PHYSIOGRAPHY AND GEOLOGY OF SOUTH-CENTRAL KANSAS

by

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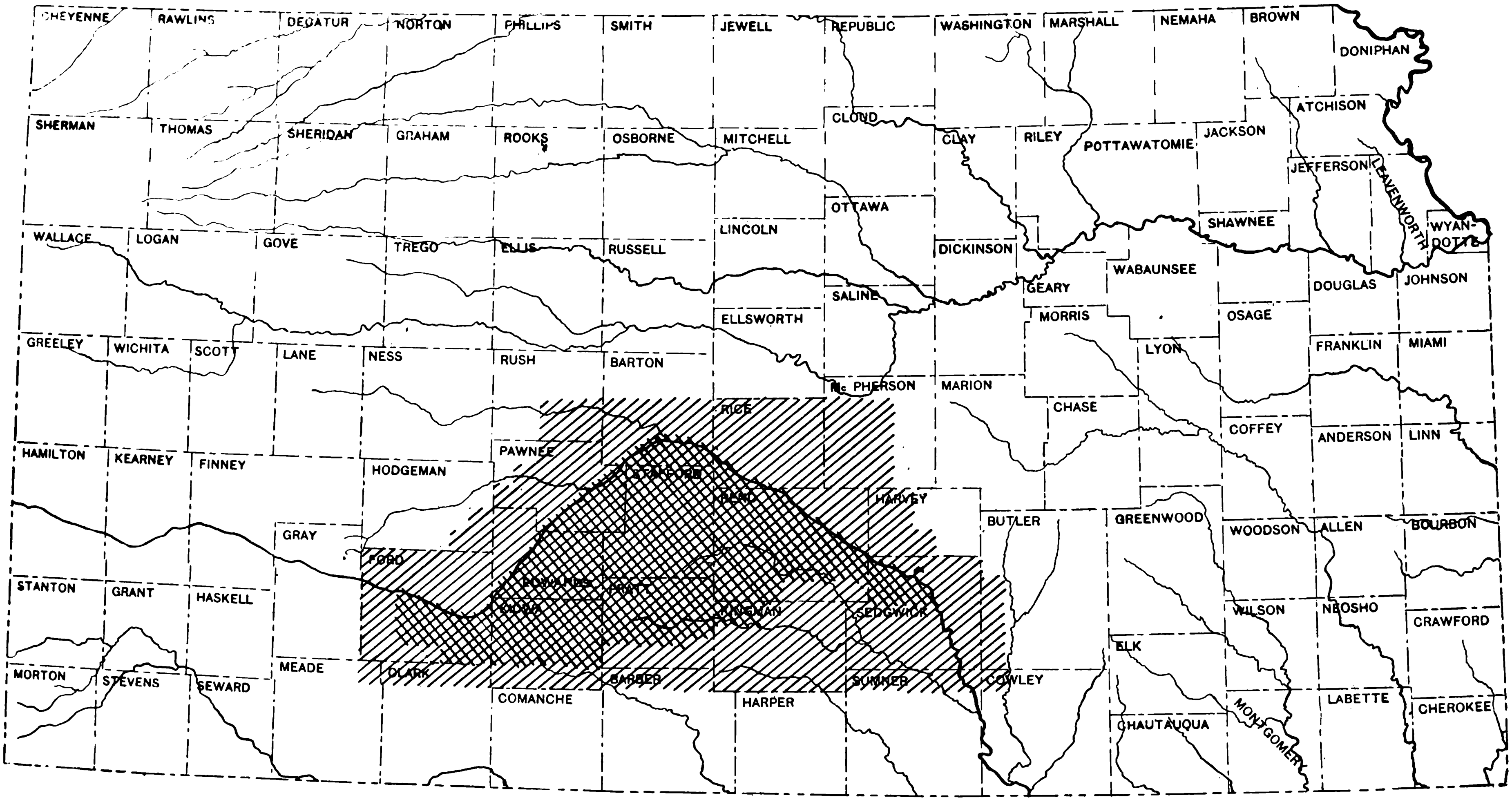
INTRODUCTION

Purpose of investigation. The geology and physiography of south-central Kansas have been of especial interest to the writer since his first acquaintance with the area in 1928.

This report has been written with the hope of contributing some new information concerning the natural features of south-central Kansas, about which very little has been published. Geological maps of this area are exceedingly generalized, and no maps based on detailed field work have ever been published.

One of the results of the present investigation has been an areal geological map (Plate V). The greater part of the area is covered by rocks of Tertiary age and younger, and is, therefore, geologically uninteresting to those engaged in the search for petroleum. However, a knowledge of the thickness of these deposits which overly the older rocks may be of use to those seeking, by geophysical methods, for structures favorable to the accumulation of petroleum.

The physiographic history of this region is far more complex than appears on first inspection. The writer has endeavored to unravel part of this history and



▨ area included in report.

▩ area studied in detail.

Plate I.

Index Map.

hopes that he may have succeeded in explaining some of the problems, such as the reason for the great bend of Arkansas River and the source and disposition of the sand in the dune areas. In addition an attempt has been made to present a picture of the pre-Tertiary topography of the region.

Location and size of area. The area described in this report lies approximately between 37° 20' and 38° 30' north latitude and 97° 10' and 100° west longitude. It occupies the northern portion of central-southern Kansas (Plate I) and includes all or part of the following counties: Barton, Rice, McPherson, Pawnee, Stafford, Reno, Harvey, Edwards, Ford, Kiowa, Pratt, Kingman, Sedgwick, Butler, Clark, Barber, Sumner and Cowley. The area involved totals about 6,500 square miles, of which the writer has studied about 4,100 square miles in detail.

Climate and Culture. This part of Kansas has a semi-arid to sub-humid climate. Two United States Weather Bureau Stations lie within the area, Dodge City near the western boundary and Wichita near the eastern boundary. The weather data for these two stations follow in tabular form (Table I), to permit of ease in comparison.

Table I.

	Dodge City (58 years)	Wichita (45 years)
Average yearly temperature	54.6	56.4
Maximum temperature	108 (July,1876,1933)	109 (June,1933)
Minimum temperature	-26 (Feb.1899)	-22 (Feb.1899)
Average annual rainfall, inches	20.69	29.89
Mean rainfall, by months, inches.		
January	0.40	0.73
February	0.72	1.20
March	0.94	1.80
April	1.99	2.86
May	2.74	4.41
June	3.24	4.56
July	3.10	3.17
August	2.67	3.01
September	1.89	3.01
October	1.37	2.38
November	0.80	1.59
December	0.61	1.00
Greatest rainfall in one year	33.55 (1881)	41.94 (1922)
Least rainfall in one year	10.12 (1893,1910)	16.11 (1917)
Percent total hours of sunshine	71	63
Wind: (Average)		
Prevailing direction	SE	S 1/
Direction highest velocity	N	NW
Highest velocity (miles per hour	58 (Jan.1877)	58 (March,1919)
Average number of days:		
Maximum temperature 90 or above	53	49
Minimum temperature 32 or below	126	94
Minimum temperature 0 or below	7	3

1/ Forty-five year average shows prevailing direction of wind at Wichita is from the south for <u>every</u> month of the year.

This brief summary indicates the average climate of the region. For locations intermediate between Wichita and Dodge City a fair approximation of weather conditions may be obtained by interpolating between the two sets of figures.

According to the above table rainfall is greatest in the growing months, a favorable circumstance for agriculture in a region of low rainfall. While the average figures indicate sufficient precipitation for crops, there are periods of drouth when the rainfall is less than normal. The year 1933 was the fourth consecutive year for such a drouth. However, in the preceeding 4 years (3 years at Dodge City) the rainfall was above normal. Hot south winds blow occasionally in the summer months and are disastrous to growing crops. The winters are usually "open". The average temperature for the winter months (December to February, inclusive) is 31.9 for Dodge City and 34.0 for Wichita. Average temperature for the summer months (June to August, inclusive) is 75.9 for Dodge City and 77.6 for Wichita.

The most important crop is winter wheat, followed by corn, kaffir corn, maize, and other forage crops. Locally, in areas close to Arkansas River where water may be obtained for irrigation from wells topping the underflow, sugar beets have been raised in recent years with some degree of success. In the lowlands (shown on Plate V as terrace deposits) near Hutchinson and Wichita, spring truck farming is profitably carried on, and the area near Hutchinson is famed for its crops of cantaloupes and other melons. Wheat and corn are raised in the sandy region, and where their cultivation is not practicable, the land is devoted to the grazing of cattle. Water is easily obtained from shallow wells in the sand hills.

Dust storms occur occasionally, especially in periods of drouth. The dust storms of the early spring of 1933 and 1934 were unusually severe. The writer talked with many of the older residents, some of whom had lived in this part of Kansas since 1880, and they agreed that these were the most severe dust storms within their memory. Thousands of square miles of land, formerly covered with buffalo grass, have been plowed up during the last two decades, and this vast expanse of loose soil is easily attacked by the wind. Lack of moisture had prevented the wheat from growing and in the absense of a protective covering an immense amount of fertile topsoil was carried away by the winds.

The residents of south-central Kansas are primarily dependent upon agriculture and its products. However, Wichita and Hutchinson are industrial centers possessing factories and flour mills. These are the largest cities in the area, Wichita having a population of 104,165 and Hutchinson 29,038 in 1932. An important part of the Kansas salt industry centers around Hutchinson, Lyons and Sterling.

South-central Kansas is steadily becoming more important in the production of petroleum. Several new wells are producing near Cunningham. Producing wells are found in the following counties (arranged in order of their production as of 1933): McPherson, Butler, Sedgwick, Cowley, Rice, Sumner, Reno, Stafford, Kingman, Barton and Edwards. Natural gas is produced in the following counties: McPherson, Cowley, Butler, Harvey, Reno, Rice, Edwards, Rush, Barber and Clark. Without exception, all of the counties in the area of this report have benefitted through money paid for oil and gas leases, and in the past several years of agricultural depression, lease money has paid much of the farm taxes in various counties.

Transportation facilities in this portion of Kansas are very good. The area is crossed by main and branch lines of the Atchinson Topeka and Santa Fe and Chicago Rock Island and Pacific and by branch lines of the Missouri Pacific (Plate V). Many all-weather highways, surfaced with conerete, bituminous mat or gravel, traverse this part of Kansas, (Fig.2). The main east-west lines of travel are highways U.S. 50 S. through Hutchinson, St. John and Kinsley and U.S. 54 through Wichita, Pratt and Greensburg. Important north-south highways run through Wichita, Kingman, Pratt, Greensburg and Dodge City. The Santa Fe Trail goes through McPherson, Lyons, Great Bend, Larned, Kinsley and Dodge City.

Method of investigation. It was manifestly impossible to cover every square mile of the area in the time available for field work. The writer has been familiar with this area since 1928, having spent part of that year and part of 1929 in field work there for the Midwest Refining Company. Subsequent trips added to his knowledge of this region and served to increase interest in the geologic and physiographic problems.

Field work on this specific problem was first begun in July and August, 1932. In December, 1932, two more weeks were spent in the field, and the remaining work was done in June, July and August of 1933.

The area was mapped by automobile survey, which was aided by the presence of roads on nearly every section line except in regions of sand dunes. While tracing the boundaries between various deposits every section line crossing the boundaries was traversed. The remainder of the area was traversed at greater inter-

Fig. 2.

Portion of a relief model of Kansas showing drainage, highways, cities and county boundaries.

Fig. 3.

Tertiary gravels, SE. cor. sec. 23, T. 24 S., R. 14 W., Stafford County.

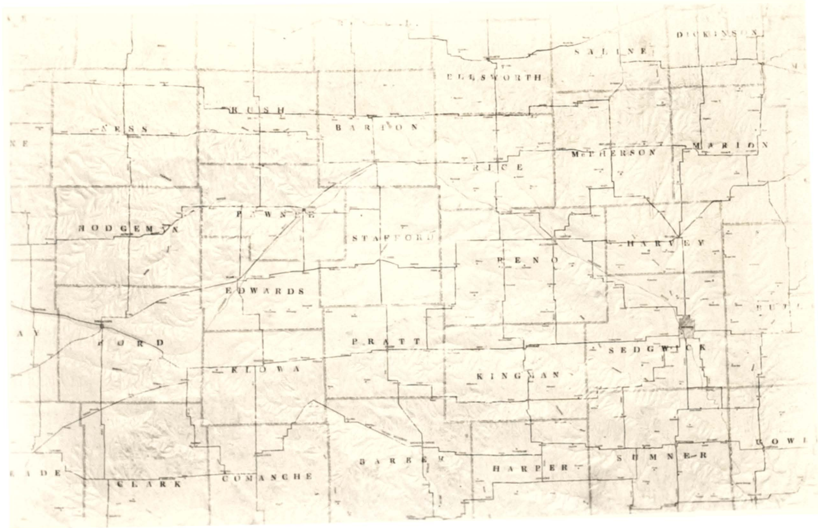

DICKINSON
SALINE
ELLSWORTH
RUSH
NESS
MARION
McPHERSON
RICE
STAFFORD
HARVEY
RENO
EDWARDS
PRATT
SEDGWICK
KIOWA
BARBER
HARPER
SUMNER
CLARK
COMANCHE

Fig. 2.

