to have been limited odd shaped masses are often produced. The concretionary granules assume the shapes of common concretions, rounded, spherical, oblong, and irregular. Plate XLI is a reproduction natural size from a photograph of such nodules gathered in the northeastern part of Logan county. Frequently instead of producing the somewhat rounded nodular concretions elongated masses extending up and down are formed, sometimes with radiating lines reaching in different directions as though water containing calcium carbonate in solution in working its way downward through the beds of clay found more ready channels there than elsewhere. Plate XLII is from the photograph of a clay bank in the southern part of Sheridan county on one of the tributaries of the Saline river. It is similar to those found over the whole country. The granules of sand and particles of clay in such cases are held together with a firmness approaching that of the mortar beds themselves. Mr. Crane, who spent the greater part of two summers in the northwestern part of the state, in describing the forms assumed by such concretionary masses likened them to the results we might expect were large quantities of molasses poured upon beds of sand and clay and allowed to work its way downward through whatever channel or more porous areas it might find. This somewhat homely illustration perhaps is as good as can be given. The elongated direction is by no means always vertical. Bifurcations and trifurcations in the mass are frequent and different vertical masses are frequently connected by radiating lines as though there was a connection between the depositing agents in the different channels.

A microscopic examination of the white masses which are thus firmly cemented shows that the calcium carbonate exists principally as well formed crystals usually of aragonite. The thinner beds of such deposits generally are not held together very firmly but are loose almost like sand. The aragonite crystals in such cases are usually small, frequently measuring no more than 1-500 of an inch in diameter. Rhombolic calcite crystals are also found, but not so abundantly as the aragonite crystals. The larger masses

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and those held together more firmly seem to be structureless as though the carbonate was deposited under such conditions that a crystalline form could not be assumed.

Origin of the Cement.—The geologic period during which the cementing material was deposited is difficult to determine, but if the views herein expressed are correct, the accumulation of the cement began as soon as the climate became arid, and continues until the present time. It may be stated, however, without reserve that the cemented masses bear evidence of having been originally deposited without the cementing material, and that the latter was deposited within them by percolating waters after they were accumulated in beds as they are now found. A question of no little importance is what water carried the calcium carbonate and what was the source of the carbonate. To answer this it is desirable to consider first a few subjects which have an important bearing on the question. The Tertiary materials as has already been explained are principally derived from debris produced by the disintegration of crystalline rocks in the mountainous areas to the west. Such debris therefore contains a relatively large amount of calcium in one form or another. In this respect it is similar to the great mass of glacial debris scattered over so large a part of northern United States, which is generally supposed to have been principally produced by the weathering of crystalline rocks lying farther to the north. The recent weathering processes of the glacial material produces large quantities of calcium carbonate as is abundantly shown from the temporary "hardness" of almost all the well water found anywhere throughout the glacial area. Is it not reasonable to suppose therefore that by the similar weathering of the Tertiary material in Kansas and elsewhere on the plains calcium carbonate will likewise be produced which would be changed to acid carbonate and dissolved by the surface waters were they existing in sufficient quantity?

The great mass of glacial material in northern United States at present lies in a humid climate. Therefore the rain waters fall upon the surface and dissolve the calcium carbonate as fast as it is formed, carrying it downward and away through the sub-drainage channels. On the great plains, however, the climatic conditions are

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different. The precipitation rarely exceeds twenty inches annually, while frequently it will not exceed ten inches per annum over large areas for a period of two or three years. When a rain falls carbon-dioxide gas is washed from the atmosphere, the same as elsewhere, and the calcium carbonate formed near the surface by previous disintegration is rendered soluble exactly as elsewhere. But the precipitation is so light and the sand beds and clays are so dry that the water, working its way downward, is largely absorbed by the dry earth before it connects with the general underground water below. Such a desiccation process would leave the calcium carbonate wherever it chanced to be; that is, it would leave it scattered throughout the sands and clays. The gravel beds and sand beds, on account of their greater porosity, would permit the circulation of water more freely than the clays. As a result the ground water near the surface in its downward migrations would follow such beds more frequently and in greater volume than the clay beds. When a horizon was reached composed principally of coarse sand and gravel a lateral movement would result from the clay beneath acting as an obstruction to downward movement. The extent of the lateral movement would depend upon the amount of water and upon the distance necessary to be passed over before a downward outlet could be found. It has already been seen that the sand and gravel beds form large parts of the Tertiary areas. The downward movement of the water from the rains would be very irregular. Where the channels were most open, that is in the gravels and clays, the movement might extend laterally for long distances. If the gravel beds are irregular in their stratigraphic relations so that almost every one comes near the surface at one place or another, it is not unreasonable to suppose that every gravel bed has had an opportunity to serve as a passageway for waters coming from the surface heavily charged with acid calcium carbonate. The ultimate drying up of such waters would deposit the carbonate in the beds of sand and gravel, the same as elsewhere. If a larger proportion of water traveled through them we would expect a correspondingly larger deposition of the carbonate.

It is a noteworthy fact that the sand beds and gravel beds which carry such large quantities of underground water rarely if ever

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have any considerable amount of the cementing material. Such an occurrence of water within the well cemented mortar beds is entirely unknown so far as our investigations have resulted. Thousands of wells have been examined which found the water in the loose sand or gravel, but no one is known to the writer in which water was obtained directly from the cemented masses. This is as it should be. The drying up of the water carrying the acid calcium carbonate could not occur here, and therefore the cement would not be deposited.

It is recognized that this explanation for the time and manner of formation of the cementing material in the mortar beds of the great west has an important bearing upon a number of subjects connected with Tertiary stratigraphy. If correct it lays aside the somewhat laborious task, attemped by different geologists, of explaining how fresh water lakes, under which such material was supposed to have been deposited, could have become sufficiently charged with calcium carbonate in solution to produce the cementing material upon proper desiccation. It obviates the difficulty of assuming that the desiccation of those lakes was possible at a time while the incoming waters were sufficiently rapid to carry the gravel and coarse sand of the mortar beds, an assumption that no one has yet been able to make appear reasonable. It leaves untouched the question of the mode of formation of the beds of sand and gravel. No matter whether they are fluviatile or lacustrine in origin it provides a cementing material for such beds after they were formed.

It also provides an explanation for some apparent perplexities of local stratigraphic conditions. On a hillside at the present time the water will penetrate to a depth of from 2 to 4 feet below the surface during a heavy rain. The evaporation destroys the moisture, leaving the cementing material only a short distance below the surface. By a repetition of this process there may often be deposited at about the same distance below the surface a layer of the white, chalky calcium carbonate from 1 to 3 feet thick in a plane inclining with the surface of the hill. Many local instances were observed of an apparent inclination of strata which doubtless originated in this way. Plate XLIII is from a photograph of a hillside south of the Cimarron river just south of the Kansas state line. Here the sand has been

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CONCRETIONARY NODULES OF CALCIUM CARBONATE FROM THE TERTIARY OF LOGAN COUNTY, NATURAL SIZE.
(Photographed by Tucker, 1896.)

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CONCRETIONARY MASSES OF CALCIUM CARBONATE IN CLAY, SHERIDAN COUNTY.
(Photographed by Haworth, 1896.)

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rolled down the side of the hill so rapidly that vegetation can not grow on it, showing that it is very recent in its movements. Yet the light layers of sand, inclined at as high an angle as it is possible for them to lodge on the hillside, are cemented sufficiently to cause the wind erosion to develop stratification marks within them. An example of this at one place seems to show that some of these sand layers had been moved during the last six months, and that the cementing material had been deposited by water working its way down the hillside after the little rains of the summer.

It is not an unfrequent occurrence to find slight incrustations on the surface of the sand in the beds of different creeks over which the water carrying acid calcium carbonate has probably passed producing a rearrangement of the sand beds less than three months previously. More than a dozen such instances were particularly noted and carefully examined.

The conclusions arrived at regarding the deposition of calcium carbonate are in harmony with well known facts regarding the accumulation of alkaline materials and other soluble salts over arid areas which have imperfect sub-drainage. It is well known that all such localities abound in soluble salts that have been produced by the decay of surface material and segregated by running water which was subsequently dried up. The famous illustrations of the world are the shores of the great inland seas, such as the Caspian sea, the Dead sea, and the Great Salt Lake, with a larger number of less noted instances occurring throughout the arid country, such as the broad sand-covered valleys of almost all the mountainous streams which flow downward through the parks and valleys where precipitation is light. Water obtained from such places is proverbially mineralized until it is unfit for domestic uses, the mineral material being accumulated in this well known manner.

THE CLAY BEDS.

In some respects the position and character of the clay beds are of importance. As the clay deposits were formed from water with almost no current they represent the opposite extreme from the gravel deposits, and are therefore equally important in a study of

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the drainage conditions of the Tertiary formation. By an examination of the well records already given it will be seen that almost every one of the wells passed through from one to many beds of clay. The Gray county well near the Cimarron found a very plastic clay almost entirely free from sand within less than thirty feet of the surface, although the well is located in the Sand Hills on the south of the Arkansas. This well shows that the sandhills are superficial in position and do not extend very far under the surface. Well No. 3 in Grant county passed through more clay than all other materials combined yet it was located on the high uplands between the two Cimarron rivers. And so with the other wells.

An examination of the various natural sections along the banks and bluffs of the streams reveals a similar set of conditions. Not unfrequently do we find a section from 25 to 100 feet in hight which contains little but plastic clay. In other places similar evidences are obtained from wells drilled by private parties scattered here and there over the country. One of the most remarkable cases yet observed is that of a well drilled during August 1896 about three fourths of a mile south of the little town of Atwater, in Meade county. Here a well went to a distance of 288 feet, passing through nothing but clay, until almost the total depth was reached. Other wells near by found a much less amount of clay. This condition is frequently met with elsewhere implying that the clay beds are lenticular masses, sometimes elongated, and at other times circular in form. They are scattered all over and through the Tertiary of Kansas, and can not be located from surface indications.

Such an oblong lenticular mass lies to the north of Garden City along the north part of the Arkansas river valley. Here, for a distance of four to six miles along the river, is a narrow strip lying just back of the river valley proper beneath which the clay exists from 75 to 100 feet in thickness. Many attempts have been made to obtain water in this particular area by different citizens, each of whom has usually abandoned his well because it was known that only a short distance either north or south water could be found in the sand beds at comparatively shallow depths, while if drilling was continued in the clay area a depth of 100 feet or more would have to be passed before water could be reached. The clay

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beds by no means are confined to such lenticular masses, but frequently appear as thin masses of clay spread out between layers of sand or gravel.

The largest proportion of clay in the aggregate is undoubtedly intimately mixed with the finer grains of sand and silt, so that the plasticity is partially destroyed, and the general properties greatly altered. It is doubtful in fact if many localities can be found where a section would not show that at least nine tenths of the vertical thickness is partially composed of clay.

PLAINS MARLS.

Professor Hay introduced the term "plains marl" to designate a large part of the Tertiary materials of the plains. Over a large proportion of the whole Tertiary area the upper part is composed of a variety of soil similar in almost every respect to the glacial soils of northern United States. The most abundant ingredient of such a soil is clay, the remainder of the prominent constituents being fine sand, a little organic matter, and some products of decomposition of the surface material producing soils. In general character this is surprisingly similar to the glacial loess so well known in many parts of the world. There is no essential difference between it and many forms of soil and clay found in the valleys, ravines, and streams of various sizes in other parts of the state, excepting that the proportion of sand may at times be greater here, and the feldspathic material is found in greater quantity. This loess-like material differs in character from the mortar beds to a considerable extent. Professor Hay has divided the whole Tertiary into two general classes, the mortar beds and the plains marls. For a convenient term to designate the difference in physical properties of the different Tertiary materials no objection is apparent to the use of either name. It should not be assumed, however, that the plains marl has any more definite stratigraphic position than the mortar beds have. Many masses of clay and sand admixtures found 100 or 200 feet beneath the surface would soon become typical plains marl were they exposed to the surface long enough to be acted upon by the atmosphere, and to receive a slight admixture of organic matter.