Fig. 3.

vals, which, however, did not exceed 4 miles except in regions of numerous sand dunes.

The writer mapped the following geologic boundaries on the areal map: (1) all boundaries between the Quaternary dune sand and the Sanborn and Ogallala formations; (2) the boundary between the Quaternary alluvium and dune sand along the south side of Arkansas River from Dodge City to Hutchinson; (3) the boundary between the Ogallala and the Permian from Langdon along the north side of the North Fork of Ninnescah River into T. 27 S., R. 4 W.; (4) the boundaries between the Ogallala, Quaternary Terrace deposits and Alluvium along the west bank of the Arkansas from Hutchinson to about Andale and Colwich. The remainder of the geologic boundaries have been taken from unpublished geologic maps of the Kansas Geological Survey.

Acknowledgments. The writer has received encouragement and assistance from Professors G.L. Knight, K.K. Landes, R.C. Moore, C.J. Posey and W.H. Schoewe, members of the faculty of the Department of Geology at the University of Kansas. The Kansas Geological Survey furnished material aid in the use of its facilities and equipment. Core drill information was very kindly furnished by the following: Empire Oil Co., Gypsy Oil Co., Midwest Exploration Co., Western Exploration Co. and R.S.

Hunt of Mt. Pleasant, Michigan. Identifications of fossils were very kindly made by Junius Henderson of Palo Alto, California, and Frank C. Baker, Urbana, Illinois. K.K. Landes accompanied the writer on visits to this area in November, 1933 and in April, 1934, and edited manuscript. M.K. Elias has aided in the investigation of the Ogallala and Sanborn formations, spending a week in the field with the writer in February, 1934. Thanks are also due to Thomas H. Allan of the Stanolind Oil and Gas Co., Tulsa, Oklahoma, and M.P. Huntington of Midwest, Wyoming for suggestions. The writer acknowledges the aid and assistance of his wife, who has helped in the preparation of the original manuscript and typed the final report.

Review of literature: A rather extensive search of the literature for articles directly pertaining to the area of this report was made. Most of the earlier workers either confined their efforts to the region north of Arkansas River, or worked south of the area of this report among the outcrops of Permian and Mesozoic rocks.

J.S. Newberry, (41)* in 1859, travelled through Kansas in a part under the command of Capt. J.M. Macomb.

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* Underlined figures are reference numbers (see list of references at end of paper); plain figures are the page numbers within the references.

Although their destination was Santa Fe, New Mexico, and their problem concerned Colorado River, Newberry studied the geology along their route in Kansas. While travelling along the Santa Fe Trail southwest from Larned, he concluded that the sand in the dunes south of Arkansas River was probably derived "from the decomposition of the Tertiary conglomerate", (41,27).

The first state geologist of Kansas, B.F. Mudge, (38,39,40) made several brief reconnaissance trips through this part of Kansas, but his reports are exceedingly generalized. The work of Mudge covered the years of 1873-1877, and was confined mainly to the Tertiary and Cretaceous. The next writer of note was F.W. Cragin, (5,7) who worked mainly on the Cretaceous and Permian, but who wrote one paper, in 1885, (6) on the Tertiary. Cragin's work applies indirectly to the area of this report.

In 1885, B.B. Smyth (45) wrote a rather general article on "The Age of Kansas". In his discussion he used the rate of removal of surface material due to the various agencies of weathering and transportation as a means of calculating the number of years necessary for the removal of those sediments that have been eroded from the surface of Kansas since the ending of Tertiary time.

Robert Hay (20) in 1890 made a geological reconnaissance in southwestern Kansas, and the United States Geological Survey published a report of this work. It is significant that, at this time, Hay distinguished the "Tertiary grit" (Ogallala of present authors) from the "Plains marl" (now recognized as loess). While these names applied by Hay were descriptive of the physical features of the rocks, as shown by Elias (11, 13-14), they are misleading in that in many places the "Tertiary grit" consists of clay and silt. Hay (20,33-34; 21,5) believed that the Tertiary sediments were lake deposits but was unable to explain, "The manner of transportation of pebbles so coarse as those found in the Tertiary conglomerate in southwestern Kansas ... and their original source, ..." (20,46). Of the "Plains marl" he wrote, (14,444)," ... it is remarkable for its lithologic similarity ... (for) samples not to be distinguished from each other (come) from the northern plains of Nebraska, the midplains (Platte-Arkansas) region, and the Panhandle of Texas". The first detailed work on the Tertiary was done by Hay (24) and the reader may study with benefit this report as published in the sixteenth annual report of the United States Geological Survey. His statements (24,553,554) that "areas of greatest imbibition of water are those with 'Tertiary grit' exposed.", and "areas of least imbibition are those where the unbroken 'marl' are at the surface", are well applied to certain areas in this report.

An important contribution to the geology of western Kansas was made by Erasmus Haworth (18a,18b), while state geologist in 1897. This report included the first explanation of some of the physiographic features of western Kansas, and a considerably advanced conception of the mode of accumulation of Tertiary materials. G.K. Gilbert (16,25) in 1896 had conceived the idea that the Tertiary materials were not of lacustrine origin, but were fluviatile in character. However, Gilbert had committed himself only with respect to the Tertiary in eastern Colorado, and had refrained from applying this concept to the Tertiary of Kansas. Haworth (18b, 233), after careful study, concluded that the characters of the Tertiary of Kansas were those of river deposits, thereby giving rise to the present school of thought.

In the years 1897-1902 several papers were published that do not apply directly to the area under consideration, but some are deserving of mention because in part they deal indirectly with south-central Kansas. Included here are: a study of underground water resources of southwestern Kansas by Haworth (17); a paper on the Pleistocene of Kansas by S.W. Williston (49); and W.D.

Johnson's "The High Plains and their Utilization" (28). Johnson studied the water resources in some detail, and discussed at length the origin of the Tertiary deposits of the High Plains modifying the conclusions of Haworth.

G.I. Adams (1) in 1902 published the first work dealing with the physiographic divisions of Kansas. His paper was later republished by the Kansas Academy of Science (1). Adams (1,117) quotes Haworth's hypothesis (18a,30-32) explaining the great bend in the present course of Arkansas River. This hypothesis was first outlined by Adams in the field and later incorporated by Haworth in his report. The idea was that when Arkansas River, which formerly flowed eastward in the manner of the present Ninnescah, had cut its course down through the Tertiary to the Dakota group (which dips to the northeast) it rapidly corraded these soft rocks and gradually migrated northeastward "down the dip" of the Dakota.

In 1905, N.H. Darton (8,155) described the thick mantle of smooth-surfaced loess which unconformably overlies the Ogallala in northern Kansas. Brief descriptions of the water resources of the counties included in the present report are given by Darton (8,285-319).

The publications of the period 1905-1915 deal mainly with water supplies. C.S. Slichter (44), in 1906, studied the underflow of Arkansas River in western Kansas. In 1911, H.N. Parker (42) wrote concerning the quality of the water supplies of Kansas, giving a generalized description of the water found in beds of various geologic age, and a summary of the water supplies of Kansas by counties. O.E. Meinzer (34) made a study of the supply of water available for irrigation near Wichita and published the results in 1914.

N.H. Darton (9) produced the next work of note in 1915, a guide-book of the Santa Fe route. This report contains a short discussion of the geology of the areas both immediately adjacent to and lying between the two Santa Fe Railroad routes between Hutchinson and Kinsley, and also the geology along the route between Kinsley and Dodge City. Darton described the shallow structural trough which crosses central Kansas in the vicinity of Great Bend and states that "it is not improbable that this structural condition was the cause of the very notable deflection of the Arkansas Valley to the northward in the region between Dodge City and Great Bend" (9, 32).

In 1918, Darton (10) wrote "The structure of parts of the central Great Plains", a continuation and extension of previous work. This report is still an important source of information on the structure of the

Dakota sandstone in the central Great Plains.

In 1920, R.C. Moore (35) assembled information from earlier papers and original sources and published the first composite work of any value on the geology of Kansas since Hay's "Geology and mineral resources of Kansas" published in 1893 (22).

N.W. Bass (2,3) in 1925 prepared a revision (covering Kansas only) of Darton's map of the structure of the Dakota sandstone, based upon later information obtained from drilled wells. He also wrote upon the structure and limits of the Kansas salt beds.

In 1927, R.C. Moore and K.K. Landes (37) compiled the available information on the geology and mineral resources of Kansas and published a report on the "Underground Resources of Kansas".

More recent articles have been mainly concerned with subsurface geology. Of the few papers that are more general in nature, the most important to this discussion is the "Physiography of Western United States", by N.M. Fenneman (15).

GEOLOGY

The discussion of the geology of south-central Kansas is divided into two portions, pre-Tertiary formations and Cenozoic rocks. Since the Cenozoic rocks are of greater importance in this area they will be discussed more fully than the pre-Tertiary formations.

Boundaries on the geologic map (Plate V) have been drawn for rocks of the following ages: the Wellington and Cimarron groups of the Permian; the Cretaceous (undifferentiated); and the Ogallala formation, terrace deposits, Sanborn formation, dune sand, and alluvium of the Cenozoic.

Numerous inliers of Ogallala and Sanborn (?) exist within the main area mapped as dune sand (Qds), and many outliers of dune sand exist in areas mapped as Sanborn (Qsb) and Ogallala(To). Most of these are too small to appear on a map of this scale. Outliers of dune sand are particularly numerous in the area around Iuka, Pratt county.

Table II gives the rock formations that are exposed over the area of this report.

Table II.

Table of rock formation in South-central Kansas

System	Series	Formation or group	Lithological character and remarks
Quaternary	Recent	Alluvium	Soil, stream alluvium, sand and gravel.
Quaternary	Recent	Dune sand	Sand
Quaternary	Pleistocene	Sanborn formation	Gravel, sand, water deposited loess and silt.
Quaternary	Pleistocene	Terrace deposits	Sands, gravels, silts and clays.
		Unconformity	
Tertiary	Pliocene	Ogallala formation	Both consolidated and unconsolidated grit, sand, gravel, clay and silt.
		Unconformity	
Cretaceous		Greenhorn limestone	Chalky limestone, thin shales, in northwest portion of area only.
Cretaceous		Graneros shale	Bluish-gray shale, sandy shale and shale lenses.
Cretaceous		Dakota group	Sandstone and shale.
Cretaceous		Cheyenne Sandstone	Sandstone.
		Unconformity	
Permian		Cimarron group	Red shales and sandstone, gypsum.
Permian		Big Blue group: Wellington shale	Shale, limestone, salt, gypsum and sandstone.

Pre-Tertiary Formations.

Permian. The Permain rocks of this area belong to two groups: the marine, nonred Wellington; and the nonmarine, red, Cimarron. The Wellington is undifferentiated and composed mainly of marine shale, limestone, salt, gypsum and sandstone. The overlying Cimarron is composed essentially of nonmarine red shales and sandstones with extensive gypsum and some salt beds.

Permian rocks are exposed in the southern and southeastern parts of this area.

Cretaceous. Exposures of Cretaceous rocks are confined to the southern edge of the map area and north of Arkansas River. They consist of the Cheyenne sandstone, (Lower Cretaceous), Dakota group, Graneros shale, and Greenhorn limestone. No Cretaceous rocks younger than the Greenhorn are exposed in this area.

The Dakota group consists of a succession of sandstones and sandy shales. It is important as a source of water in the northwestern portion of the area. The Graneros shale is exposed north of Arkansas River, and consists of bluish gray shale with sandy lenses. The Greenhorn limestone may be seen north of the Arkansas in about the SW. cor. sec. 13, T. 27 S., R. 23 W. It is mainly a chalky shale with thin limestone beds.

Cenozoic rocks. The major portion of the surface rocks in this region are Cenozoic in age (Plate V). In sedimentary deposits, especially those of continental origin, complex relationships often exist. Fig. (1), shows diagrammatically the overlapping sedimentation of the Cenozoic rocks in the area covered by this report. The diagram does not show quantitative relations of Tertiary and Quaternary rocks either as to time intervals or amounts of materials deposited. The Cenozoic rocks are separated into Tertiary and Quaternary in the following discussion.

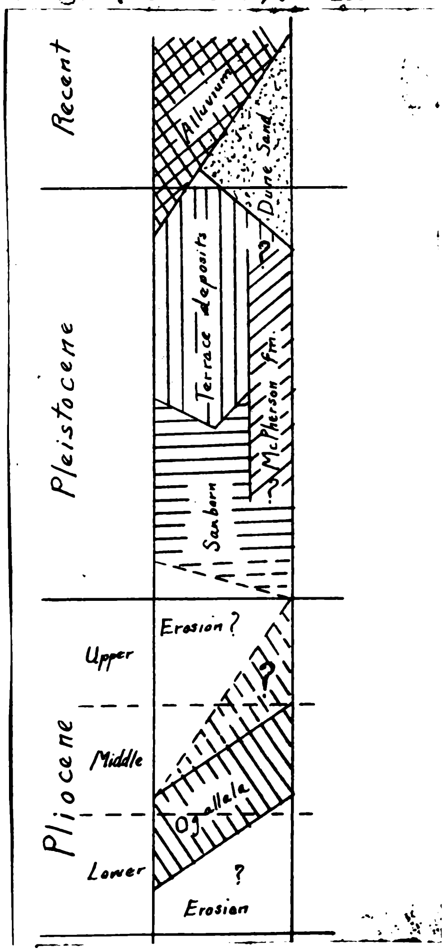

Fig.1.

Tertiary

Ogallala formation. Exposures of the Ogallala formation are poor, due to the small amount of relief in this region. Good exposures south of Arkansas River are found only in the "breaks" which lie along the south edge of the High Plains (15,25-26), separating the High

Plains from the Red Hills Upland. To obtain a true knowledge of the lithology of the Ogallala beds it is necessary to study records of well or core-holes or to travel southward to the "breaks". The Ogallala changes rapidly horizontally and no beds exist that are mappable over wide areas.

The Ogallala formation is separated from older rocks by a regional unconformity of vast horizontal extent. Within the area of this report the Ogallala overlies (going from east to west) Permian, Comanchean and Cretaceous rocks. The pre-Ogallala unconformity represents a long period of erosion, probably all of Tertiary time up to and possibly including earlier Pliocene time, for no Tertiary formations older than Ogallala are present. The assigned time value of the stratigraphic hiatus may be too great, but lacking evidence of earlier Tertiary beds in this region the writer considers that erosion lasted from latest Cretaceous to early Pliocene time.

The Ogallala in this area consists of sand, unsorted gravels, sandy clays, clays, loam and (locally) volcanic ash. The prevailing color of the clays and loam is a light shade of buff-red, but some gray and light green clays are also present. Calcium carbonate is a common constituent in the Ogallala rocks. It may cement the sands and gravels into hard, resistant "mortar beds" or it may occur as nodules (11,18b) of irregular shapes.

M.K. Elias, in company with the writer, visited this region endeavoring to establish the age of the local Ogallala with respect to that of Wallace county, Kansas, where he had made an extensive study of the Tertiary (11,131-163). It was concluded from field evidence that the lowest Ogallala (possibly the lowest third) of Wallace county was missing in the region of the present report. This conclusion conforms with the idea of a general eastern overlap of the Ogallala, which was established by M.K. Elias 1/ through field investigations in northwestern Kansas and southwestern Nebraska. Thus, as we go westward in Kansas, the Ogallala becomes progressively thicker partly because of the added presence of older beds which are missing in central Kansas. The Ogallala in central Kansas is composed of only the younger, upper beds, capped in places by algal limestone.

A section of the Ogallala was studied near the center of the south line of sec. 29, T. 29 S., R. 22 W., north of the Arkansas at Ford. About 65 feet of beds were measured (it was impossible to measure a greater

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1/ Oral communication.

section due to overlapping by the younger Sanborn beds), the lowermost containing small pebbles of Cretaceous rocks. About a mile west, on the north side of Highway U.S. 154, the Ogallala is in contact with the Dakota sandstone. In the first exposure, just above the basal pebble-bearing part (which is only a few feet above the Dakota described in the second exposure), are found fossil fruits of Biorbia fossilia; Celtis willistoni; Krynitzkia chaneyi, and K. auriculata (12,13). The presence of these fruits indicates (13) that this section corresponds with the upper part of the Wallace county Ogallala (11,143). In recent papers (12,13) M.K. Elias has zoned the Ogallala by means of fossil fruits, and they constitute our only means of correlation of this formation in the absence of invertebrate and vertebrate fossils.

Ogallala time closed with the deposition of the "algal limestone" (11,136-142), (13) and its presence therefore defines the upper limit of that formation. Algal limestone crops out at the common corner of sections 21,22,27 and 28, T. 25 S., R. 20 W. on top of a hill at an elevation of about 2,260 feet. The algal limestone is in contact with Dakota sandstone, the lower part containing pebbles of Dakota, in about the center of section 27 at an elevation of about 2,220 feet.

The lower elevation of the latter exposure is undoubtedly due to a local subsidence or disturbance. About 200 feet south of the N. ¼ cor. sec. 2, T. 24 S., R. 19 W., algal limestone is again found resting on Dakota sandstone at an elevation of about 2,120 feet. It is probable that in these two localities ridges of Dakota existed, or possibly there was a single ridge through both locations, which was not covered in earlier Ogallala time, but which was finally submerged in the lake in which the algal limestone was deposited.

According to Elias, the algal limestone was deposited in a water body that he has named Lake Wallace 1/ (Plate III). This lake existed at the end of middle Pliocene time (13). The map of the lake is based upon a progress map loaned through the kindness of M.K. Elias. The algal limestone is believed to have been deposited in a zone of shallow water (probably not exceeding 15 feet in depth) around the borders of Lake Wallace. A remarkable feature of this shallow-water is its width which in places exceeds 30 miles. The Ogallala floor upon which Lake Wallace formed must have been exceptionally flat to have permitted the existence of this wide shallow zone, for in lakes of the present day such a

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1/ Existence of this lake was inferred by M.K. Elias in order to account for the deposition of the algal limestone (11,140-141).

zone rarely attains a width of one mile.

The writer and M.K. Elias in February, 1934, visited an outcrop of Ogallala beds that was being exploited for road materials. This exposure is at the northwest corner of the intersection of Fourth and Chestnut Streets, Dodge City, Kansas. At about 7 feet from the top and 10 feet from the bottom of the exposure is a zone of cross-bedded gravel, irregularly cemented with calcium carbonate in places, and containing green "clayballs". Some of these clayballs are remarkably large, up to 2.5 feet in diameter. They consisted of a rather plastic green clay containing no admixed gravel. Near the base of the gravel zone are several seams of lignitic coal.

South of the Arkansas, at Ford, much of the Ogallala formation has been removed by erosion and the younger Sanborn formation occurs at elevations corresponding to those of the Ogallala on the north side of the river.

The inlier of Tertiary shown on the areal map (Plate V) southwest of St. John consists mainly of cross-bedded gravels with some clays (Fig.3). Buff-red clays containing numerous calcium carbonate nodules, and interbedded sands cemented with calcium carbonate, outcrop in the western part of this locality.

An exposure of volcanic ash occurs in the SW. cor. sec. 23, T. 27 S., R. 11 W., Pratt county. This outcrop is 3 miles east and 2 miles north of Cairo, a station on the A.T. & S.F. east of Pratt. It is not of any commercial importance (31,40) because of clayey impurities and small horizontal extent.

Because of the cover of the Sanborn formation in the western part of the region, and generally poor exposures elsewhere, it is difficult to estimate the true thickness of Ogallala deposits. Logs of wells drilled in search for oil are not based on studies of samples, and invariably they combine Quaternary and Ogallala as "sand and gravel", and the writer believes that in some cases soft Dakota sandstone is included also in the logs under the same heading.

Thousands of dollars have been spent by various oil companies in core-drilling this part of Kansas and this work would seemingly be of benefit in a study of the Tertiary and Quaternary rocks. However the objectives of core-drilling are key beds in the Permian, and no attention is paid to younger beds, the driller "fishtailing" until a suitable "landing" is found for the casing so that "fluid" can be retained in the hole, after which drilling is resumed and carried into the Permian. A vast amount of geologic information, especially valuable from the standpoint of water supplies, might have been assembled at little or no extra cost. An accurate record of the Tertiary, its thickness, materials, etc., would be invaluable in studying the geology and mineral resources of this region.

The Ogallala formation was deposited upon an erosional surface, made up of formations varying in age from Permian in the eastern part of this region to Cretaceous (Dakota, possibly Graneros in places) in the western part. This erosional surface was uneven, and doubtless the topography was rougher (Plate IV) and the relief greater than that of the present surface of erosion because in pre-Tertiary time the exposed formations possessed alternating hard and soft layers which tend to make a rough topography. On this pre-Ogallala surface ridges of Dakota and Cheyenne sandstones, with intervening shale valleys probably existed and in the area of outcrops of Permian rocks there appears to have been a modified sink-hole and ridge topography.

The thickest continuous section of Ogallala beds was measured in the NW. ¼, NW. ¼, sec. 19, T. 30 S., R. 20 W., totalling 62.5 feet (Fig.5). Another section was measured in the SW. ¼, SW. ¼, sec. 12, T. 30 S., R. 21 W., totalling 60 feet. These sections are both in the rough country of the "breaks", and similar sec-

Section of Ogallala in NW. ¼, NE. ¼, sec. 19, T. 30 S., R. 20 W., Kiowa County.

	Feet
Residual soil, containing gravel	2
Gravel	9
Yellow-brown sand, clayey (some streaks of pure clay) calcareous concretions	19
Sand and gravel, cemented	8.5
Coarse sand and gravel, cross-bedded	11.5
Light-brown, flaky shale	0.5
Coarse sand and gravel, cross-bedded	7
Clayey sand, infiltrated with calcium carbonate	5
Sand, clayey (concealed by alluvium)	?
Total	62.5

Section of Ogallala in SW. ¼, sec. 12, T. 30 R. 21 W., Clark County.

	Feet
Soil	3
Reddish-brown, clayey-sand, with small calcareous concretions	16.5
Covered	4.5
Coarse sand and gravel, cross-bedded, unconsolidated	31.5
Red clayey-sand	2
Sandy-marl	1
Clay, mottled red and green (true thickness concealed)	1.5
Total	60.0

tions can be found travelling to the east or west along this belt of rough country. Farther east in Reno county the Ogallala formation becomes thinner and the maximum continuous section exposed is about 30 feet of clays in the SE. $\frac{1}{4}$, SW. $\frac{1}{4}$, SE. $\frac{1}{4}$, sec. 1, T. 23 S., R. 7 W., fronting on an old flood plain of the Arkansas.

It is difficult to formulate conclusions as to the original thickness of the Ogallala. The formation becomes thinner eastward due to overlap, as explained earlier in this paper, and the original thickness has been reduced by later erosion. The writer believes that the Ogallala of this region is everywhere less than 70 feet thick. It is possible that there are exceptions where the Ogallala was deposited in deep and as yet undiscovered valleys.

Prior to the deposition of the Sanborn formation, the Ogallala deposits suffered erosion. At present the formation is protected in the western part of the region from further erosion by the presence of younger Quaternary beds, but in the eastern part it has suffered additional erosion, and in consequence is thinner than it was originally. West of Arkansas River in Sedgwick county the Ogallala reaches a maximum thickness of about 40 feet in the SW. cor. sec. 11, T. 26 S., R. 4 W., and thins rapidly westward in section 10,

Fig. 4.

Exposures of Ogallala formation (SW. ¼, sec. 3, T. 29 S., R. 17 W., Kiowa County) showing unconsolidated gravels.

Fig. 5.

Ogallala formation exposed in creek bank. (NW. ¼, NW. ¼, sec. 19, T. 30 S., R. 20 W., Kiowa County) measured section described in text was made at this locality.

Fig. 4.

Fig. 5.

where it is in contact with the underlying Permian, to almost nothing. Hay (20,34) mentions a locality 3 miles northeast of Wichita (not visited by the writer) where about 8 feet of Tertiary is exposed. Haworth (19,287) believes that this is probably an outcrop of the McPherson formation ("Equus beds"), the sand being imbedded in a limy matrix which resembles the Tertiary of western Kansas. A similar outcrop, identified as consolidated McPherson formation deposits, has been observed by R.C. Moore [1] in a valley on the east side of Arkansas River a short distance south of Wichita. It occurs some 40 feet above the level of the Arkansas River flood plain. Probably the Ogallala of the eastern portion of the region was never much more than 50 feet in maximum thickness.

It is difficult also to estimate the original thickness of the Ogallala in the western portion of the area. Not only did the Ogallala suffer erosion prior to the deposition of the overlying Sanborn formation, but this Quaternary cover is more than 150 feet thick in places, preventing any measurements of present thickness of the Ogallala excepting where pierced by wells. What the

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1/ Personal communication.

nature of the topography of the pre-Ogallala erosion surface was like is impossible to ascertain in the absence of reliable well information.