Plains marl by no means covers all the surface. A considerable

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part of the whole area is covered by sand in the form of sand dunes that are so prominent along the south side of the Arkansas river and elsewhere, so that it will not do to assume that plains marl is a continuous formation covering the whole surface.

It is probable that many of the properties of the plains marl are largely due to the action of wind. Strong winds which are common in the plains country continually exercise a sorting action on the surface materials, effecting a separation of the finer from the coarser. It is probable that many of the sand dunes owe their existence as such largely to the finer silt and soil having been blown away, leaving the sand behind as a residual property. Correspondingly the accumulation of the fine material on the surface in other parts of the plains may be to a great extent an important factor in the production of the plains marl. The winds therefore have been an important agent in the arrangement of the surface materials, and probably continue that function to the present time. Could we have had an absence of wind over the whole of the plains from the close of Tertiary time to the present it might well be assumed that the division of the surface material into sand dunes and plains marl would scarcely have been possible. From these considerations it may be concluded that the plains marls in themselves have but little stratigraphic importance, although they are so prominent a surface feature over wide areas at the prsent time.

THE SAND DUNES.

The location and general character of the sand dunes along the southern side of the Arkansas river were fully described in the article on physiography while describing that river. Other sandy areas are found here and there over the state which are of more than passing interest. On the eastern side of Crooked creek, from the vicinity of Wilburn to near Fowler, a sand area occurs which covers from twenty to thirty square miles, and which in many respects is very similar to the Arkansas area. Along the Cimarron river, particularly in the western part of its course in the state, sandhills abound. This is true in Grant county, and in Stevens, Morton, and Stafford counties, but perhaps more particulary true in Stevens county than elsewhere. Here on the south side of the

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Cimarron sandhills rivaling those along the Arkansas river cover wide areas. Likewise north of the river in different parts of the country sandhills are by no means unknown, although they are not so abundant as south of the Arkansas.

Origin of Sand Dunes.—It is probable that the first essential in the formation of sand dunes was the somewhat irregular deposition of sandy material during Tertiary time. One can hardly believe that the distribution of sand throughout the Tertiary over the whole state was uniform. The cause of this lack of uniformity must be looked for in connection with the character of the drainage which brought the materials from the mountainous area and spread it over the great plains. A second factor which is doubtless important, and which has heretofore received but little attention, is the action of water during recent times in carrying away the finer and more easily movable particles of clay and silt, leaving sand behind as a residual product. There are so many examples of this process producing accumulations of sand that one can not doubt its efficiency. In order to accomplish this result the surface of the country must have sufficient inclination to produce a comparatively rapid drainage. The greater portion of the great plains of Kansas does not possess such drainage, but we find it in almost ideal form in the southern part of the state from Meade county eastward to Barber county. Here the inclination to the southeast is frequently as much as 20 to 25 feet to the mile. Every stream that rises in the upland has cut its channel to a depth of from 100 to 200 feet. At its mouth the little stream has reached its base level and the deepening of the channel has long ago ceased, and a widening process has been carried to a considerable extent. This wide valley or flood plain invariably is covered with sand which is simply a residual product left behind when the finer materials were carried away. The whole Tertiary from north to south contains a sufficient amount of sand to produce such residual masses were the proper drainage carried on. The production of many of the arroyos by sub-surface creeping, as already described in the article on drainage, would carry sand along with the silt and clay so that such sand washes or sand areas could not be produced by this kind of erosion. But the sand

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would be left behind farther down stream where surface action began.

A third factor in the production of sand dunes is the action of wind. The same winds that separated the silt and clay particles from the sand and blew them to great distances producing by their lodgment the plains marl likewise moved the sand grains from place to place and caused them to accumulate in certain areas which we now call sand hills, or sand dunes. The separating process of the wind is similar in most respects to that of water, so that here the sand left behind is a residual product from which the finer particles of clay and silt have been removed. The wind is constantly working over the loose surface materials, separating them into classes dependent upon their facility for being moved, and is producing accumulations of one kind at one place by making additions, and of another kind elsewhere by having matter taken away from it.

It is believed that all or nearly all the sand hills of the entire state have been produced by one or another of these agents or by a combination of them. It is not infrequent to find gravel near the top of the sand hills on the south side of the Arkansas river, gravels which are too large to have been blown out of the river and into their present lodgment places. The idea[1] that the sand hills on the south side of the Arkansas are due to northerly winds blowing sand from the river, as the same is now being carried downward from year to year, is hardly compatible with the presence of the larger gravel in the sandhills as just mentioned. Neither is it capable of explaining the occurrence of so many sandy areas in other parts of the state. If a north wind is more prevalent in the vicinity of the Arkansas river, so as to blow the sand from the river southward rather than northward, it may well be asked why we find so much sand north of the Cimarron river in the vicinity of Englewood and elsewhere, as has already been stated. The two localities are so close together that of course when a strong north wind prevailed at one place a correspondingly strong one would prevail at the other. It is by no means contended that the wind has not blown

1 G. K. Gilbert, Underground Water of the Arkansas Valley in Eastern Colorado, p 30. Extracted from the Seventeenth Annual Report of the Director U. S. Geological Survey.

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large quantities of sand from the river upon the dry land.

There is a sentiment with the residents of the west that during the last fifteen years sands have traveled from the sandhills northward into the Arkansas river valley to a much greater extent than from the river channel outward upon the river valley. The filling up of the valley at the south end of the Cimarron bridge, as noticed in the discussion of the Arkansas river, is usually claimed by the citizens of that place to be largely due to sand traveling from the sand hills on the south. It is true, of course, that public sentiment is often in error, but one may well suppose that during the last fifteen years those who are residing in the Arkansas river valley, and who are having their farms yearly increased or decreased in size, depending upon their location in the river valley, would make relatively accurate observations upon this subject.

We have no means of determining the climatic conditions in prehistoric times. The sandhills on the south side of the river might be credited to northerly winds in prehistoric times were it not for the large gravel found in them frequently at the summit of the hills. But this would not account for the sand of other areas farther to the south, particularly those north of the Cimarron. Taking all in all it would seem that the explanations given include sufficient causes, each of which is in harmony with the results as we can now observe them. They are in brief, first, the unequal distribution of sand throughout the Tertiary materials at the time of deposition, and second, the separation of the finer material from the sand by water action and by wind action, leaving the sand behind after the finer material has been carried away. The particular shape of the sand dunes at the present time may be principally due to the action of wind, which has worn out cavities and built up hills and hillocks in such an iregular manner.

SURFACE GRAVELS.

Coarse gravel are found here and there over the surface throughout the Tertiary area of Kansas. Such formations are by no means as common or as extensive as the sand masses. In every instance noted they seem to be due entirely to the breaking down of mortar beds formations from which the gravel came to be scattered over

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the surface. Where a mortar bed once firmly cemented is brought to the surface by the erosive action of wind or water removing the plains marl from above it the weathering agents tend sooner or later to destroy the cementing calcium carbonate and set the gravel free. They are scattered over the surface in such cases, covering it to varying depths depending upon the amount of gravel in the mortar beds, and the degree to which decomposition has been carried. At almost every place where the mortar beds are prominent features of a hillside or terrace the surface below is covered with gravel, sometimes to several inches in thickness.

SUMMARY OF CONCLUSIONS ON STRATIGRAPHY.

It is doubtful if there can be any regularity discovered between the beds of the different kinds of Tertiary material in western Kansas. The mortar beds occur at all positions from the base to the summit, as do also the sands and the clays. It has been found impossible to trace a bed of any one material very far in any direction. The records of the state wells adds to this difficulty rather than to lessen it. Neither does the assistance of paleontology lessen the difficulty, but it rather increases it. In Phillips county the mortar beds contain skeletons of the rhinoceros and other animals indicating that they should be correlated with the Loupe Fork beds of Nebraska, and that they are about the oldest Tertiary beds in Kansas. To the southwest in Meade county a mass of conglomerate which is as typical a mortar bed as can be found is rich in fossil horses, llamas, elephants, etc., which paleontologists class as Pleistocene fossils. We therefore have the mortar beds with Loup Fork fossils at one place, and with Pleistocene fossils in another, not only showing a lack of stratigraphic continuity, but showing that, after all, the so-called Tertiary of our state may be part Tertiary and part Pleistocene! Other Pleistocene fossils have been found in the so-called plains marl, as is fully brought out in the following article by Professor Williston. Paleontology therefore adds difficulty to the stratigraphic problem provided we try to divide the Kansas Tertiary into terranes, as has usually been done.[1] If, how-

1 See almost all literature on the Kansas Tertiary, particularly Hay's various geologic sections and descriptions, Scott's discussion of the Tertiary in Bulletin G. S. A., Vol. 6, p., and Cragin's discussion of the Meade Gravels, etc., Colorado College Studies, Vol. VI, p. 53 et seq.

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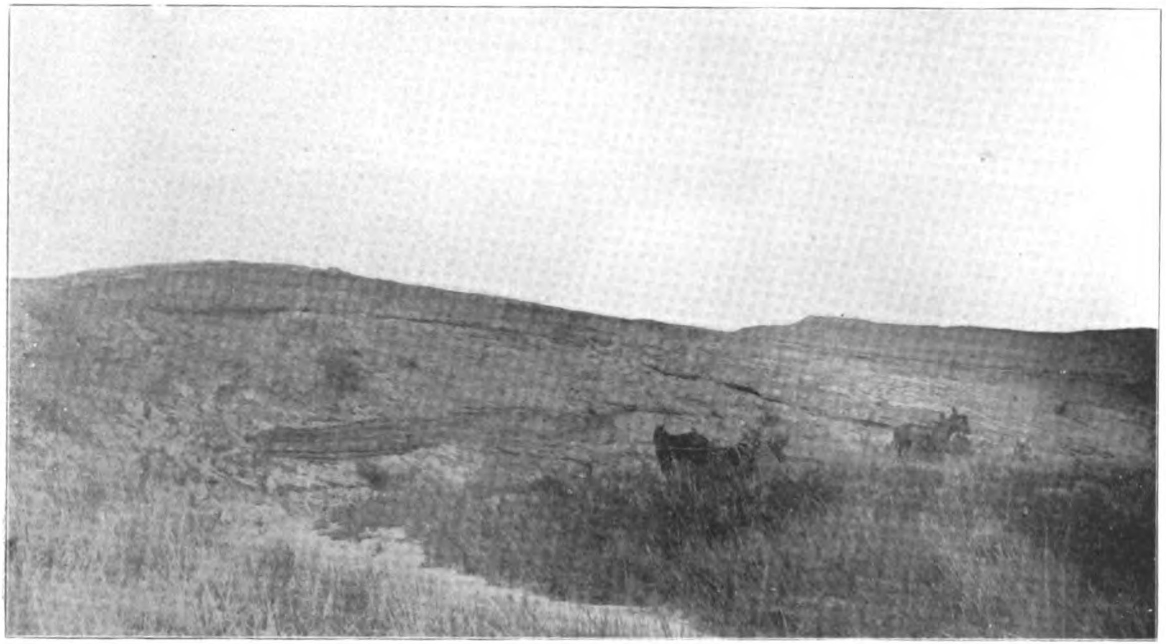

WEAKLY CEMENTED SAND IN A LANDSLIDE, SOUTH SIDE CIMARRON RIVER NEAR ENGLEWOOD.
(Photographed by Haworth, 1896.)