K.K. Landes and the writer visited the northern portion of Clark county in April, 1934. A section of the Ogallala was examined in about the W. ¼ cor. sec. 32, T. 30 S., R. 23 W. About 35 to 40 feet of algal limestone capped-Ogallala is present, composed almost entirely of calcareous "grit", with fossil fruits (Biorbia fossilia, and Bariochloa sp. "Z") 9 feet below the top. Here the Ogallala rests on Cretaceous rocks. Another section about seven miles to the southeast was measured. This appears below.

Section of Ogallala in center of NE. ¼ sec. 34, T. 31 S., R. 23 W.

	Feet
Algal limestone (Chlorelopsis bradlei)..........	2
Calcareous grit (containing fossil fruits of Biorbia fossilia, and Celtis willistoni, in lower 4 feet......................................	8
Conglomerate, boulders mainly of Dakota sandstone with some up to 4 feet long, and some igneous cobbles, cemented by a matrix of calcareous rock......................................	12
Cretaceous Rocks..............................	
Total................................	22

QUATERNARY

There are five main types of Quaternary deposits in the south-central Kansas region. Because of overlapping age relationships, (Fig. 1) it is clear that parts of one deposit may be older than parts of another, even though the latter as a whole is younger. Two especially interesting Quaternary deposits were discovered in the course of field studies. These are a lake deposit and an outcrop of what has been erroneously called Dakota sandstone. While the lake deposit is intermediate in age between Ogallala and Quaternary dune sand the writer hesitates to correlate this isolated deposit with the Sanborn and will discuss it separately. The so-called Dakota sandstone is closely related to the dune sands.

The Quaternary deposits will be discussed in the following order: Sanborn formation, Equus beds, Terrace deposits, Dune Sand, "Dakota sandstone", Pleistocene lake material and alluvium.

Sanborn Formation. The name Sanborn was proposed by M.K. Elias during his studies in Wallace county. He states: "The name Sanborn formation is proposed for the loess with some gravel and sand at the base, which is widely distributed on the divides in western Kansas. The name is intended as a substitute for the old terms

'Tertiary marl' or 'Plains marl' introduced for this formation by Robert Hay" (11,163).

Hay (14,444) in 1893 wrote concerning the Tertiary formations as follows: "The highest I call the plains marl ... it is remarkable for its lithologic similarity ... samples not to be distinguished from each other from the northern plains of Nebraska, the midplains (Platte-Arkansas) region and the Panhandle of Texas. It is argillaceous, arenaceous and calcareous everywhere, and its varieties are due simply to the predominance of one or the other of its principal ingredients".

In south-central Kansas the Sanborn formation differs somewhat in lithology from that described by Elias (11,163-180). The following principal differences have been observed: the Sanborn of southern Kansas is far less arenaceous and gravelly at its base; it shows distinct bedding, a feature entirely lacking in northwestern Kansas; it has short, discontinuous zones of pebbles; it is darker in color; it is more arenaceous throughout; and contains fossil invertebrates, while the Sanborn formation of northwestern Kansas is nonfossiliferous.

The Sanborn in the area of this report has the following characteristics and relations. It unconformably overlies the Ogallala and older formations. Where exposed in valleys or artificially made cuts it stands nearly vertical in cliffs, after the manner of loess, (47, 272-276). Although porous it does not readily imbibe moisture. Extensive cultivation, however, somewhat modifies this character. Stagnant pools of water are common in poorly drained parts of the High Plains after heavy rainfall, and this is mainly due to failure of the Sanborn to readily absorb the moisture. The color of the Sanborn material is usually a dark buff, with a somewhat reddish tinge, although some zones are gray and others a chocolate-brown. Bands of pebbles are common, indicating deposition by water, a fact further evidenced by distinct bedding of the loess-like materials. Small rounded concretions of calcium carbonate are most abundant, although larger and more irregular ones are found and in places elongated root-like forms are present. A deposit of pure white volcanic ash was found in the Sanborn in Clark county in the SE. $\frac{1}{4}$, sec. 23, T. 30 S., R. 24 W.

As noted previously the Sanborn of southern Kansas contains fossils. These are molluscan, and are most numerous in the pebbly zones. Junius Henderson of Palo Alto, California has very kindly furnished the following identification of Sanborn fossils submitted to him by the writer.

Gastropoda:-

Cochlicopa lubrica (Müll.)

Discus cronkhitei anthonyi, Pilsbry

Ferrissia sp., (*F. parallelus*, *Haldeman?*)

Gastrocopta armifera, Say

Gastrocopta pellucida, (likely *G.p. hordeacella*, Pilsbry)

Gyraulus parvus, Say

Helisoma antrosa, Conrad

Helisoma antrosa, Say

Lymnaea bulimoides cockerelli P. & F. (?)

Physa sp.

Punctun sp., (*P. minutissumum?*)

Pupilla muscorum, L.

Succinea avara, Say

Pelecypoda:-

Sphaerium sp.

Henderson 1/ says of the above list, "All still represented in living fauna, so far as specifically identified". Therefore the correlation of Quaternary formations by means of non-marine mollusks is unsatisfactory.

1/ Personal letter to the writer, March 5, 1934.

The Sanborn formation varies in thickness from nothing to at least 150 feet. Outcrops of great thickness are seldom found due to poor exposures (as in the case of the Ogallala), and one must rely upon well logs, often of a doubtful nature, for information as to thickness. Water well logs are helpful, however, as the Sanborn contains no aquifers except possibly in the extreme basal portion, while the Ogallala is a good source of water. Near the south ¼ cor. sec. 13, T. 28 S., R. 23 W. at least 75 feet of Sanborn is exposed, and a water well pierced an additional 75 feet making at least 150 feet of Sanborn formation in this locality. This figure may be exceptional rather than average through the filling of an older valley by Sanborn materials. Ogallala deposits lie on Dakota sandstone north of Arkansas River in sec. 19, T. 27 S., R. 22 W., at approximately the same elevation as the preceeding locality. Therefore both of these formations have been eroded and later Sanborn has been deposited in the country south of the Arkansas. This indicates that considerable erosion took place, at least locally, in the post-Ogallala - pre-Sanborn interval.

The High Plains (Plate II) of south-central Kansas are covered with a blanket of Sanborn deposits as far east as about the eastern boundary of Kiowa county.

The writer has identified Sanborn beds as far southwest as sec. 13, T. 31 S., R. 24 W. and it is his opinion that this formation covers the surface of most of southwestern Kansas.

From the drillers log of a well drilled by the Carter Oil Company southeast of Bucklin (center of NE. 1/4, sec. 22, T. 29 S., R. 21 W.) it appears that there is here about 110 feet of Sanborn formation. This is underlain by 150 feet of Ogallala that in turn rest on basal Dakota shale. About 4 miles south of this location the Sanborn thins to nothing, the surface elevation having dropped sufficiently to expose Ogallala. The city water well at Bucklin records about 100 feet of beds that are referable to the Sanborn formation.

The writer accompanied by K.K. Landes examined a small deposit of volcanic ash in the SE. cor. sec. 23, T. 30 S., R. 24 W., Clark county. The ash occurs within the Sanborn formation. Most of the ash is pure white and wind blown, but the uppermost few feet of the deposit consists of bedded gray ash which was probably deposited in water.

<u>McPherson</u> <u>Formation</u>. The McPherson formation is also known as "Equus beds" owing to the occurrence of horse bones within the formation. These beds were not studied in the field by the writer and the following

description is taken mainly from the work of Erasmus Haworth and J.W. Beede (19,285). Knowledge of these beds and their occurrence is necessary in a study of the physiographic history of south-central Kansas.

The McPherson beds are not continuous in the sense of marine or lacustrine deposits, but are fluvial deposits consisting of irregular alternating layers of sand, clay, gravel and in places volcanic ash. The McPherson beds are loosely cemented by calcium carbonate locally, and contain nodules of calcium carbonate at some horizons. A large part of this deposit is uncemented however and is an excellent soft water reservoir. The thickness varies from a few feet to about 150 feet.

The McPherson beds fill a broad channel carved out of the Permian shales and (in the northern part) Dakota sandstone. The channel extends from the Smoky Hill river at the north to the Arkansas river in Sedgwick county. The deposits cover the entire eastern half of McPherson county south of a line drawn from Lindsborg to Canton, all of Harvey county west of Newton, and most of eastern Reno county.

Terrace deposits. These deposits were made by Arkansas River and its tributaries when the river flowed at a somewhat higher elevation, and in different parts of its valley than at present, a low escarpment separates the recent alluvium from the terrace deposits.

The terrace deposits are composed of alternating layers of sand, clay and silt. At present the top of the terrace lies 8 to 12 feet above the Arkansas river. The deposits are fertile and adapted for diversified farming. The sandier portions contain an excellent soil for raising early spring produce.

Dune sands. The dune sands of south-central Kansas have been the subject of considerable comment by laymen, but have received only scant consideration by geologists. In the area of this report (Plate V) there are over 2,500 square miles covered by dune sand 1/, although this does not necessarily imply that sand dunes exist everywhere, as there are wide areas with a coating of dune sand that does not exceed much more than two feet in thickness.

The writer studied many samples of dune sand attempting to establish a relationship between grain sizes, kinds of minerals and the present distribution of sand dunes. It was thought that possibly there existed areas of sand dunes intimately related with respect to grain

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1/ Dune sand is used in the sense of sand that has been, and is being, transported by aeolian agencies.
Sand dune is used in the sense of a topographic elevation apparently constituted entirely of dune sand.

size and mineral content, and that there might exist essential differences in these characters between two or more areas of sand dunes. Results of this study were disappointing and no definite conclusions could be made.

The dune sands grade in size from an average maximum of 1 mm. in diameter, down to particles less than 1/16 mm. in diameter. They are typically subangular, with a very small percentage of rounded grains of which only a few are well rounded. Most of the minerals are fresh, and many of the grains show but little frosting on their surfaces. The most abundant minerals found in the dune sands, in order of abundance are: quartz, feldspar, zircon, ferromagnesian minerals (chlorite, hornblende, etc.), garnet, and magnetite.

The blanket of dune sand is not very thick. It reaches a maximum thickness in the sand dunes of greatest topographic relief 1/.

There is apparently little relation between the sizes of the dunes and their age. Both small and large "live dunes" (those which lack vegetal covering and are free to move - see Figures 7 and 8) and stationary dunes

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1/ The reader is here referred to the topographic maps of the United States Geological Survey, which are available for the entire area.

Fig. 6.

Typical Sand Dune (W. $\frac{1}{4}$ cor. sec. 36, T. 28 S., R. 17 W., Kiowa County) showing aeolian stratification.

Fig. 7.

Typical area of sand dunes not covered with vegetation. "Bald Hills", southwest of Kinsley, Edwards County.

Fig. 6.

Fig. 7.

(held in place by a covering of vegetation, Fig.10) were observed. Blow-outs (fig.9) are common in some localities. These may be caused by local absence of vegetation or they may form where stock has trampled the vegetal covering allowing the wind to blow the sand.

The writer made search for fossil remains in the dune sand in an endeavor to establish the age of some of the sand dunes, but was unsuccessful. The dunes overlap on the Sanborn and older formations. The source and distribution of the sand will be discussed under Physiography.

Supposed Occurrence of Dakota Sandstone. While working in this part of Kansas, the writer heard from various sources of an outcrop of Dakota sandstone in the NW. ¼, SE. ¼, sec. 27, T. 25 S., R. 18 W. A visit was made to this locality several years before the present report was undertaken and another visit was made in August, 1933. At the time of this second visit a pit over 7 feet in depth was dug in order to obtain good samples.

The location is in a small depression, bounded on the west, north and east by sand dunes, and to the south by a low swell in the topography. The section uncovered, showed the following: soil, 6 inches; brownish red sandstone, 6 to 8 inches; and loose yellow brown sand,

Fig. 8.

Sand dune, bare of vegetation. "Bald Hills", southwest of Kinsley, Edwards County.

Fig. 9.

Blow outs (in center background) caused by removal of vegetal covering from sand dune. (N. ¼ cor. sec. 30, T. 21 S., R. 11 W., Stafford County).

Fig. 8.

Fig. 9.

6 feet (in which the hole was bottomed). The two types of sands along with samples of the nearby dunes were carefully examined and heavy mineral analyses made. The sands were also sieved, and the percentage weights of various screen sizes compared.

The brownish-red sandstone was cemented mainly with limonite. In addition to quartz the following minerals were found: feldspar (orthoclase and microcline), hornblende, chlorite, garnet, magnetite, zircon, monazite, tourmaline, biotite and glaucophane. The Dakota sandstone does not have this assemblage of minerals so far as known to the writer. Sand from the neighboring dunes, and from the bottom of the test pit, gave similar mineral assemblages, but the percentage of the heavy minerals was far less in these samples than in the brownish red sandstone.

The writer believes that this peculiar sandstone represents a concentration of the heavy minerals in a depression among the sand hills. This concentration was caused by the wind, which was probably deflected by neighboring dunes with consequent lessening of ability to lift the heavier minerals and thereby bringing about their concentration in the depression. The depression was probably filled at various times with rain water, and this alternate wetting and drying decomposed the iron-bearing minerals producing hydrous iron oxide or limonite, the cementing material.

Pleistocene Lake in Stafford county. About 0.2 mile west of the SE. cor. sec. 10, T. 25 S., R. 14 W. on the north side of the road the writer found evidence of a former lake. Fossils were collected, and later (in February, 1934) the writer accompanied by M.K. Elias revisited this locality and made further collections. On the latter visit the writer, by means of a soil auger, cored a section over 7 feet deep which follows;

	Feet
Surface soil.	0.3
Clay, Gray, fossiliferous.	2
Clayey sand, Gray to rust color.	1
Sand, Gray, medium grained, rusty spots. .	1
Sand, Brown, medium grained, few small calcareous nodules.	1.5
Sand, Brown, coarse with pebbles	0.5
Sand, Brown, coarser	1
Total depth cored	7

Samples of the gray clay were thoroughly dried and then washed and the fossils separated into sizes by screening. This latter operation was performed in water to protect the fragile shells. Specimens were sent to Frank C. Baker for age identification of the deposit, and a complete set of fossils was sent to Junius Henderson, who very kindly identified the species present.

The clay appeared to contain many fossils when first examined in the field and after washing it was discovered that fossils were present in profusion. In order of abundance they are; ostracodes, gastropods, and pelecypods, with some reworked Cretaceous foraminifera. There was likewise found an abundance of fruits of Chara, a lime depositing plant.

According to Frank C. Baker 1/, the material "represents a Pleistocene fauna ... with one exception of fresh water origin".

The identifications furnished by Junius Henderson follows:

<u>Ferrissia</u>, sp. (young)
<u>Gyraulus</u> <u>parvus</u> (Say)
<u>Helisoma</u> sp. fragments, probably <u>H</u>. <u>antrosa</u> (Conrad)
<u>Lymnaea</u> <u>caperata</u> (Say)
<u>Lymnaea</u> cf. <u>modicella</u> <u>rustica</u> (Lea)
<u>Menetus</u> <u>exacuous</u> (Say)
<u>Physa</u> (young)
<u>Vertigo</u> sp.

1/ Letter to the writer, February, 1934.

Henderson states [1] that the deposit is probably Pleistocene.

It appears that during Pleistocene time there existed a fresh water lake in this area. Possibly there were numerous lakes over this part of Kansas and their deposits may at some future date be correlated with the Sanborn formation in the western part of the area.

Rattlesnake Creek flows northward about a half mile west of this deposit. It appears from physiographic relations that the present creek has cut down 4 to 6 feet in the old lake bed. In fact this lake was probably a part of the course of Rattlesnake Creek in its youthful stage.

Alluvium. The alluvial material brought down by the streams belong to this class of deposits. All of the wide valleys in this area are floored by such deposits, but in order to keep the geologic map free from a confusing maze of boundaries the boundary of alluvial deposit along Arkansas River only is shown.

Alluvial deposits occur along both the North and South Forks of Ninnescah River, extending almost to their headwaters. The same can be said of the other large streams of this area.

1/ Letter to the writer, March, 1934.

Fig. 10.

Typical area of grass covered Quaternary dune sand (sec. 1, T. 25 S., R. 19 W., Edwards County).

Fig. 11.

Dry bed of Arkansas River South of Kinsley, Edwards County.

Fig. 10.

Fig. 11.

PHYSIOGRAPHY

The area of the present report lies entirely within the Interior Plains (15, plate I). That portion east of about the Hutchinson meridian lies within the Osage Plains section of the Central Lowlands province and the remainder of the area lies in the Plains Border section of the Great Plains province.

South-central Kansas is fairly well drained, all of the streams flowing eventually into Arkansas River. The principal streams are the Arkansas and Ninnescah rivers, Rattlesnake Creek and Medicine Lodge and Chikaskia rivers. All of these streams except Arkansas River (Figures 11 and 12) and Rattlesnake Creek flow the year round. The permanent flowing streams are fed by springs, the water coming mainly from the base of the Tertiary.

G.I. Adams (1) in 1903 prepared the first physiographic map of Kansas, showing the various smaller divisions within the state. This work remained essentially unchanged until R.C. Moore (36) in 1930 published a map on the "Surface features of Kansas". Wilfrid Webster (48) published a "Physiographic map of Kansas" in 1931.

The writer noted several points of difference between the physiography seen in the field and that shown on existing maps. Adams states (1,116-117), concerning the Great Bend Lowland:

"The Arkansas river ... valley comprises a broad stretch of generally diversified lowlands which represents a local base-level of the stream. ... The western limit is found along the course from Larned to Great Bend, where it impinges against the Dakota sandstone. Its southern limit lies im Oklahoma, where the river, in passing around the southern end of the Flint hills and eroding its channel across resistant beds, has been confined to a narrow valley. The area of the Great Bend lowland is largely covered with sandy accumulations, which in places form sand-hills and in other localities are spread out as a thin mantle. The Equus Beds, in McPherson county, belong to this formation. The eastern boundary of the lowland is the line of intersection of the structural plain of the western slope of the Flint hills with the level country of the Arkansas valley, and is not strongly marked by any topographic features. It may be drawn with reference to the occurence of the limestones, on the surface of which the Flint Hills upland is developed. The Great Bend lowland, considering ... the prairie plains, is a natural part of them,".

The northeastern and northern boundaries of the Great Bend lowland (1) are the southward facing escarpments of Cretaceous rocks. South-central Kansas lies almost wholly in the Great Bend Prairie (or lowland) as mapped by Adams, Moore, and Webster. However, examination of this physiographic division in the field raised several questions.

Granted that large (and even small) physiographic divisions or subdivisions are not ideally uniform, it is a desirable feature to have uniformity if possible. A physiographic division is dependent upon topography, which in turn is dependent upon geologic formations and erosion. The writer, in order to obtain more dis-

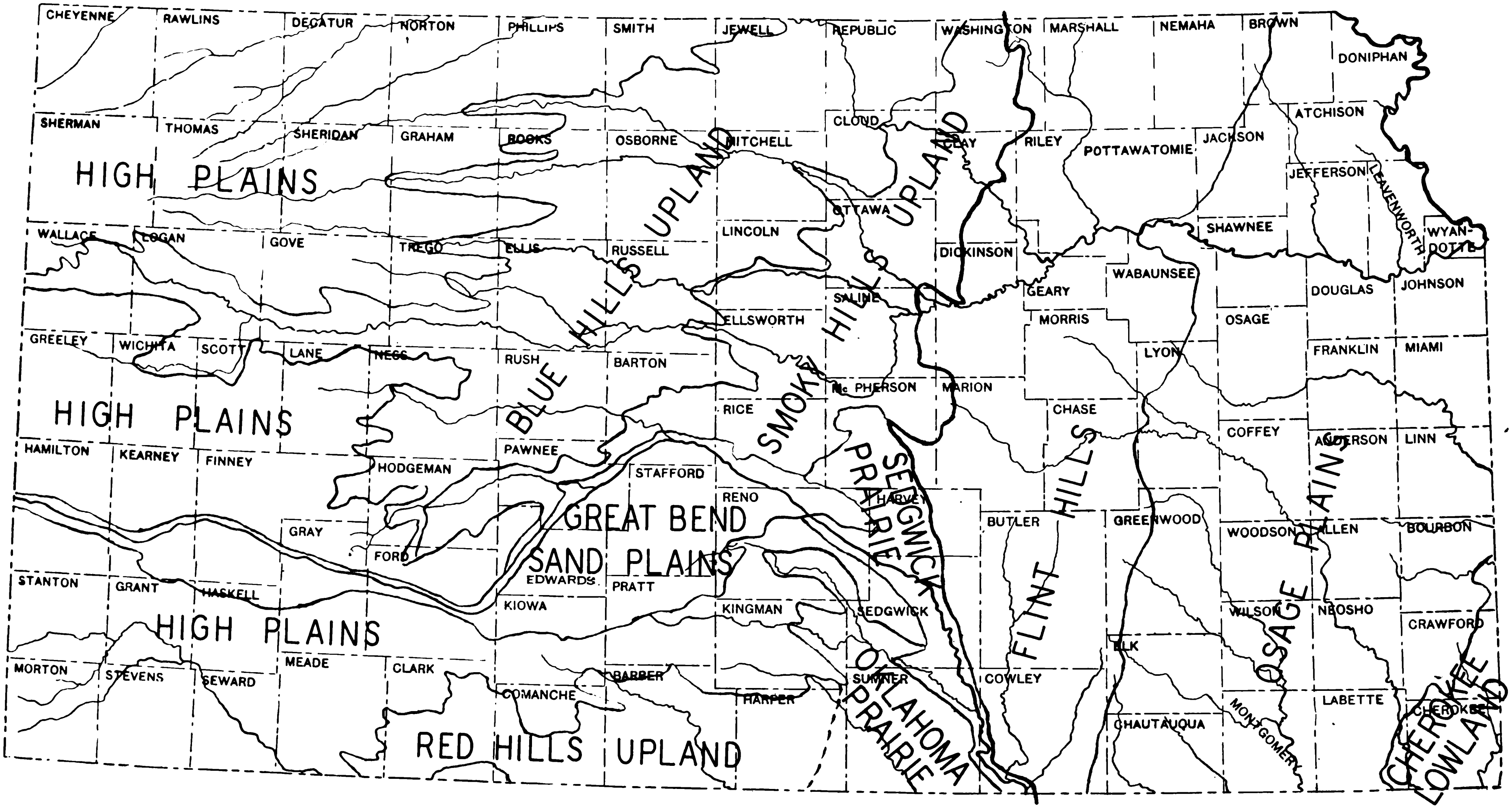

Plate II.

Physiographic Subdivisions of Kansas.

tinct and uniform provinces in this portion of Kansas, proposes several revisions of physiographic boundaries which are shown on Plate II and discussed in the following paragraphs. This revision involves the division of the Great Bend Prairie into the following smaller and more integral units: the Great Bend Sand Plains; the Sedgwick Prairie, and the Oklahoma Prairie of Adams (1,116). The last named subdivision lies largely outside of the area studied by the writer so will not be discussed further in this report.

Great Bend Sand Plains. This name is proposed for a portion of the area formerly designated as the Great Bend Prairie (Plate II). It extends along and south of Arkansas River, and includes mainly that area mapped as Quaternary dune sand (Qds). Its northern boundary is the southward and southeastward facing escarpment of the Cretaceous and younger rocks on the north side of the Arkansas. Its southern boundary is the boundary between the Quaternary dune sand and older formations. Its northeastern boundary is the western boundary of the McPherson formation which extends south to the south end of the sand hills east of Hutchinson. From that point the boundary turns west and crosses the Arkansas near Hutchinson and then follows the boundary between the Ogallala and the Quaternary dune sand.

This subdivision seem to the writer to be a natural unit, as essentially the same topographic characteristics prevail over the entire area. In travelling over this region one receives the impression of sand hills resting on a plain, the only variation being in the number and size of the sand hills. These sand hills or dunes are the dominant topographic feature throughout this physiographic division both here and westward across the state. The High Plains in the western part of the state are severed by the Great Bend Sand Plains.

The Great Bend Sand Plains is so named because it is typically developed in the area within the great bend of Arkansas River.

Sedgwick Prairie. Parts of McPherson, Harvey, Reno, Sedgwick and Sumner counties are covered mainly by Terrace deposits, and by Alluvium along Arkansas River. The writer proposes the name Sedgwick Prairie for this area. The Terrace deposits have developed a rolling surface that in places appears almost flat. This is the prevailing physiographic character of the Sedgwick Prairie.

The western boundary of the Sedgwick Prairie is the break in the topography between the Terrace deposits and the higher Ogallala from just west of Hutchinson to the southwest of Wichita, and the break between the

Permian and Terrace deposits from there south. This topographic escarpment is very evident along the western boundary of the Sedgwick Prairie until in the vicinity of Hutchinson where it fades away under the dune sand. From there the boundary crosses the Arkansas and swings around the southern end of an arm of the Great Bend Sand Plains and then turns northwestward and follows along the eastern edge of the sand dune area until it finally turns north along the western border of the McPherson formation. The northern boundary is the break between the rolling topography of the McPherson formation and the older Permian beds. The eastern boundary is not well defined, but is the break between the structural slope on the western edge of the Flint Hills and the flatter topography of the McPherson formation. From Sedgwick southward the boundary lies between the alluvial flats along the Arkansas and the structural plains to the east.

The name Sedgwick Prairie is used because of its development in Sedgwick county (Plate II).

Origin of present course of Arkansas River.