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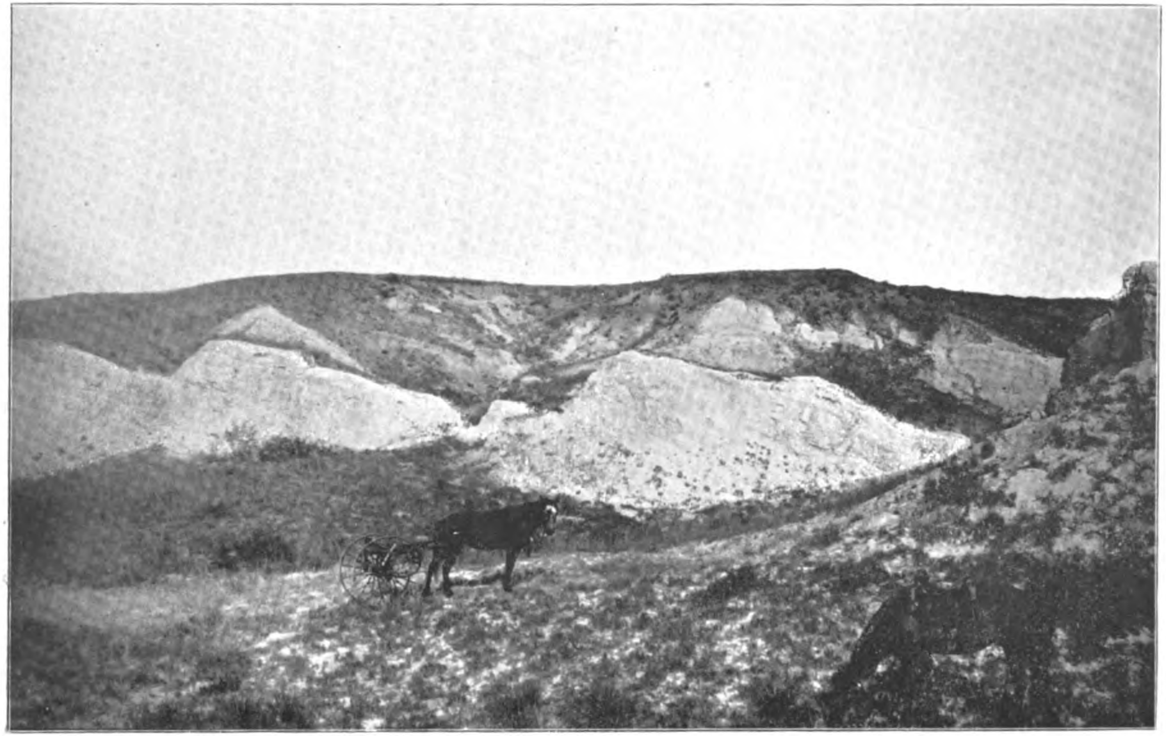

WHITE TERTIARY BLUFFS WITH INCLINED STRATA, SOUTH BANK OF CIMARRON RIVER.
(Photographed by Haworth, 1896.)

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ever, we adopt the more rational view that the materials were principally accumulated by river action throughout a period extending from the earliest indicated by paleontology to the present the above difficulties disappear.

ORIGIN AND MODE OF FORMATION OF THE TERTIARY.

From what has already been given it will be seen there is little if any room for doubt regarding the source of the Tertiary material. It has principally come from the great Rocky mountain area to the west. Portions of the mountain area have been dry land from early geologic times, and the weathering agents have acted upon such in the usual manner producing the ordinary products of decomposition of crystalline rocks, such as sand, pebbles of various sizes, etc. It is probable that throughout the main period of geologic history the elevation of these dry land areas was so small that the drainage carried away but a small proportion of the debris thus produced and that as a result an extraordinary amount of it was ready for transportation as soon as the elevation became sufficient to produce a considerable fall. It need not be doubted that a part of the Tertiary material was obtained from the underlying Cretaceous, but examination shows that this constitutes but an unimportant part. When the final elevation of the whole mounainous area was effected and the drainage became established across the great plains area to the Mississippi, the eastward migration of great quantities of debris began.

Mode of Deposition.—Formerly geologists thought that the Tertiary of the plains from north to south was deposited under lake water, that large inland fresh water lakes were formed at different places as a result of the mountain drainage not reaching entirely across the plains. The Tertiary formations in different places in the west have uniformly been explained in this way. The application of such a mode of accumulation to the great plains has rarely if ever been questioned so far as our literature shows. In his "Report on the Fortieth Parallel," King[1] states that a large portion of the

1 Vol. I, p. 451.

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plains area was covered by a fresh water lake in which the Tertiary material accumulated. He says:

"At the close of the Eocene a large part of the plains area, from middle Kansas indefinitely northward, became depressed and received the drainage which now forms the western affluents of the Mississippi, the Missouri, the Red river, and other of the British Columbia rivers, forming a wide sheet of water.

"For this I propose the name Sioux Lake.

"Unfortunately the Fortieth Parallel area only covers a very slight exposure of the series of the Miocene beds which accumulated in Sioux Lake, to which, long since, Hayden gave the name of the White River group."

From that date—1878—to the present time the literature of the plains, with one exception, seems to show no objections to this statement. On the contrary the general application of the lake deposits have been carried southward, covering the whole of the state. In his discussion of the origin of the Tertiary in eastern Colorado along the Arkansas river in 1896 Gilbert[1] deviates from the customary method and decides that they were fluviatile in character rather than lacustrine. After speaking of the erosion which was set up by the uplifting of the mountain area he says:

"Eventually the process of erosion was completely arrested and processes of decomposition took its place. This change was brought about by some modification of conditions which is not yet clearly understood. Perhaps the plains region was depressed at the west, and the slopes thus rendered so gentle that the streams could no longer carry off the detritus which came from the mountains, and it was deposited on the way. Perhaps a barrier was lifted at the east so that the base level stood higher. Whatever the cause the streams which flowed from the mountains onto the plains and thence eastward across the plains, ceased to carve valleys in the region of the plains and began to deposit sediment. When they had filled their channels so that their beds lay higher than the neighboring country, they broke through their banks, shifting their courses to new positions, and they thus came to flow in succession over all parts of the plains and to distribute their deposit widely, so that

1 Loc. cit., p. 25.

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the whole plain in the district here described was covered by sands and gravels brought from the cañons and valleys of the Rocky mountains."

He skillfully avoided committing himself regarding the Kansas Tertiary, probably because he was not yet sufficiently familiar with the conditions in Kansas to think himself justified in advancing views contrary to the popular idea. He says:

"It is thought by geologists who have studied the formations of Kansas that lakes were formed there during a portion or the whole of this period, so that the sedimentation was from still water instead of from the currents of sluggish streams."

The relative positions of the gravel, sand, and clay of the Tertiary over the whole of Kansas, as already given at considerable length, corresponds much better to river deposits than to lake deposits. The irregularity of formation succession, the limited lateral extent of the beds of gravel, clay and sand, the frequent steepness of the cross-bedding plains, all correspond to river deposits but are not characteristic of lake deposits. It is difficult to understand how such irregularity of material could have resulted if the Sioux Lake of King, or any other lake, had extended southward across the whole of the western part of Kansas and been a factor in the accumulation of the Tertiary materials. It is quite possible that during Tertiary time in which there were so many changes in the velocity of the water carrying the sediments, lesser local lakes and lagoons and swamps and marshes may have existed in different places and for varying lengths of time. But when we consider the Kansas Tertiary as a whole and yet in detail, it must be admitted that the materials themselves have many indications of river deposits and a very few of lake deposits. As best one can judge from the literature on the subject it is probable the heavy beds of loess-like material reaching nearly 1000 feet in thickness in Dakota, are of lake formation. The southern limit of such a lake has not been located and may have reached for a short time into Kansas territory. It is probable that no definite line will be found between this lake and the undoubted river deposits in the Arkansas river territory.

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If it was changed from a great lake into lesser lakes, then to the wide mouths or outlets of the streams during times of sluggish movement in the coarse gravel, depositions of a rapid current may be and probably are graded from one form into another so that no definite line of demarcation exists.

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THE McPHERSON EQUUS BEDS.

BY

ERASMAS HAWORTH,

AND

J. W. BEEDE.

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THE McPHERSON EQUUS BEDS.

CONTENTS.

LOCATION.[1]

There is a formation of considerable economic and scientific interest located in McPherson, western Marion, Harvey, and eastern Reno counties. A large channel is carved out of the Permian shales and, in the northern part, Dakota sandstone. Its eastern limit, Plate XLV, is a line trending north and south along the west side of Sand creek to a place a few miles north and west of Lehigh, Marion county. Here it turns westward about twenty miles, then northward to the Smoky Hill river. Its western boundary, beginning at Smoky Hill river, runs south just east of Edward's creek to the Little Arkansas river, south of which the sandhills seem to encroach upon its area. It is well shown in the wells at Halstead and in all probability extends south to the general Tertiary or Pleistocene area along the Arkansas river. The "Tertiary grit" referred to by Professor Hay,[2] just east of Wichita, is probably an outcrop of this formation, as on the margins of the area, and the isolated patches, the sand is imbedded in a limy matrix which resembles the "Tertiary grit" farther west.

Over the deeper portions of the channel and well to its western edge lies a chain of lakes and basins extending from the large basin two miles west of McPherson to the Arkansas river south of Patterson. The area north of the Little Arkansas river is about eight

1 Mr. Beede did the greater part of the field work indicated in this paper.
2 Bulletin 57, U. S. Geological Survey, p. 34 and fig. 9.

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hundred square miles. South of it, it is probably over one hundred square miles, exclusive of the sandhills.

TOPOGRAPHY.

The rough surface of the Permian to the east, the Dakota to the north, and the peculiar topography of the sandhills to the southwest, form a marked contrast to the monotonously level surface of the Equus beds area. There are several places where one may travel three or four miles without rising or descending twenty feet. Along the east and west section lines two miles north of McPherson one may travel ten miles without passing a sag of more than twenty feet. As a rule there is just slope enough to the surface for good drainage, while occasionally the water stands in lakes and basins in slight swales in the surface. The largest of the lakes is Lake Inman, ten miles southwest of McPherson. The largest basin is nearly three miles in diameter, and is situated two miles west of McPherson.

The divide between the Arkansas and the Smoky Hill river passes through this area and averages a little more than 1500 feet above sea level.[1] The Arkansas river at the southeastern limit is 1290 feet, a fall of 200 feet in sixty miles. The Smoky Hill river, at its nearest approach, is within four miles of the divide, but its bed is nearly 200 feet below it. The Little Arkansas river drains the entire area of the Equus beds except a very small portion north of the divide, drained by the Smoky Hill, whose small tributaries are rapidly cutting into the divide, and will cause it to migrate farther south in the course of time, as the streams on the south are already at their base level and are not carrying the soil away to any considerable extent.

STRUCTURE.

These beds consist of alternating layers of sand and clay with a stratum of "volcanic ash" in part of the northern area. Near the bottom of the deepest part of the channel there is a heavy stratum of gravel, as shown in sections 1, 2, and 3, figures 1, 2 and 3 of Plate XLVI, which pass through McPherson, Harvey county, and Halstead respectively. This bed lies at a depth of 140 to 150 feet or

1 U. S. Topographic Sheets.

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ALCES, SPECIES UNDETERMINED. FROM THE LOESS NEAR KANSAS CITY, FIFTY FEET BELOW SURFACE.
(Photographed by Williston, 1896.)