Present course of Arkansas river. Laymen and geologists alike have pondered and argued over the problem of the present course of the Arkansas. Why does this river have such a pronounced bend in its course, while other rivers in Kansas do not? It is the purpose of the present writer to review the explanations hitherto given and to present his own explanation for this perplexing problem.

Before proceeding with possible solutions of the problem let us first consider the geological setting of the country through which Arkansas River flows and then review a few interesting facts concerning the history of the river within the memory of the white man.

Preceeding the deposition of the Tertiary Ogallala, and following the deposition of the Cretaceous rocks, there was a period of time for which we have (at present) no lithological evidence or record. Possible solutiōns of this hiatus are: (1) there was no deposition of rocks during this interval and erosion was the active geologic agent; (2) there was deposition of rocks which were subsequently eroded prior to the deposition of the Ogallala; and (3) combinations of (1) and (2).

Regardless of which explanation is correct, the fact remains that in the eastern part of the area of this report, the Ogallala lies on Permian beds, while in the western part it rests upon rocks belonging to the Dakota and Colorado groups (Cretaceous) and in far western Kansas the Ogallala lies upon the Cretaceous Pierre shale. Thus, preceeding deposition of the Ogallala, there existed a period during which an enormous amount of erosion was accomplished, and in the eastern part of the area (for example, Sedgwick county) probably 3,000 feet of sediments had been eroded prior to Ogallala deposition.

One can only postulate the drainage patterns which existed during this time for with the deposition of the Ogallala these were obliterated and new systems of streams were inaugurated. In all probability Kansas was tilted eastward at the end of Cretaceous time (Laramide revolution) when the Rocky Mountains were uplifted. Such a tilt would be conducive to the development of eastward flowing consequent streams. Considering the development of such eastward flowing streams, the question arises as to whether (in approximately the latitude of the present report) the Flint Hills constituted an effective barrier and turned the streams southward (or northward?) as at present, or did the streams flow eastward through the hills as Cottonwood River does now? Lack of evidence to the contrary forces us to assume that the Flint Hills (which then existed farther to the east than at present as subsequent erosion has caused them to migrate westward) constituted a barrier then as now.

It appears highly probable that the courses of streams in the far eastern part of this area (Sedgwick, Sumner and Cowley counties) were controlled by the strike of the rock formations. That is, the eastward flowing streams were diverted to a direction more nearly parallel to the strike (about north-south) of the resistant beds. Beds relatively resistant to erosion are present in the Chase and Marion formations of the Big Blue group (Permian). A southward trending valley in this area would not have been filled with a very thick deposit of Ogallala, and would have been undergoing erosion during the period that Lake Wallace was in existence.

Ground-water discharge into the trough of this old valley, which was floored by impervious shales, would aid in its being reoccupied by a stream in late Ogallala (middle Pliocene) time. Eastward flowing tributaries of such a stream would be consequent on the Ogallala surface. That part of the present Arkansas River extending southward from Wichita possibly was in existence in late Pliocene time.

Miles upon miles of the channel of the present Arkansas River are dry the greater part of the year

(Fig. 11), and only by digging in the loose gravel and sand in its bed is water obtained. However, historical data testify that the river has not always been in its present condition. In 1893, J.R. Mead (33, 111-112) wrote of the Arkansas as "A Dying River". His period of observation extended back only to 1859, but in this interval of time he had noted many changes in the river.

> " ... as early as 1852 boats were built at Pueblo, Colorado, in which mountain traders and trappers, sometimes in parties of 15 or 20 in one boat, with their effects, floated down the swift current of the river to Arkansas, ... Occasionally the river was a dry bed of sand above the mouth of the ever-flowing Little Arkansas for a couple of months in the fall. ... There was no opportunity for the formation of islands; the sand bars were constantly changing and moving down stream. Before the settlement of the country the bordering plains were tramped hard and eaten bare by innumerable buffalo, allowing the rainfall to speedily flow into the ravines and creeks, thence to the river ... The breaking up of the soil consequent upon the settlement of the country allowed the rainfall to soak into the ground, and the river soon ceased to carry its usual volume of water, not noticeable until about 1880. ... numerous irrigating ditches were dug in western Kansas and in Colorado, sufficient at the present time to divert the entire water of the river to the thirsty plains. Thus for the past 10 or 15 years we have observed the evolution of a great river into a sandy waste or insignificant stream. ... once moving sand bars became fixed, and are speedily covered with young cottonwoods and willows. ... when a freshet occurs it ... deposits several inches of mud and sand among the growing trees; these thrive and grow rapidly".

We may see from this account, that the present river is much smaller than formerly. Haworth (18a, 28-29) wrote, "We have ample evidence, ... that at the present time a filling-in process is in operation.

Fig. 12.

Arkansas River in flood. South of Kinsley, Edwards County. (See Fig. 11).

Fig. 13.

Exposures of gravels in terrace on Bluff Creek. (NE. $\frac{1}{4}$, sec. 25, T. 30 S., R. 24 W., Clark County).

Large boulder --------Dakota sandstone.

Small cobble ---------algal limestone (Ogallala).

Fig. 12.

Fig. 13.

Within the last fifteen years a very noticeable filling-in of the river channel has occurred. 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 the sands. Such an accumulation of sand is in no way due to the presence of the bridge, ...".

Factual Information. Arkansas River makes a great bend to the north between Ford and Wichita. The present valley contains a large amount of fill (18a,28).

Toward the end of Ogallala time Lake Wallace (Plate III 1/) was formed and around the borders of this lake algal limestone was deposited (11,136-142, 13). The time of deposition of the algal limestone was between middle Pliocene and the close of the Tertiary period, according to M.K. Elias 2/. The present valley of Bluff Creek, in northern Clark county, furnishes additional evidence of the existence of this lake (or some other large body of water). Here are terrace deposits made by a mighty stream. Huge boulders of Dakota sandstone (Fig. 13) and algal limestone that are topographically

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1/ Used through the courtesy of M.K. Elias.

2/ Oral communication.

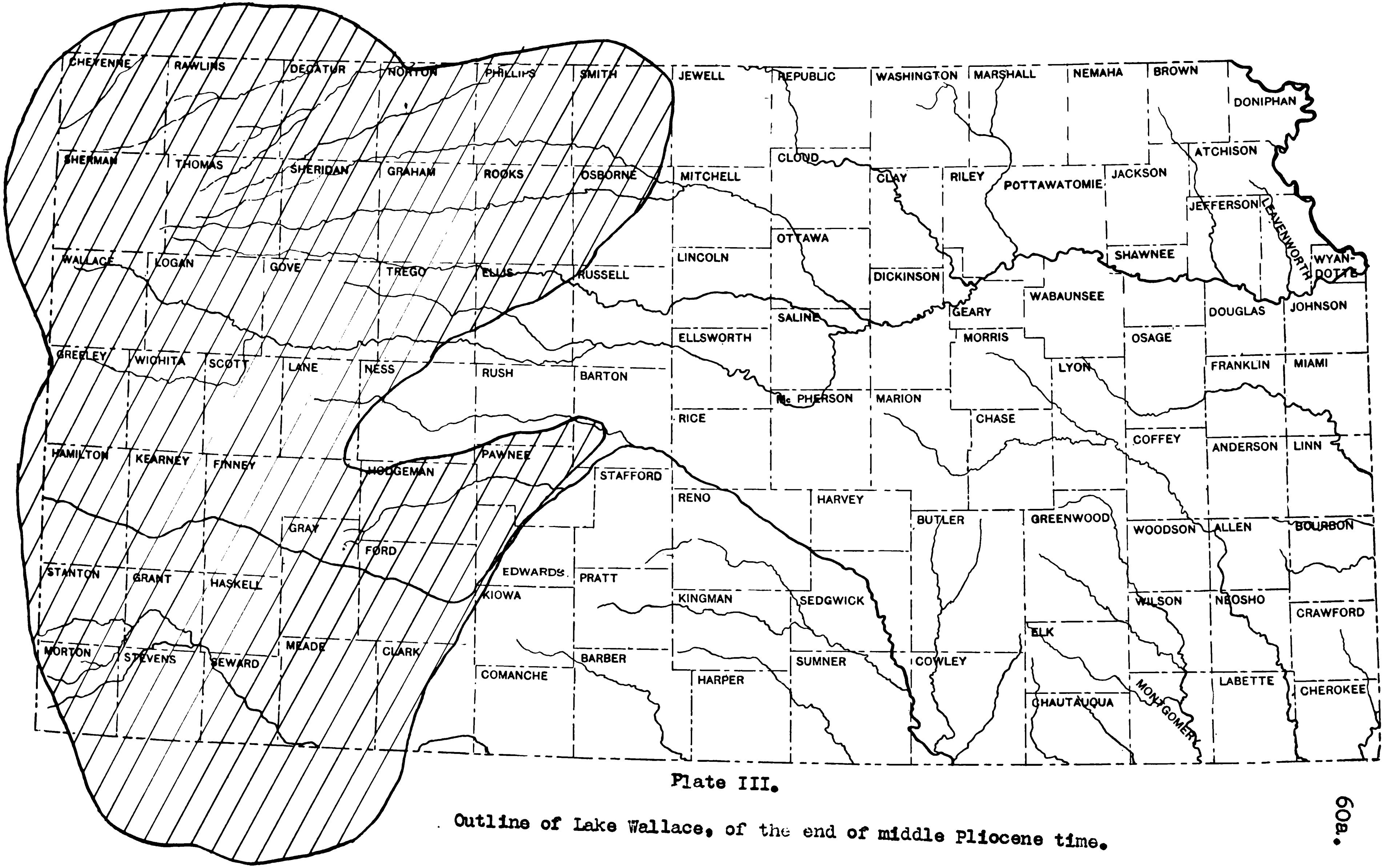

Plate III.

Outline of Lake Wallace, of the end of middle Pliocene time.

higher than their outcrops on Bluff Creek occur in a gravel pit (N. ¼ cor. sec. 25, T. 30 S., R. 24 W.) only seven miles below the present headwaters. In all probability a pre-Bluff Creek was one of the outlets of Lake Wallace when it was drained.

The Ogallala and Dakota formations have been eroded at Ford south of Arkansas River, but they outcrop on the north side of the river. At least 150 feet of Sanborn (according to outcrop and well information) occupies the space where the Ogallala and Dakota formations would normally occur south of the river. Obviously this area was the scene of active erosion, followed by deposition of Sanborn beds.

Elevations of two algal limestone outcrops in Edwards county differ 140 feet in about 13 miles. The lower outcrop lies to the northeast of the higher one, so there is a dip of about 10 feet per mile in that direction. About 19 miles to the southwest, Ogallala lies on Dakota sandstone and the algal limestone is absent. Assuming that the elevation of the algal limestone would be at least that of the top of the present Ogallala surface, the same dip continues.

The existence of a buried channel, now filled with the McPherson formation, which extends from near Wichita northward to Lindsborg on Smoky Hill River, has been proved by core drilling, water wells, etc.

Possible Explanations. G.I. Adams developed a theory to explain the abnormal course of Arkansas River during the course of his field studies in southern Kansas. This theory was subsequently incorporated by Erasmus Haworth in a report (18a,30-32). Pertinent quotations follow:

"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. 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. ... the general inclination of the strata of the Dakota is to the northeast ... it would seem the cause of the river's great bend to the north is the existence of the easily corraded Dakota sandstone. ... 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. ... why the river did not break through the uplands in the vicinity of McPherson county ... To answer this ... great Flint-Hills area ... 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. 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. 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. ... 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".

In reviewing this or any other theory we must remember that Arkansas River is a post-Ogallala stream, in other words its present course has been determined since the last deposition of any Tertiary material in this part of Kansas. True, portions of Arkansas River may occupy channels that existed in pre-Ogallala time. This would be more likely to occur where the fill of Ogallala was thinner and where ground-water discharge was locallized within the channel. Tightly cemented mortar beds, or zones of limestone within the Ogallala, would reduce the probabilities of reoccupation. Locallization of ground-water discharge into pre-Ogallala valleys would be impeded if layers of impervious clay existed within the Ogallala. The reader must always have in mind the fact that the Ogallala formation was deposited as a continuous sheet of material over and beyond the narrow belt of land now occupied by the Arkansas.

If Arkansas River migrated northward down the dip of the Dakota sandstone, some evidence of a former channel or channels should exist. These channels could possibly be buried in the region covered by dune sand, but in the eastern portion of the area (Plate V) such a covering does not exist. It seems highly improbable that a stream the size of the pre-Arkansas could have cut across outcrops of Tertiary and Permian rocks and then migrated northward without leaving a trace of a channel. Further evidence as to this improbability follows.