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more at McPherson and contains an abundance of water, as it does wherever it is found. The upper part of the gravel stratum grades into a stratum many feet in thickness, which is partly argillaceous and partly arenaceous, sometimes containing isolated sand beds, or at least sand beds of great irregularity, and which contain very little water. The upper surface of this stratum is nearly on a level with the rim of the deeper channel (see sections referred to above). Over this and also extending over a very slightly undulating Permian floor for fifteen miles to the east is a stratum of sand varying in thickness from 30 feet (at McPherson, according to Prof. S. Z. Sharp) to 3 feet in other places farther east, but averaging 6 or 8 feet in thickness. This stratum also contains a good supply of water. It covers nearly the entire area of the Equus beds except perhaps a portion to the north. The uppermost stratum is composed of clay varying in color and texture. It covers the entire area and is from 10 to 35 feet in thickness. Within this clay layer in the northern part of McPherson county is a stratum of volcanic ash from 18 to 24 inches thick.

Nodules of calcium carbonate are frequently found in both the upper and lower stratum of clay. As a rule they are very irregular in form, but generally show a slight roundness of form. Some of these are quite hard, while others are very soft, as is the case at the McPherson sand pit on the Boggs farm two miles southeast of the city, where it is 20 inches thick in places. A specimen of this was submitted to Dr. G. P. Grimsley, who states that it is "one mass of small prismatic crystals with pyramidal terminations, with strong double refraction and no cleavage. They effervesce with acids and are crystals of aragonite ($CaCO_3$), the orthorhombic form of calcium carbonate." No structure could be determined in the hard nodules. Doctor Grimsley pronounces the volcanic ash as "glass grains or flakes, fine and angular, some of which are feebly doubly refracting." A specimen of the sand was examined by him and found to be "rounded quartz grains with a number of angular ones." Specimens of Dakota sandstone and sand from Dakota sandhills were also pronounced of the same character, except differing in fineness. As no feldspar grains were found in the sand it would

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seem to have originated from the Dakota sandstone rather than to belong to the Tertiary sands at the west, or the glacial sands farther east.

The fossils of this formation are those of the Equus beds according to Dr. S. W. Williston. Those reported are:[1] *Megalonyx*, subsequently described as *M. Leydeyi*, *Equus major* De Kay, *Spherum striatum* Lam., *S. Sulcatum* Lam., *Pisidium abditum* Haldeman, *Anodonta* sp., *Valvata tricarinate* Say, and *Gammaria* sp.

It may be well to note here the physical characteristics of the rocks through which the valley containing the Equus beds and the present valley of the Smoky Hill river are cut. The former is in the main cut through soft, easily eroded Permian shales. The northern portion has been cut through a considerable amount of Dakota sandstone. The 200 or more feet removed north of this is largely Dakota (60 feet of Permian). The section at the Smoky Hill buttes will give a good idea of the general nature of the rock: A few feet of soft sandstone at the bottom, then 110 feet of shale, 200 feet of sandstone (now soft and friable), and a covered slope constitutes the section. The latter is probably sand, as the water percolates through it freely down to the top of the shales, where it breaks forth as springs. The upper part of the 200 feet is a comparatively hard sandstone 10 or 12 feet in thickness. Though the texture of the materials in the above section may vary, and does for different localities, the hardness and friability remain practically constant, making the material admirably suited for rapid erosion. This is true of the entire eastern portion of Saline and McPherson counties.

ORIGIN.

Two papers have been published on this formation, one by Professor Udden,[1] the other by Professor Sharp.[3] The latter expresses the opinion that it is of glacial origin. It was thought that the ice formed a dam across the Kansas river somewhere below and that the water, backing up to Salina, burst through the divide at the place where the north end of this formation is situated. In evi-

1 Udden, American Geologist, vol. VII., No. 6, June 1891.

2 Loc. cit.

3 Bulletin Kansas State Board of Agriculture, quarter ending March 13, 1894, pt. 2, pp. 26, 30.

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dence of this theory he cites some boulders on Battle Hill as being of glacial origin, dropped or deposited by a stranded iceberg from the terminus of the ice sheet.

The boulders on Battle Hill, Battle Hill township, McPherson county, are not the rounded quartzite boulders of the moraine, but cross-bedded sandstone of the Dakota formation lying nearly in place. They are about 3 feet thick, hard and angular, some of them quite large. There is also an absence of other moraine material, which a melting iceberg or ice sheet would certainly have deposited. Rocks very similar to these may be seen in place a mile southeast of Salina, two miles north of Twin Hills, (northeast corner of Delmore township, McPherson county,) and four miles west of Battle Hill. Here the soft, almost incoherent sandstones, removed from beneath the hard sandstone, which allowed the large blocks of the latter to gradually tip and tilt over the surface of the hill, and some of them have worked their way down its sides some distance. In one of these, on the northeast face of the north hill, the lower part grades into brownish Dakota sandstone.

The elevation of Battle Hill is 1550 feet, which is about the same as the elevation of the highest of the deposits of the Equus beds. The elevation of the terminus of the ice sheet in Shawnee and Wabaunsee counties, so far as definitely located, is about 1050 feet, or not over 1100 feet above sea level.[1] The planation of the surface is so slight that were it not for the small amount of material left by the glacier it would have been difficult indeed to recognize the former existence of glaciers in that portion of the state. Consequently it seems probable that the ice sheet was comparatively thin at its southwestern portion, the limit of which is even yet not entirely known. The elevation of the divides between the Kansas and Marais des Cygnes rivers south of Topeka is 1100 feet. This is over 400 feet below the boulders at Battle Hill, or the more elevated deposits of the Equus beds. How far up the Kansas river the loess is found is not known, but it probably does not extend above Topeka as far as to the summit of the flint hills in Wabaunsee county. It seems probable, therefore, that the waters of the Kansas river would have flowed around the foot of the glacier to the east of

1 All elevations based upon U. S. Topographic Sheets.

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these hills rather than to rise to an elevation of 1550 feet, which is even higher than the divide between the Kansas and the Neosho river in the flint hills of Wabaunsee county, which are now considered to be quite above and south of the terminus of the ice sheet.

Professor Udden in the article above referred to suggests that the waters which deposited these beds must have connected with another body of water in the valley of the Smoky Hill river to the north, and states that the river has cut its channel through these deposits.

The elevation of the McPherson divide at its central point is a trifle over 1500 feet. To the southward at a distance of thirty eight miles the Arkansas river flows at an elevation of a little over 1400 feet, or a fall of 100 feet in thirty eight miles. The bed of the Smoky Hill river eight miles farther north is 1300 feet. The city well at McPherson, starting 1475 feet above sea level, was put down 150 feet (the present water supply is taken from a depth of 140 feet) without striking the bottom of the deposit. This makes the bottom of the well 25 feet above the bed of the Smoky Hill river two miles south of Lindsborg, or about the same level as the bed four miles east of Marquette, still on the northern boundary of the Equus beds. The present elevation of the Arkansas river at the mouth of the Little Arkansas is 1290 feet. This difference of elevation of the two rivers is party due to the fact that the Smoky Hill flows nearly east across the north end of the beds while the Arkansas flows southeast, making its distance greater in crossing the southern end of the formation. The relation of the two river beds and the records of the McPherson and Halstead wells is shown on section 4, figure 4, Plate XLVI. The section begins at the mouth of Sharp's creek and passes along the western edge of McPherson and a trifle east of Halstead to the Arkansas. It will be seen at a glance that the two rivers are at the same level at the extremities of the elevation and that the gravel in the McPherson well lies in exactly the same level, while the gravel of the Halstead well passes below it. The fact should also be borne in mind that the Arkansas river has reached its base level and filled its channel to some extent, though how much is not definitely known.

The above figures would seem to indicate that at one time the

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Smoky Hill river ran south instead of north and emptied into the Arkansas. But it is difficult to understand why it should have excavated so great a channel and covered so wide a flood plain here and so narrow a valley west of Marquette. However, the encroachment of the sandhills on its southern area may offer a slight suggestion as to the partial choking of the southern outlet causing more rapid deposition to the north, and thus elevating the channel and widening the flood plain.

But there are other facts which seem to detract from this explanation of the origin of these beds. If the Smoky Hill river at one time flowed south into the Arkansas, then one of a number of conditions must have obtained.

First: The Saline could have received a short tributary from the southwest, occupying the position the Smoky now has throughout that part of its course above Salina where it flows north. The source of this tributary could have gradually migrated southwestward by natural processes until it captured the Smoky at the point of the big curve in the present river. The accumulation of sand above referred to along the northern side of the Arkansas would have assisted in this by elevating the mouth of the old Smoky. But unfortunately for this view no part of its course south of McPherson is as high as the high McPherson ridge, which is 1550 feet above sea level near McPherson to the north. Were this ridge formed by the natural filling-up process in the old valley of the Smoky before its capture, we should find some evidence of a corresponding filling further up stream in the present valley and a widening of the valley corresponding somewhat with the wide valley now occupied by the Equus beds. No such filling or widening of the valley is noticeable. Further, at all points above the McPherson ridge the bottom of the channel must have been at least as high as the ridge, and a short distance away it must have been higher. At present one must pass upstream over thirty miles, to above Ellsworth, before the river channel has an elevation of 1550 feet. After the capture, on account of the Saline near Salina being so much lower than the Smoky in its hypothetical position, a rapid deepening of the channel would have occurred throughout a distance of from thirty to fifty miles above Salina, and a new flood

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plain, the present one, would have been formed. No such phenomena have been observed. The present wide valley above Salina also somewhat opposes this view, as it is difficult to understand how the short tributary supposed to have captured the Smoky could have produced so wide a valley, while its width and depth at present between Lindsborg and Salina seem altogether too great to have been excavated since the deposition of the Equus beds. The Smoky Hill buttes, Soldier Cap mound, Iron mound, and North Pole mound register the ancient elevation of the surface of Saline county, and indicate the removal of over 200 feet of material consisting of Dakota sandstone and shales and Permian shales, from the entire valley, which is nine miles wide in its widest place, including Dry creek valley. The valley between the Smoky Hill river and Dry creek is now largely covered with Pleistocene river deposits with occasional mounds of Permian shale rising to the surface. The average width of this valley is two and one half miles, over which the sand and clay average about 35 to 40 feet in thickness. The bed of Dry creek is about on a level with that of the Smoky Hill river, and during very high water in the latter its overflows its banks at Bridgeport and part of the water runs down Dry creek and empties into the Saline river north of Salina.

Second: It may be supposed that at one time the Saline and the Smoky flowed south into the Arkansas, joining each other at the big curve in the Smoky south of Salina. In this case a short tributary to the Solomon occupying the position of the present Smoky between Salina and Solomon City would have been the capturing stream, tapping the Saline river near Salina, and ultimately causing the Smoky to flow up the old Saline channel from the point of confluence of the two streams to the point of capture. The whole valley of the Saline, therefore, must have been elevated above the McPherson ridge and probably would have had a flood plain of considerable width, while the flood plain of the upper Smoky would have been about the same as above given in the first supposition. When the capture was made the great fall from this supposed elevation at Salina to Solomon City would have caused a rapid deepening of the channel in both the Saline and the Smoky, and new flood plains would finally have been formed along both

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streams, as already explained for the Smoky. No such conditions have been noticed along either stream. Further, the great elevation required for the Saline would have carried it across the uplands into the Solomon above Minneapolis. Neither does the character of the present valley between the mouth of the Saline and the mouth of the Solomon river appear to have been so recently a mere lateral to the Solomon only a few miles long.

Third: If the materials of the Equus beds were brought down from the west by the Smoky Hill river, or by any other stream, or if the materials are largely of glacial origin, then they should correspond closely in character with the recent river sands or with the glacial material. Almost every handful of sand gathered from the valley of the Arkansas, the Smoky, or the Saline, streams passing through the Tertiary regions of the west, is largely composed of feldspar gravels, and frequently fragments of other rock-forming minerals are seen. Likewise the sands of the lower Kansas river valley which are so largely of glacial origin have a great abundance of feldspar gravels. But the sands of these Equus beds so far as examined by Doctor Grimsley seem to have no feldspar whatever. This strongly implies that they are obtained directly from the Dakota sandstone, as that rock is almost if not entirely free from feldspar gravel in this part of the state.

At present it must be admitted that no satisfactory explanation of the origin of the Equus beds channel, nor of the agency for the deposition of the materials, has been advanced. A further study of the problems involved is in progress.

ECONOMIC INTEREST.

This strip of country is particularly fertile and very valuable farm land. The soil seems to possess nearly all the peculiarities necessary to the growth of the various farm products. It is so level that it can almost all be cultivated, the uplands being about as good as the bottom lands. The water supply is almost ideal. Over the entire eastern portion at a depth of 18 to 30 feet, pure, soft water is found in good supply. The soft arenaceous texture of the clay above the sand beds containing the water makes well digging easy. Over the western portion the wells vary from 40 to

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150 feet in depth, but the water is always good and there is an "inexhaustible" supply of it. The wonderful amount of water contained in this lower gravel bed of small extent is remarkable. A glance at section 4 will suggest that the supply may be traced, upon further investigation, to the Smoky Hill and Arkansas rivers.

The streams have no native timber on them worthy of note, but on the uplands and valleys cotton-woods and other trees thrive wherever planted, their roots penetrating the clay to the sand for water. This is in marked contrast to the country just to the east, where the Permian shales are the surface rock. Here the cotton-wood trees grow to be fair sized trees and then die.

The rainfall is sufficient on this area to produce a fair crop almost every year. The area covers over nine hundred square miles and may be said to be the richest farm land of any area of its size in Kansas, and its inhabitants the most thrifty.

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THE PLEISTOCENE OF KANSAS.

BY

S. W. WILLISTON.

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THE PLEISTOCENE.

Following the terminology of Dana, the Pleistocene of North America has two well limited periods, the Glacial and the Champlain, the former characterized by the prevalence of glacial conditions, the latter by fluvial, by an ameliorated climate, luxuriant forest growths, and more or less submergence. The third period of the Quaternary, the Recent, is characterized by a partial return to the colder climate, the elevation of the land, the development of the prairies, and a drier climate. It is precisely at this time, that of the change from the warmer and moister climate to the colder and drier one, that we would expect the culmination of the more susceptible forms of life and rapid change in the flora and fauna. Cope has already called attention to this change in an article that I will quote from further on. Every additional fact furnished from Kansas seems to substantiate his conclusions that the Megalonyx fauna of the east and the Equus fauna of the west were contemporaneous and that both occurred during the period of depression, that is during late Pleistocene time. It is strange that some writers should still follow Marsh in his location of the Equus fauna in the Pliocene. That Marsh does so is not surprising, since, as Hatcher has shown, he has confounded the Loup Fork and Equus faunas in part, and seems to be unaware of recent publications on the subject.

That there was a depression in Kansas during Champlain times is certain. That this depression was considerable I do not believe, inasmuch as the river terraces in the eastern part of the state nowhere exceed twenty feet in total height.

"The Equus beds are always to be distinguished by the presence of Elephas primigenius, when other forms less easily preserved are not recognized."[1] This species is the most common fossil, or at

1 Cope Vert. Pal. Llan. Estac. p. 75.

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least the one of which we have most knowledge, in the Quaternary deposits of the state, and is the most widely distributed, and the conclusion is, hence, that the Equus beds are the prevailing superficial deposits of the state, a conclusion borne out by the other vertebrate fossils that are known. That all the forms given below were contemporaneous, is of course not yet proven, but I believe that they were.

Cragin, in a recent paper[1] has given a preliminary notice of three terranes in Clark county, which he wrongly ascribes to the late Pliocene. The lithological characters of these terranes are of course nearly worthless save for local use, and he has not yet given a critical list of the vertebrate fossils contained in them. The lowermost of these, which he calls the Meade gravels, contained "abundant remains of horses, llamas, elephants, turtles, etc.," some of which are "Elephas imperator (?), Megalonyx leidyi, Equus complicatus, E. curvidens, Auchenia huerfanensis, etc." Lying upon this terrane are the volcanic ash beds, which he calls the "Pearlette Beds," and upon the ash beds are the "Kingsdown Marls, consisting of yellowish brown, lacustrine or slack-water marls containing variously shaped concretions of carbonate or silicate of lime." This latter included Elephas, and reached a thickness of one hundred feet in Clark county, and has "more than twice that thickness at certain localities on divides further west." All these terranes he locates in the Equus beds of Cope. It seems to me that further and careful study of the fossils is desirable before we assume as certain that the late Pleistocene in Kansas reached the great thickness of over two hundred and fifty feet.

The following list includes all the species of vertebrate fossils found in the Kansas Pleistocene, of which I have any knowledge:

Homo sapiens.
Mastodon americanus.
Elephas primigenius.
E. imperator (?). [Cragin.]
Bison americanus.
Bison antiquus.
B. crampianus.

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1 Colorado College Studies, Vol. VI, p. 53.

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B. alleni.
Alces, species indet.
Equus major.
E. excelsus.
E. occidentalis.
E. complicatus. [Cragin.]
E. curvidens. [Cragin.]
Platygonus compressus.
Camelops kansanus.
Auchenia huerfanensis.
Camelids, species indet.
Megalonyx leidyi.
Mylodon (?) species indet.
Canis lupus.
Canis, species indet.
Geomys bursarius.

Homo sapiens: The contemporaneity of man with the Equus fauna is, I think assured by the discovery of arrowheads associated with the remains of *Bos antiquus*, in Gove county, by Mr. H. T. Martin.

Mastodon americanus: This species is rather rare in Kansas. An excellent pair of jaws was discovered some years ago in the alluvium of the Wakarusa valley, near Lawrence, and I have further knowledge of the same species from Manhattan and Jewell county. Reputed discoveries of this Mastodon are not always to be trusted, since it is commonly confounded with *Elephas primigenius.*

Elephas primigenius: This species has been found in nearly all parts of the state, but occurs most frequently in the western and southern parts, and yet more frequently in the Indian Territory south of Kansas. Three years ago an extraordinary deposit was discovered in Lane county in the valley of the Smoky Hill by Mr. Chas. Sternberg, the veteran collector of Kansas. From a small area, not more than two or three rods in diameter, portions of a score or more of these animals were obtained, together with others of *Equus excelsus* and of a small dog. Some seventy or more of the teeth are now in the University collection. The deposit was in a

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basin in a small ravine that had been hollowed out of the Niobrara chalk, and considerably below the Loup Fork beds, which here yielded teeth of *Protohippus placidus.* In the vicinity, and from a higher horizon were obtained teeth of *Protohippus lenticularis*, a typical Goodnight beds species. There can be no question of the local character of the Elephas deposit. Everything indicates that the spot was the site of some old spring to which the different animals had come and died.

A large series of *Elephas primigenius* bones were obtained some years ago from the reddish alluvium of Clark county.

Bison americanus: Teeth agreeing quite with this species were obtained some years ago from eight or ten feet below the surface in the alluvium of the Wakarusa valley. There is also a jaw of this species in the collection from the southern part of the state bearing this label: "Found on strip pit (coal), on S. L. Cherry's place, in blue muck clay and on top of coal, six or seven feet from surface." Awhile ago Professor Hay sent to me for examination a part of a skeleton from the western part of the state, partly fossilized, and which Hay thought to have been a contemporary with extinct species.

Bison antiquus: The only known occurrence of this species is in Gove county, in the valley of the Smoky Hill, where Mr. H. T. Martin obtained for our museum two years ago a complete skeleton, which will be mounted. The material in which it was found was quite like that of the Elephas and Platygonus deposits not far distant. As already stated, with these specimens were found arrowheads, well fashioned but small.

Bison crampianus: This species was described by Cope from a part of a skull found near Wellington, associated with *Elephas primigenius.*

Bison alleni: This species was described from a specimen discovered in the Blue river near Manhattan. The description is meagre. The horizon is located in the "lower Pliocene." Upon what evidence I know not, as the type specimen was purchased by myself from the finder of it.

Alces species indet: An extinct species of moose or an allied animal is represented by maxillary and mandibular bones in the University

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collection, figured herewith. Plate XLVII. There is no record of the collector, though I doubt not they were obtained by Judge West, who rarely attached his name to the specimens in the collection. They have the following label, in Judge West's handwriting: "From the loess near Kansas City, fifty feet from surface," and are accompanied by several skulls of *Geomys bursarius*, all of which are partly enclosed in an exceedingly hard matrix. Possibly the moose is *Cervalces americanus*, of which I can find no adequate description of the dentition. The teeth are larger than are the largest specimens of the living moose in our collection, obtained by Professor Dyche. The upper molars differ especially in the presence of a prominent tooth-like process or projection near the base of the premolars on the outer side posteriorly, and which encloses a cavity between it and the tooth. It is largest on the second premolar, and is represented by a rudiment on the first true molar at the base of the strong middle column. In addition, the second and third premolars differ markedly in the much stouter anterior column exteriorly, which is dilated and turned backwards, and which would give, when worn, a T-shaped surface. The first and second upper molars have a small, tooth-like process in the valley internally. If the species is not *C. americanus*, it must be distinct from any hitherto described.

Equus major: So far as I am aware, the only occurrence of this species in Kansas, is from the vicinity of McPherson, associated with *Megalonyx leidyi*. The determination is by Cope.

Equus occidentalis: Several teeth from Bluff creek, Clark county, agree perfectly with the figures and descriptions of this species given by Cope.

Equus excelsus: A complete upper dentition, agreeing quite with this species, was found in the Elephas deposit in Lane county before mentioned, by Sternberg.

Platygonus compressus: The skeletons of peccary obtained from near Goodland in this state I am more and more inclined to identify with this species, notwithstanding the differences they present. If the species is *compressus*, it is very important in the correlation of the Megalonyx and Equus beds.

Camelops kansanus: This species, described in 1856 from the

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"Drift" of Kansas by Leidy has never since been identified. Possibly it is the same as one or the other of the following species:

Auchenia huerfanensis: This species was described by Cragin from Texas. Its identity with the Kansas species needs further verification, inasmuch as the bones from this state examined by Cragin are uncharacteristic.

Camelid, species indet: Two metapodials, differing considerably in size, are in the University collection, which can be referred to this family only at present. One of them, the smaller, was discovered by Mr. C. N. Gould in Barber county. The unworn fourth lower molar of a large species was discovered by Mr. F. H. Rose, about ten miles northeast of Dodge City.

Canis species, indet: A complete mandible of a small species of dog was obtained in the Elephant deposits in Lane county by Mr. Martin. I do not at present have access to the specimen and can not give the specific name.

Canis lupus: A complete skull and other parts of the skeleton are in the University collection obtained from near Goodland, in apparently the same deposits as those which yielded the *Platygonus* remains.