Arkansas River from Ford to Great Bend has a total length of 78 miles and drops from 2,350 feet to 1,840 feet in elevation (U.S. Geol. Survey topographic sheets). This gives a gradient of 6½ feet per mile at the present time. A stream from Ford east "across the north of Kiowa, Pratt and Kingman counties" (18a,31) as postulated by Haworth would hardly have had a lower gradient than that figured from the difference in elevations between Arkansas River at Ford and Ninnescah River at Pratt (1830 feet). Such a stream if it flowed in a straight-line would be 54 miles long and would have a gradient of about 9 2/3 feet per mile.

Just how much the present Arkansas has filled in its channel at Ford is not known, but according to Haworth (18a,28), "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". Assuming a fill of 50 feet at Ford, this would reduce the gradient of the hypothetical east-flowing stream to 8 2/3 feet per mile (or probably about 8 feet per mile allowing for normal deviation from a straight course). A stream with such a gradient would possess a relatively large valley, and the migration of this stream northward to the position now occupied by the Arkansas should have left ample evidence in the way of abandoned valleys and stream deposits.

The only evidence found by the writer that might be used to substantiate this theory is in the valley of the Ninnescah. Just south of Pratt, this stream is but 12 miles from its headwaters, and yet it is a broad terraced valley in which the stream is entrenched. This valley may have been occupied by an older and larger stream, but there is strong evidence against the theory that this stream might have migrated northward as postulated by Haworth. One may travel clear to the Arkansas near Hutchinson observing the outcrops of the Ogallala, in which evidence of intermediate channels should be preserved, without finding any such evidence. Suspicion might rest upon the North Fork of Ninnescah and its broad flat valley, but when the size of its drainage-area is taken into consideration, such development if not out of the ordinary.

The next theory to be discussed is that of N.H. Darton (9,31-32) who writes: "In this region the beds lie nearly level, for the gentle westward dips which exist in the region east of Hutchinson gradually give place in this portion of central Kansas to equally low eastward dips, ... The shallow trough resulting from this change of dip crosses central Kansas in the vicinity of Great Bend, and it is not improbable that this structural condition was the cause of the very notable deflection of the Arkansas Valley to the northward in the region between Dodge and Great Bend".

It is difficult to visualize the geographic location of Arkansas River before "notable deflection ... northward", as Darton did not specifically state any former course for the river. Although he stresses structural conditions (without mentioning just what formation or formations the river migrated across), his theory is otherwise essentially the same as that of Haworth. The writer believes that the same lack of evidence that exists for the theory of Adams and Haworth applies to the theory of Darton.

The testimony given by Robert T. Hill in court during the Red River dispute between Oklahoma and Texas includes remarks concerning the Arkansas River of Kansas.

Hill (26,165) states: "First the regional patterns or rather the persistence of certain peculiarities of patterns as the various rivers crossed certain regions, were shown, and this was exemplified by illustrating the manner in which the various rivers crossed the Central Region and were deflected northeastward from their normal southeastward directions, so as to constitute the so-called Great Bends, as typically exemplified in the Great Bend of the Arkansas, which deflections were supposedly caused by the attempts of the rivers to overcome the westerly dipping strata of the Permian and Pennsylvanian series as exposed by the downcutting of these rivers in their passage across a belt of such structures seen in eastern and southern Kansas, north-central Oklahoma and north central Texas." 1/

Apparently, from the above statement, the "deflection" of Arkansas River into its great bend was caused when it had cut through younger rocks and reached the Permian and Pennsylvanian beds. Omitting, for the sake of argument, the existence of Tertiary and younger beds, the Arkansas should not have started its great bend un-

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1/ The original testimony given in this case was not available to the writer, as it exists only in the records of the United States Supreme Court, Washington, D.C.

til it had reached a point on a northeast-southwest line passing through northeastern Pratt county. West of this line younger Cretaceous beds lie on the Permian and in these beds the river, normally, should have cut its course to the southeast (according to Hill) until it began cutting into the Permian and older beds. Furthermore, there should now exist a bend to the north beginning about 44 miles due south of the extreme northern point on the present bend. Obviously, this is not the present situation. The fact that Arkansas River is a post-Ogallala stream and therefore would have had to cut its channel through these Tertiary beds in addition to the Cretaceous beds before reaching the underlying Permian would have caused the earliest bending to take place still farther east, which is likewise contrary to the present situation.

The only large streams in Kansas that even approximate the conditions as stated by Hill are the Cottonwood and Kansas (east of Abilene) rivers, and the course of Kansas River in its eastern portion has been affected by continental glaciation. Hence, Arkansas River does not "typically exemplify" the conditions set forth by Hill.

The writer has at several times heard yet another explanation for the present course of the Arkansas, but does not know to whom it should be credited. Some of the details have been forgotten, but the basic points are as follows: Arkansas River flowed almost due east from Ford, and from about Pratt eastward it followed essentially the course of the present Ninnescah. The country south of the present great bend of the Arkansas was slowly uplifted into a large anticlinal structure, the axis of which ran about north-south through Pratt. As this structure was slowly elevated, Arkansas River was forced steadily northward around the northern end of the anticline until it reached approximately its present course.

It has already been stated that evidence of former channels (which are necessary for the northward migration of this stream) is lacking. Where the western flank of this anticline should be according to the above theory, we find the Cretaceous rocks dipping to the northeast. Any uplift that is proposed to account for the great bend of the Arkansas must necessarily involve beds of Cretaceous age. No evidence in support of such a theory can be found.

The writer has developed a theory intended to explain the present course of the Arkansas. The following stages are postulated:

1. Pre-Ogallala drainage.

2. Ogallala deposition (not including algal limestone).

3. Development of early drainage patterns.

4. Westward tilting and formation of Lake Wallace.

5. Eastward tilting and drainage of Lake Wallace.

6. Deposition of Sanborn formation.

7. Headward erosion of streams which developed their initial patterns in Stage 3, and development of present drainage.

These stages will be discussed in detail in the following pages.

1. Pre-Ogallala drainage.

The writer believes (as stated before) that Arkansas River in Kansas, from the Oklahoma boundary upstream to the vicinity of Wichita, approximately occupies a channel that had its inception in pre-Ogallala time. This stream will hereafter be referred to as the "Wichita-Arkansas". The buried channel (now filled with the McPherson formation) which extends northward from Wichita to the present Smoky Hill River is considered to be a northward extension of the "Wichita-Arkansas".

The "Wichita-Arkansas" probably developed tributaries prior to Ogallala time and one of these could have had its course in about the present position of the Arkansas from Wichita northwest through Hutchinson.

This stream will be referred to as the "Hutchinson-Arkansas".

2. Ogallala deposition.

The deposition of the Ogallala formation obliterated the pre-Ogallala drainage in south-central Kansas. This blanket of unsorted and mainly unconsolidated materials filled the channel of the "Wichita-Arkansas" and extended eastward beyond the present course of the Arkansas. However, the conditions of deposition did not permit the establishment of permanent lines of drainage which were not inaugurated until sheet flood deposition of the Ogallala had ceased.

3. Development of early drainage patterns.

The "Wichita-Arkansas", where filled with Ogallala materials, would probably be readily re-excavated for the following reasons: (1) the Ogallala was undoubtedly comparatively thin in this part of central Kansas so the channel would not have been deeply filled, and (2) this old valley was floored by impervious Permian shales and concentration of ground-water discharge in the old channel would aid in its being reoccupied by a stream in upper Pliocene time. Tributaries to "Wichita-Arkansas" River developed westward as consequent streams upon the Ogallala depositional surface. Thus, we may infer from the southeastward trend of the streams in south-central

Kansas, that east of the eastern boundary of Lake Wallace, (Plate III) the slope was southeastward. Development of the drainage was undoubtedly slow at first due to insufficiency of water supply as evidenced by cessation of the deposition of the Ogallala.

4. Westward tilting and formation of Lake Wallace.

The depositional surface of the Ogallala in general sloped eastward prior to the formation of Lake Wallace. A very gradual westward tilting occurred near the end of the period of deposition of the unconsolidated Ogallala materials. According to M.K. Elias 1/, in northwestern Kansas the upper portion of the Ogallala immediately underlying the algal limestone shows lithologic characters at considerable variance with the older portions of this formation. In this upper portion there is a marked dominance of chemical (calcium carbonate) materials over mechanical (gravels) materials. The same conditions obtain in southern Kansas, where the algal limestone is underlain by deposits of calcareous grit with subordinate amounts of clastic materials. Apparently this marks the beginning of the slow, gradual westward tilting. It is not to be inferred that coarse

1/ Oral communication.

materials were not deposited during this interval, as heavy floods would still be effective in moving gravels, etc., but such deposits comprise only a minor portion of the uppermost Ogallala.

Swampy conditions undoubtedly existed during this gradual westward tilting which led to the formation of Lake Wallace. The eastern rim of this lake 1/ was formed by the dip-slope to the west of the Greenhorn limestone and the more resistant sandstones of the Dakota group.

This lake occupied at the time of maximum development about the western one-third of Kansas, extending north into southernmost Nebraska, and south from Kansas through Texas and Beaver counties Oklahoma into the northern portion of the Texas Panhandle and westward into Colorado. South-central Kansas west of a northeast-southwest line through the northwest corner of Kiowa county was covered by Lake Wallace (Plate III). It is not definitely understood at the present time how long the lake was in existence, but it is highly probable that the deposits of algal limestone formed in this lake represent all of upper Pliocene time 2/.

1/ M.K. Elias, oral communication.

2/ M.K. Elias, oral communication.

In that part of south-central Kansas not covered by the lake streams were able to develop and cut their courses westward by headward erosion in the Ogallala formation. Among these streams was the predecessor of the South Fork of Ninnescah River which will be referred to as the "pre-Ninnescah".

During the time Lake Wallace was in existence, the "Hutchinson-Arkansas" was reoccupied when the "Wichita-Arkansas" cut back to the former junction of the two streams, and ground-water concentration in the former valley joined the waters of the latter stream.

5. Eastward tilting and drainage of Lake Wallace.

Lake Wallace was probably drained at the close of the Tertiary, when the Rocky Mountains were re-elevated (32) during the Cascadian Disturbance. This uplift of the Rockies caused a tilting of the High Plains region to the east, draining the lake. A search was made for possible outlets that carried off its overflow water. It was realized that such evidence might have been destroyed by erosion in Quaternary time, or hidden by a cover of Sanborn. But is was considered that valleys indicative of considerable erosion and now occupied by "misfit streams" 1/ might furnish evidence of a former

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1/ "misfit streams" are those that at present are incapable of performing the amount of erosion indicated by their valleys (27).

outlet of Lake Wallace. The writer in company with K.K. Landes visited northern Clark county and discovered a possible outlet to this lake in the valley now occupied by Bluff Creek in T. 30 S., Ranges 23 and 24 W. The outlet stream will be referred to as "pre-Bluff Creek". The evidence available showed that "pre-Bluff Creek" was an outlet when Lake Wallace was drained. Erosion and deposition in the lower reaches of Bluff Creek have probably destroyed any evidence that might prove that "pre-Bluff Creek" served as an outlet while Lake Wallace was in existence.

Evidence of the existence of "pre-Bluff Creek" consists of a terrace, below which Bluff Creek has cut its bed about 8 to 12 feet, and upon which lies the Sanborn formation which also covers the divides in this area. Boulders of algal limestone (which was deposited in Lake Wallace), and large pieces of Dakota sandstone up to 90 pounds in weight (Fig. 13)were found in the gravels of this terrace. Boulders of igneous rocks, common in the Ogallala formation, were also found. Since the boulders of algal limestone and Dakota sandstone are topographically higher in the terrace than their outcrops along Bluff Creek, they must have been carried from points to the northwest by the rushing waters of "pre-Bluff Creek".

It is not meant to be implied that this terrace, which represents an old flood plain of "pre-Bluff Creek", has existed in its present relations from the time of its formation. After "pre-Bluff Creek" ceased to exist, due to the lowering of the waters of Lake Wallace, the valley was filled in by the Sanborn formation. Subsequently Bluff Creek came into being, occupying the approximate site of pre-Bluff Creek, and carved its valley in the Sanborn formation uncovering and entrenching itself into the old flood plain.

Other streams which have carved valleys headward through the Ogallala and older beds possess somewhat widened valley rims. Bluff Creek, however, runs through a canyon in sections 24, 25 and 36, T. 30 S., R. 23 W. This gorge (the walls are nearly vertical in places) averages about half a mile in width, and at its deepest point (in the north half of sec. 2, T. 31 S., R. 23 W.) is 200 feet deep. As "pre-Bluff Creek" cascaded over the Ogallala escarpment it carved the gorge, leaving evidence of rapid erosion by a swiftly flowing stream. Bluff Creek Canyon is truly an impressive sight.