Megalonyx leidyi: An excellent skull of this species, the type specimen, was obtained a few years ago from the Equus beds near McPherson, associated with *Equus major*, a species found associated in the east with *Megalonyx*. Cragin has reported the same species from Clark county, associated with other species of *Equus*. He does not state upon what evidence the identity is based.

Mylodon (?) species indet: A fibula, figures 12 and 13, was doubtfully referred to *Mylodon* by myself in a paper in the Kans. Univ. Quarterly. The bone came from thirty feet below the surface in a well at Seneca, Kansas.

Geomys bursarius: A number of skulls of this species were found associated with remains of the Alces described above, fifty feet below the surface in the "loess" near Kansas City. The skulls can not be freed from the very hard matrix, but such portions as are exposed agree perfectly with the living species.

Bones of the living *Spermophilus tredecemlineatus* were found

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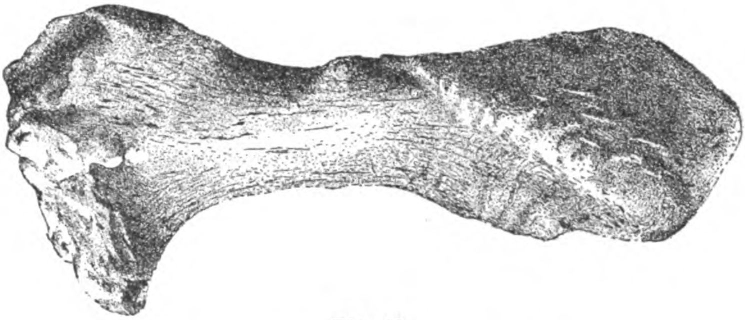

Fig. 12.
Mylodon Sp. External view of fibula.

Fig. 13.
Mylodon Sp. Internal view of fibula.

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associated with the bones of *Platygonus* at Goodland, but I suspect that they were from old burrows.

Cragin has reported Felids from the Meade gravels, and Cope has described a sabre-toothed cat *(Dinobastis)* from Oklahoma.

Usually the Pleistocene, or Quaternary deposits in eastern Kansas do not exceed sixty or seventy feet in thickness, though one hundred and fifty is the thickness given for them at Kansas City by Mudge. At Lawrence, borings in the river valley gave about sixty feet as the thickness, or about forty feet below the present river bed. Of course it is possible that borings elsewhere in the river valley might give greater depths. The material at these depths was coarse gravel, partly of glacial origin. Variations in the coarseness of the gravel and sand were found at different depths, but no fine, sandy marl was found save at or near the surface. I leave it for others to name the various "terranes!"

The Equus beds evidently form the whole of the superficial deposits of western Kansas. They are, towards the surface at any rate, composed of a light colored, calcareous marl, the Plains marl of Hay, with sufficient clay to make fair bricks, which burn a light red. Its depth it is impossible to say, though I suspect that it is considerable. If Cragin is right in ascribing two hundred feet and over as its possible thickness, then in all probability there are a hundred feet or more of it on the upland plains. In the river valleys, the material scarcely differs, save often for the presence of a greater proportion of calcareous material derived from the Cretaceous beds below them.

How these upland deposits were formed is not clear to me. That there could have been extensive lakes over these plains during Champlain times is impossible, since contemporary deposits, of local origin, are found in the valleys, containing vertebrate fossils of the Champlain epoch, and lakes on the uplands must need have been banked up to have existed. That they are river deposits is equally indefensible. Taking into consideration the uniform fineness of the material, the barrenness of fossils, and their poor petrifaction, and the absence of coarser pebbles, everything seems to show an aeolian origin.

Hatcher found evidence of unconformability between the Loup

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Fork and Equus beds in western Nebraska, and stated that Marsh had confounded them and confounded the fossils which he had described from them, which seems not at all unlikely in view of the bit of ancient history he has given us in the Amer. Jour. Science for December of 1896, in his scheme of the nomenclature and characteristic fossils of the later Neozoic epochs.

Since the Loup Fork is Miocene or early Pliocene and the Equus beds clearly late Pleistocene, it is quite certain that there must have been a considerable interval between them, which in Texas is represented by both the Blanco and Goodnight beds. The Goodnight beds exist in Kansas, and I confidently believe that the Blanco will be found also.

In conclusion because of its pertinency to the present subject, I will quote from a paper of Cope's in the American Naturalist for 1895, p. 598:

"The Equus beds are found covering areas of various extent in Oregon, Nevada, California, the Staked Plains, southern Texas, Chihuahua, the valley of Mexico. Their most eastern station is western Nebraska. They contain a fauna which includes one extinct species of the Megalonyx beds (Equus major Dek.) and the recent Castor fiber. They contain the extinct genus of sloths, Mylodon, of a species different from that of the east, and four species of camels of the genus Holomeniscus, and a peccary. Recent species of Canis and Thomomys occur, while two extinct horses (Equus occidentalis and E. tau) are common. The hairy elephant, E. primigenius, is abundant, while Mastodon americanus is rare, if occurring at all. The proportion of recent to extinct species and genera in the Equus beds is very similar to that occurring in the Megalonyx fauna, while they differ as to details. This fauna has also disappeared from the continent, a few species, as in the east, surviving to a later date. Was its disappearance due to a submergence, as in the east?"

That there was any submergence of the western plains during the Champlain epoch I can not believe possible.

His Megalonyx fauna of the east "includes the extinct genera of mammalia, Platygonus, Smilodon, Megalonyx, Mylodon, Mastodon,

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and extinct species of Bos, Dicotyles, Equus, Tapirus, Ursus, Castor, Arvicola, and Lagomys."

As is seen above, all these extinct genera, with the exception of Smilodon, which is replaced by Dinobastis, occur in Kansas.

"The remains of man have been shown to occur in the gold-bearing gravels. I have found them (obsidian spear and arrowheads) in profusion mixed with the bones of the extinct fauna at Fossil Lake, Oregon, in a friable and windblown formation. This man, however, so far at least as regards California, was not paleolithic, since he made mostly ground pestles and mortars."

"There is, therefore, considerable probability that man was a contemporary of the Equus fauna, and the Equus fauna was contemporary with the Megalonyx fauna of the east," all of which conclusions the evidence from Kansas substantiates.

The problems of especial interest in the Neocene deposits of Kansas are the position, thickness and characteristics of the Goodnight beds, the determination of the Blanco beds and the relative extent of all of these and of the Equus bedy overlying them.

As already stated, Marsh is hopelessly befogged on these subjects and his published statements are misleading.

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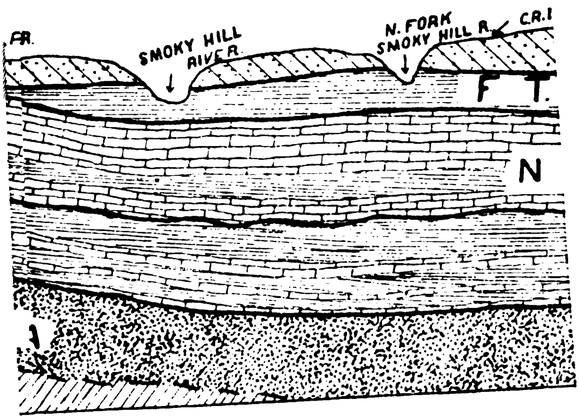

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Fig. 1.

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VERTICAL SECTIONS OF THE CRETACEOUS FOR NORTH HALF OF KANSAS.

Fig. 1. Relative position and average thickness of Upper Cretaceous.
Fig. 2. Details of Dakota and Benton.

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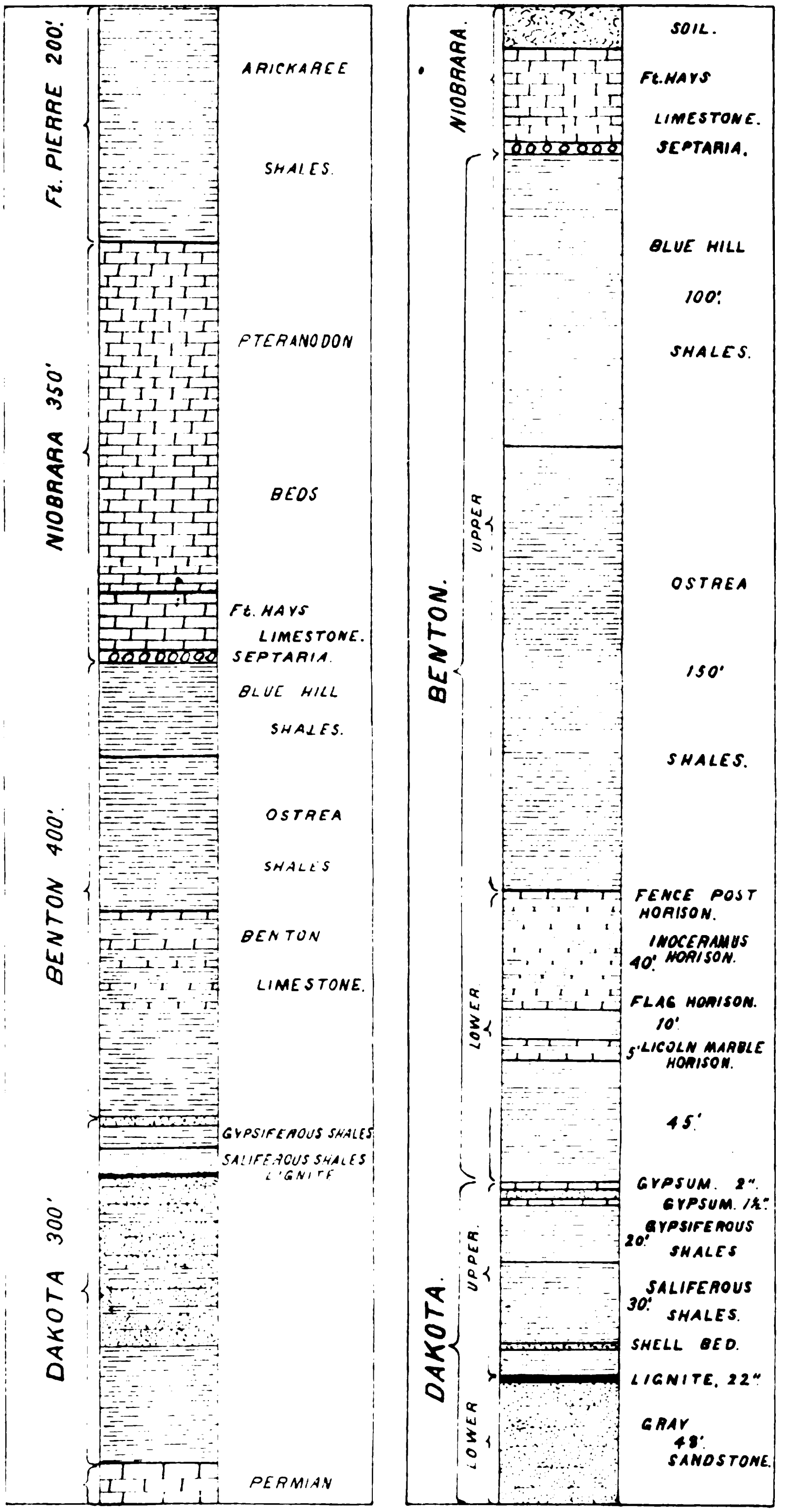

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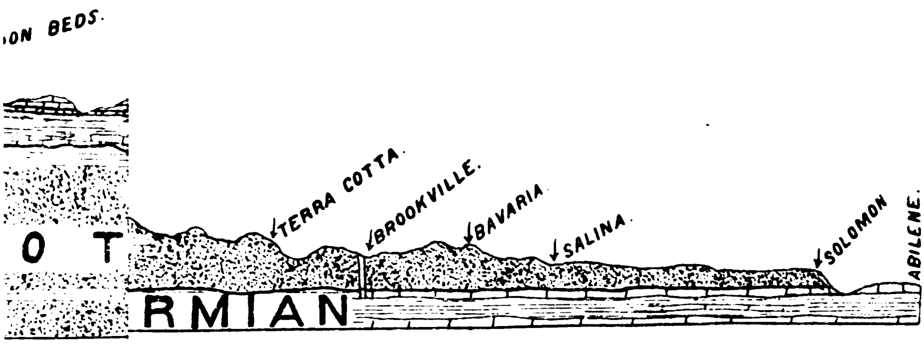

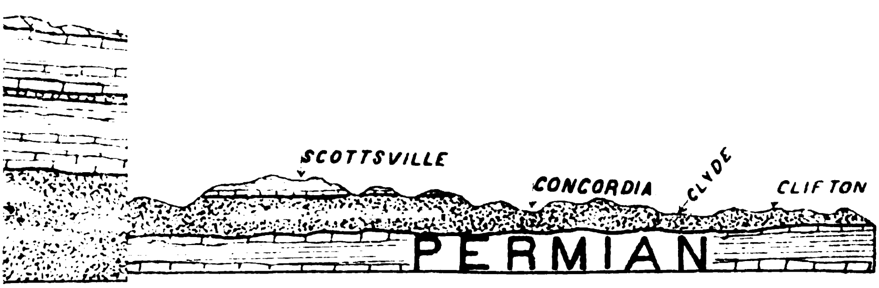

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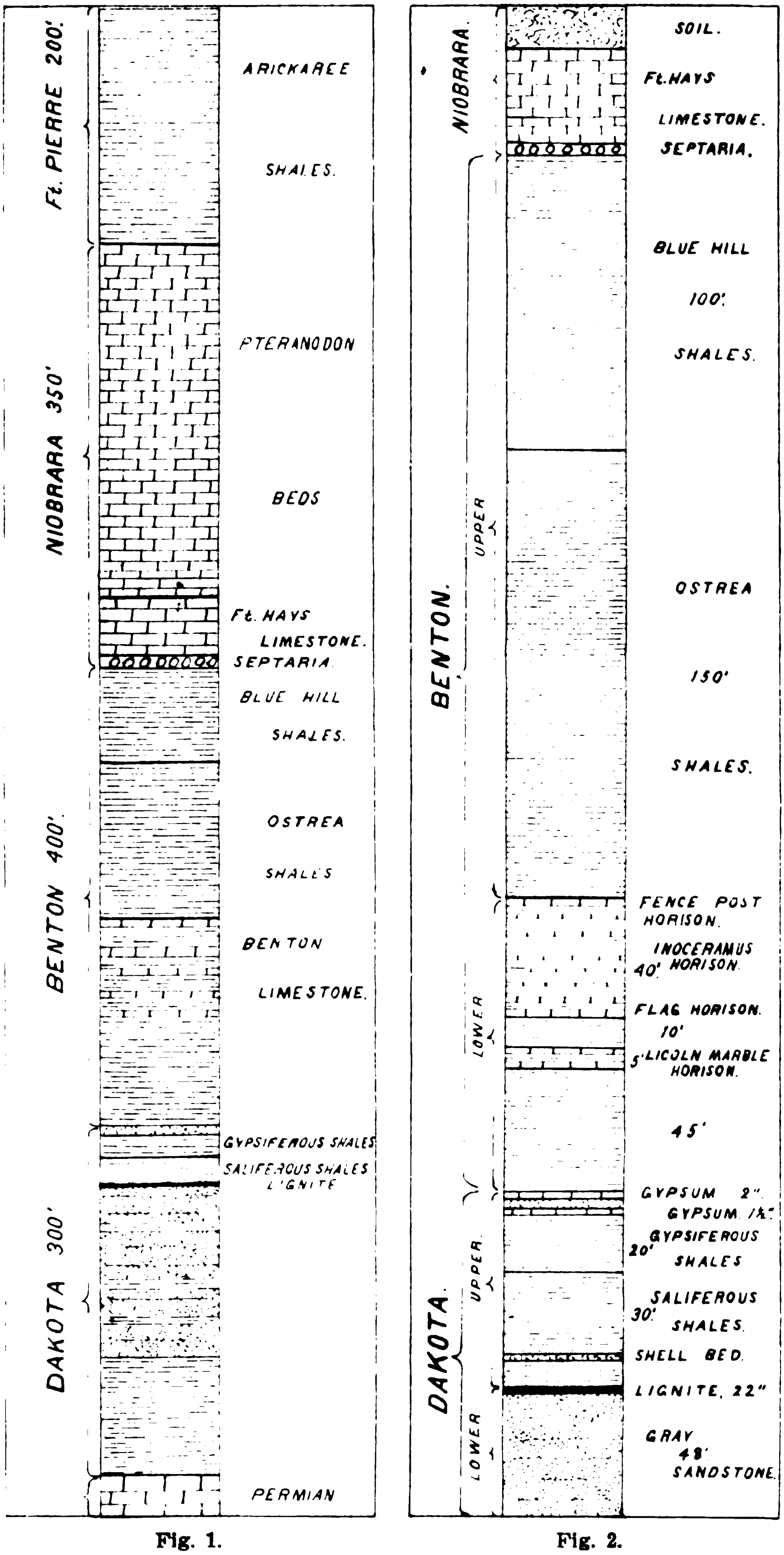

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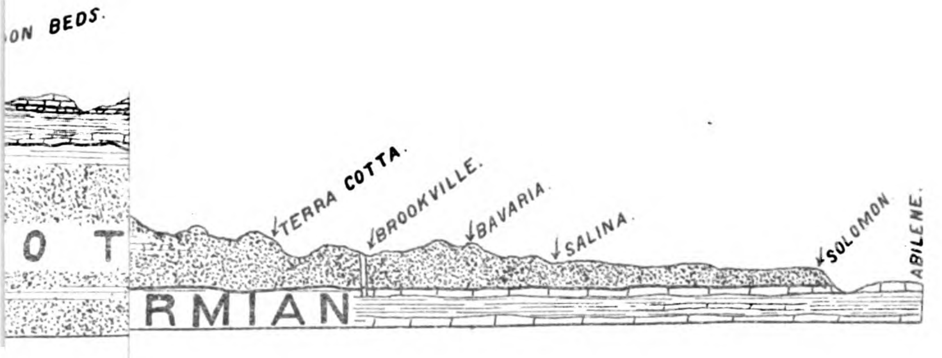
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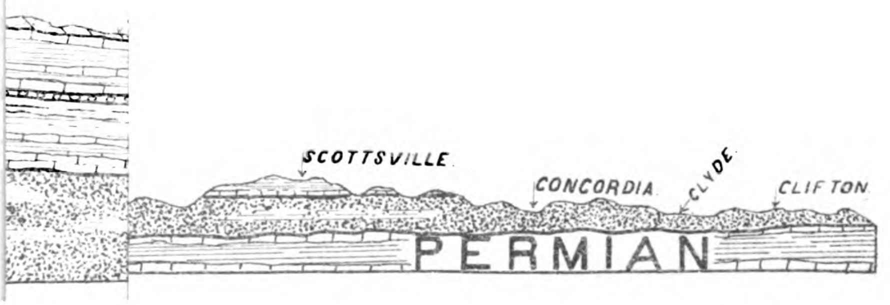
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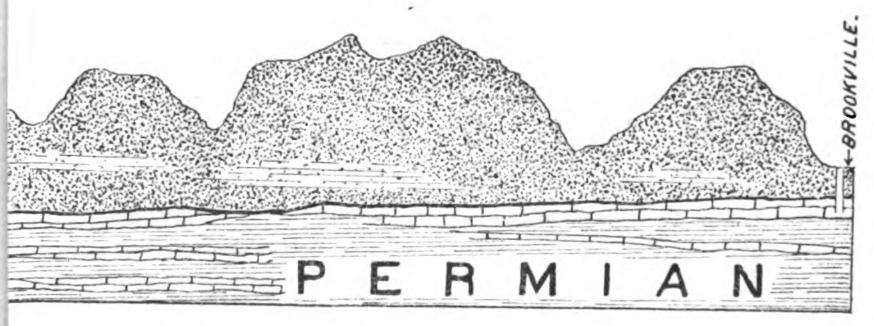

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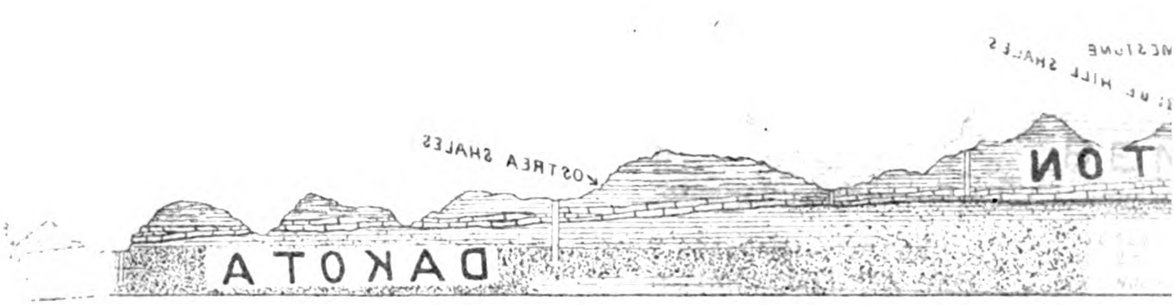

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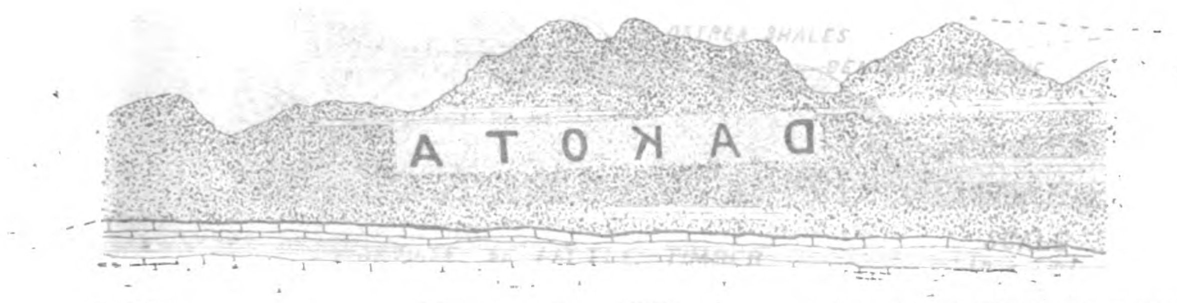

Fig. 2.

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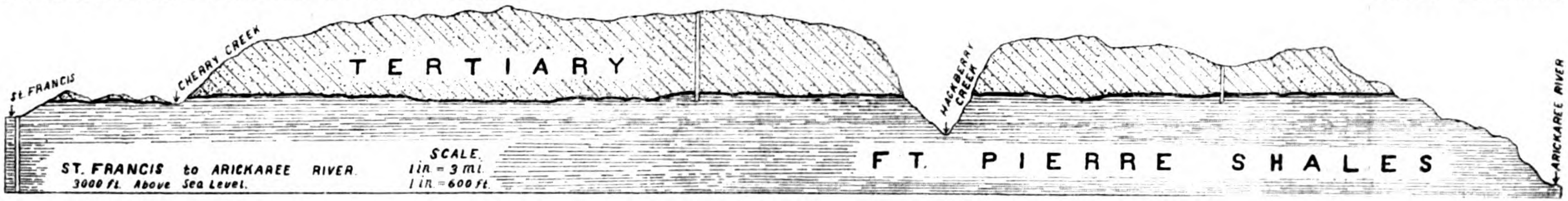

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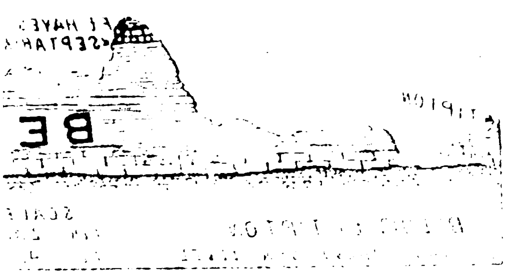

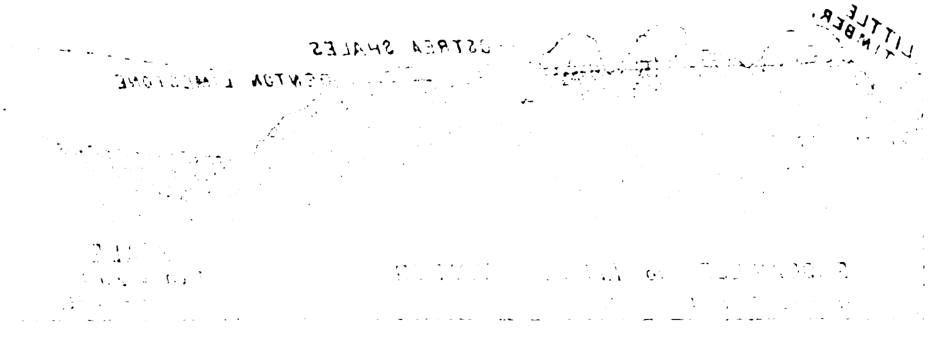

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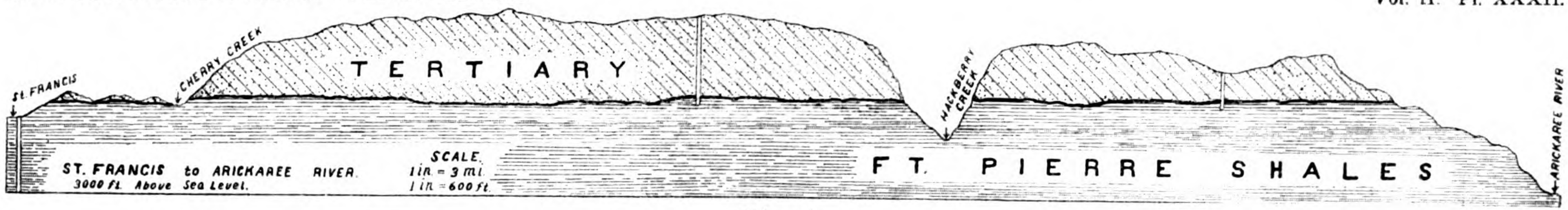

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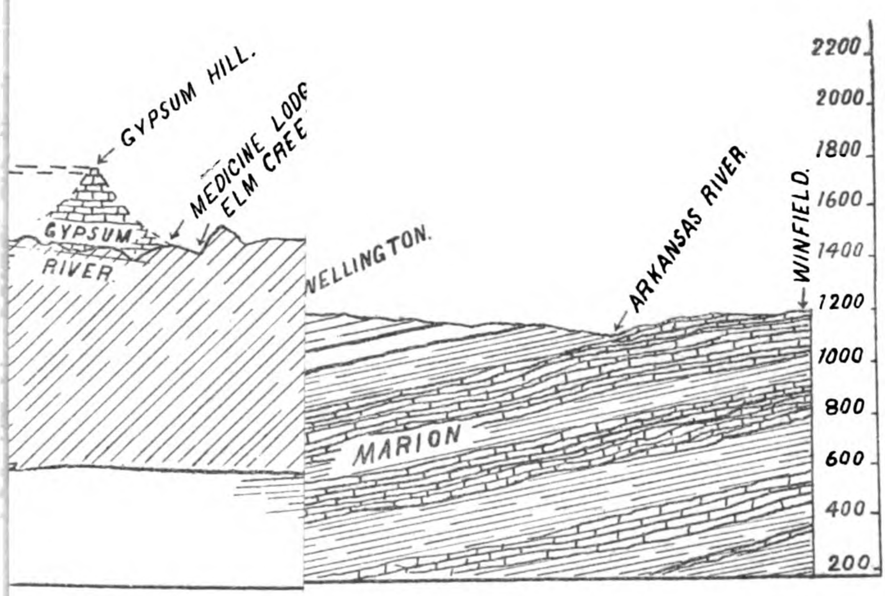

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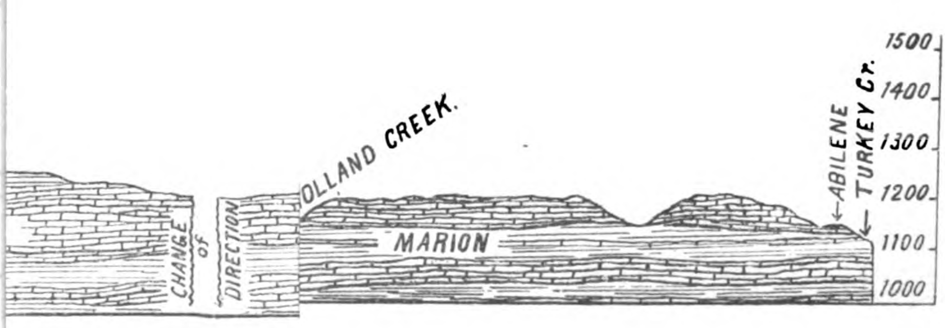

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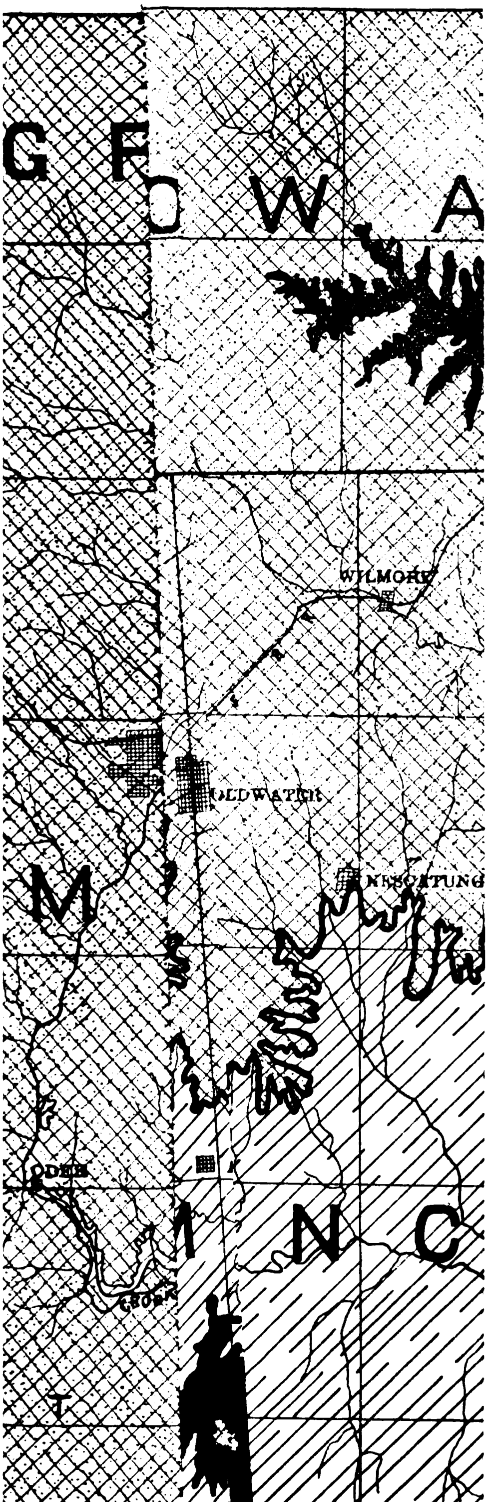

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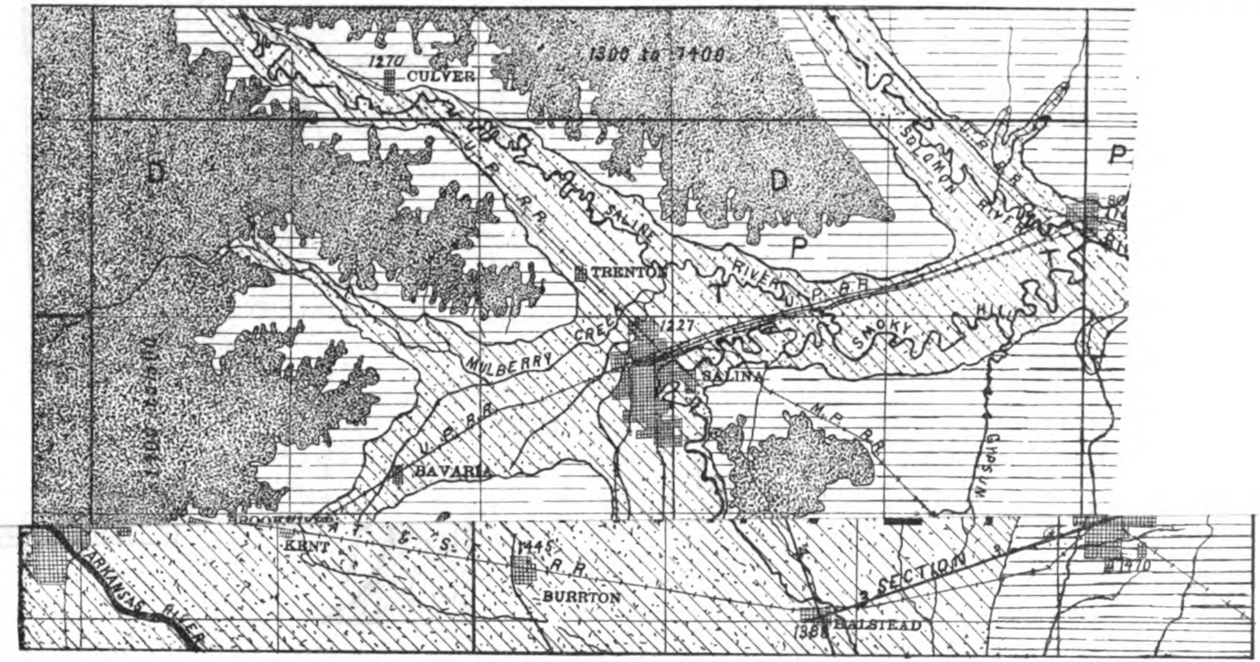

GEOLOGIC MAP OF McPHERSON AND VICINITY.

By C. S. Prosser and J. W. Beede.

Horizontally ruled ....Permian.
Solid black ....Comanche.
Heavily stippled ....Dakota.
Lightly stippled and ruled......Equus Beds.

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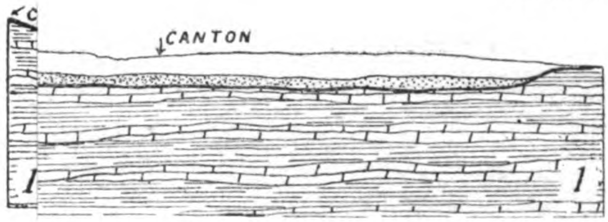

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