A mile and a half upstream from this gorge may be seen angular slabs of Cretaceous and Permian rocks up to 6 feet in width and weighing hundreds of pounds. These are found within the materials of the terrace deposits of "pre-Bluff Creek" and in the bed of present Bluff Creek where it has excavated its channel into the old flood plain. These are the largest boulders that have ever been seen in Kansas by the writer, with the exception of glacial erratics in the northeastern part of the state.

6. Deposition of the Sanborn formation.

It appears that after the draining of Lake Wallace there was resumption of sheet-flood deposition similar to that of pre-algal Ogallala time. M.K. Elias (11,163, 177,178) in northwestern Kansas, found gravels in the base of the Sanborn formation (immediately overlying the algal limestone) with boulders up to 2½ feet in diameter. Gravel is found in the base of the Sanborn of south-central Kansas, but it is less plentiful and contains no boulders as large as those described by Elias. These deposits indicate a rainfall of the torrential type, with resulting sheet-flood deposition over the flat floor of abandoned Lake Wallace, and their limited vertical range indicates that this type of deposition was short lived, being most active during the beginning of Sanborn time. The old bed of Lake Wallace was undoubtedly covered by these materials, East of the lake however, the waters probably sought and followed established drainage channels along which the debris was deposited.

Possibility of the existence of playa-like lakes over the southern part of western Kansas is indicated by the distinct bedding of the loess-like materials above the gravels of the Sanborn formation.

Deposition of the Sanborn formation, during and subsequent to the development of the present Arkansas has undoubtedly covered many points of evidence. The present Bluff Creek (near the gravel pit mentioned in sec. 25, T. 30 S., R. 24 W.) has cut its way down in the Sanborn formation during the reoccupation of "pre-Bluff Creek" valley, and Sanborn is exposed in the valley walls from the terrace in the present valley to the tops of the adjoining divides, a difference in elevation of over 80 feet.

7. Development of present drainage.

It is possible that "pre-Ninnescah" could have received some of the water from Lake Wallace when it drained, but there is no evidence for this statement. Following the sheet-flood deposition of the basal Sanborn over the abandoned bed of Lake Wallace the "pre-Ninnescah" proceeded to erode headward in a westerly direction across this gravel veneered flat. That part of the "pre-Ninnescah" west of Ford will be referred to as the "Ninnescah-Arkansas". We find some evidence that the southern portion of former Lake Wallace was tilted slightly south of east, for the course of the "Ninnescah-Arkansas" has a southeasterly direction west of Ford.

Coincident deposition of the upper portion of the Sanborn may have tended to slow up the westward headward erosion of "Ninnescah-Arkansas". However, the gradual tilting toward the east of western Kansas with consequent increase of gradient probably off-set the added load of Sanborn materials so that this stream developed westward rather rapidly.

"Ninnescah-Arkansas" cut its way westward through the old bed of Lake Wallace and finally joined with a relic stream of the eastward flowing drainage that formerly supplied water to Lake Wallace. The writer constructed a profile of present Arkansas River to see if there might still exist a "break" in the profile where a relic stream from the westward entered into Lake Wallace. But no break was found because of the amount of fill existing in the present Arkansas River channel, possibly 50 to 100 feet according to Haworth (18a,28).

Meanwhile, the eastward tilting caused the headward erosion of the "Hutchinson-Arkansas" to change from its northwest direction to one more nearly west. It is probable that at this time it flowed westward just north of the northern boundary of Stafford county. According to Thomas H. Allan 1/ a considerable thickness of river sand and gravel was encountered when core drilling in this area.

The tilting in the southeastern portion of former Lake Wallace then assumed a northern component and the headward movement of the "Hutchinson-Arkansas" swung to the southwest, starting that portion of the river which the writer calls the "Kinsley-Hutchinson-Arkansas". Doubtless this stream cut headward rapidly toward the southwest in the soft Ogallala and Dakota rocks. Evidence of a northeast direction of tilting in post-Ogallala time (post-algal time, hence in all probability post-Tertiary) is found in the elevation of two outcrops of algal limestone in Edwards county (south of the N. ¼ cor. sec. 2, T. 24 S., R. 19 W., elevation 2,120 feet, and at the southeast corner of section 21, T. 25 S., R. 20 W., elevation 2,260 feet), and in the elevation of an outcrop of Ogallala (from which the overlying algal limestone has been eroded) in Ford county (S. ¼ cor. sec. 19, T. 27 S., R. 23 W., elevation 2,400 feet). Although these three locations are in about a northeast - southwest line and consequently do not give the true amount

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1/ Letter to the writer, September, 1932.

of tilting and its direction, they do give evidence of a northeast tilting amounting to about 10 feet per mile in this area in post-Tertiary time. The "Kinsley-Hutchinson-Arkansas" favored by this northeast tilting finally cut its way southwest until it pirated "Ninnescah-Arkansas" River east of Ford.

The piracy of "Ninnescah-Arkansas" by the "Kinsley-Hutchinson-Arkansas" was the initiation of the present course of Arkansas River. In relatively recent time the Arkansas River had migrated northward a distance of about 6 miles immediately south of Great Bend. Haworth (18a, 28-29) states that Arkansas River has moved northward, due to the "filling in process ... principally on the south side", in western Kansas. Additional evidence has been supplied by Allan 1/, "core drilling near Ellinwood indicates that the present channel of the Arkansas is farther north than the original".

The reader may object to the absence of any mention of Medicine Lodge River. Many laymen, and some geologists, have suggested that Arkansas River at one time left its present course near Ford and joined the headwaters of the Medicine Lodge. The writer considered this possibility, but abandoned it after field and

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1/ Thomas H. Allan, letter to the writer, September, 1932.

office studies. Although Medicine Lodge River is now flowing in a channel cut in an old terrace, this terrace is made up of much different material than that found on Bluff Creek. Furthermore, according to C.L. Knight 1/ (30), who has studied the geology of Barber county, field evidence is opposed to the conception of a former connection of Medicine Lodge River with the Arkansas.

In brief, the present course of Arkansas River has been caused by headward erosion and stream piracy during successive tiltings in different directions of this part of Kansas.

Source and disposition of Sand Dunes.

The major portion of the sand dunes lie on the south side of Arkansas River. Sand dunes occur north of the river on the uplands north of Ford, near Great Bend, and east and northeast of Hutchinson.

Various theories on the origin of the sand have been proposed. The first field observation of record upon this subject were made by J.S. Newberry who travelled along the Santa Fe Trail in 1859. While in the vicinity of Larned he made the following conclusion (41, 27), "The sand-hills, which border the Arkansas on the south side, seem to have been derived from the de-

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1/ Oral communication.

composition of the Tertiary conglomerate".

Haworth (18a,31) in writing of the country south of the great bend of Arkansas River calls these sand areas "a sandy accumulation strongly resembling the general river sands". The writer infers from Haworth's explanation of the great bend of the Arkansas (18a,30-32) that he attributes this sand mainly to the postulated northward migration of the river to its present location.

Robert Hay (20,44-45) believes that much of the material of the sand dunes is of strictly local origin, increased by sand brought from the west by Arkansas River. He did not regard "the sand hills referred to as owing all their substance to the sands transported from the west", (20,44).

According to R.C. Moore (35,94), "The sand has been derived chiefly from the alluvial flats along Arkansas river, being blown out by the winds, which are prevailingly from the northwest. Indirectly, much of the sand comes from the weathering of the Dakota sandstone and Tertiary deposits in the region".

In so far as the writer could determine there are no distinct differences in the mineralogic content of the sands. There has been so much blowing about and mixing that the sands have become uniform in composition, so mineralogical examination is fruitless in attempting to determine origin.

The wind direction is important in considering how much sand has been blown from Arkansas River. Previous writers speak of the winds as "prevailing from the northwest". The writer realizes that the few years of weather observations in this area are but a fraction of the time involved in the transportation of the sand and the formation of dunes. However the prevailing winds, according to the records of the Dodge City and Wichita weather bureau stations (58 and 45 years of observations, respectively), are from the south. True, the strongest winds come from the northwest, but these are in the winter months when the least amount of materials is moved.

K.K. Landes in writing on "Volcanic Ash in Kansas" believes that "Mount Capulin and its neighbors in northern New Mexico ... seem to be the most probable source of the Pleistocene ash" (31a,939). This would indicate winds from the southwest which agrees with present conditions. However there is a possibility that the presence of ice to the north in Pleistocene time may have altered the prevailing direction of the wind.

According to Haworth (18a,29) "Southernly winds and the river currents have filled in the bottom to the south ... so that the bottom land has been carried far to the north". The writer has observed, in the sand dune areas south of Arkansas River and southwest of Kinsley, that trails over which he had travelled six years before have been covered by sand dunes growing from the southwest.

An inspection of the outlines of the dunes as shown on topographic sheets of the United States Geological Survey shows that the sand dunes have no prevailing direction of their longer axes. Just as many dunes may be found to prove prevailing wind directions from the northwest as from the southwest, and south. Inspection of the dunes in the field leads to the same results. If, as some postulate, the dunes on the south side of Arkansas River are formed by prevailing northwest winds, how may we explain the many dunes immediately north of Rattlesnake Creek (and they are much closer to the creek than apparent on the topographic sheets) in T. 25 S., Ranges 14 and 15 W., and the scarcity of dunes to the south of the same creek? This situation is especially striking when seen in the field.

It is the writer's opinion that the ideas of Hay (20,44-45) most nearly portray actual conditions. The Sanborn, Ogallala and Dakota formations certainly contain sufficient sand to furnish a source. A zone of sand in the Sanborn which is 4 feet thick and the base not exposed occurs in about the S. ¼ cor. sec. 22, T. 28 S., R. 18 W. The writer believes that the bulk of the material of the present sand dunes are derived from the residual soils of the older formations. The winds have reworked these materials, and streams flowing across this area both in the past and present have no doubt contributed sands. A continuous belt of sand dunes extends from the beginning of the northward swing of Arkansas River east of Ford to Great Bend. Very likely it has been this belt of dunes which has supported the idea that the present arrangement of the sand dunes was due to the "prevailing northwest winds", and that Arkansas River was the main source of the sand.

Before discussing these dunes, let us investigate those to the northeast of Hutchinson. N.H. Darton (9, 27) writes of them as "a range of sand dunes -- low, irregular hills composed of loose sand which the wind has blown out of the flats along Arkansas River". However, Robert Hay reported finding outcrops of Dakota sandstone (sec. 33, T. 22 S., R. 5 W.) in the hills and calls them "sedentary sandhills" (23,228) formed from the subjacent Dakota sandstone. He also believed that in regions such as this the sand dunes remained more or less stationary, "The mass remains; the molecules are in motion" (23,228). Inspection of the present distribution of Dakota in this region tends to confirm the explanation of Hay.

Although he cannot offer actual proof through outcrops, the writer believes that the bulk of the sand in the dune area which parallels Arkansas River in Ford, Edwards, Pawnee, Stafford and Barton counties came from underlying Dakota sandstone. Exposures of this sandstone occur along the north side of the Arkansas at elevations corresponding to those of the sand dunes. A well drilled for oil by the Amerada and Wilcox companies (NW. $\frac{1}{4}$, NW. $\frac{1}{4}$, SW. $\frac{1}{4}$, sec. 32, T. 25 S., R. 19 W., elevation 2,222 feet) is about $3\frac{1}{8}$ miles east and level with an outcrop of Dakota sandstone. The driller logged the upper portion as follows: sand, 60 feet; yellow shale, 20 feet; pink clay, 80 feet; and sandy blue gumbo 75 feet. This indicates to the writer that the well was in the Dakota practically from the start. The driller did not differentiate the dune sand from the rest of the first 60 feet of sand. The log of the well drilled by the Mid-Kansas Oil and Gas Company (SE. $\frac{1}{4}$, NE. $\frac{1}{4}$, NE. $\frac{1}{4}$, sec. 30, T. 24 S., R. 18 W.) is quite similar to that of the Amerada-Wilcox well. Search for large quantities of soft water in these sand hills should be accompanied by coring and the cores should be carefully examined. If, as the writer believes, Dakota sandstone is found not far below the surface, there is no hope for a large supply of soft water as the Dakota carries hard water.

In conclusion, the following points are emphasized. First, the greater mass of the sand in the dune areas has been derived from older rocks, namely the Dakota, Ogallala and Sanborn formations. Second, this sand has been transported no great distance; the sandy flats of Arkansas River have not been the universal source. Third, streams, both present and past, have probably contributed sand to these dunes, but the amount has been relatively insignificant. Fourth, the wind has not caused these great colonies of dunes to migrate in various directions to sundry parts of this region, but has mainly confined its activity to building dunes of sand derived by residual concentration from older formations. However, it is not meant to imply that the wind has not blown small amounts of sand over the area, thus mixing the dune ingredients.

Contour Map on the Base of the Tertiary.

An attempt was made to determine the pre-Tertiary topography of south-central Kansas and its relation to present topography. Information for such an investigation must necessarily be obtained by borings which have

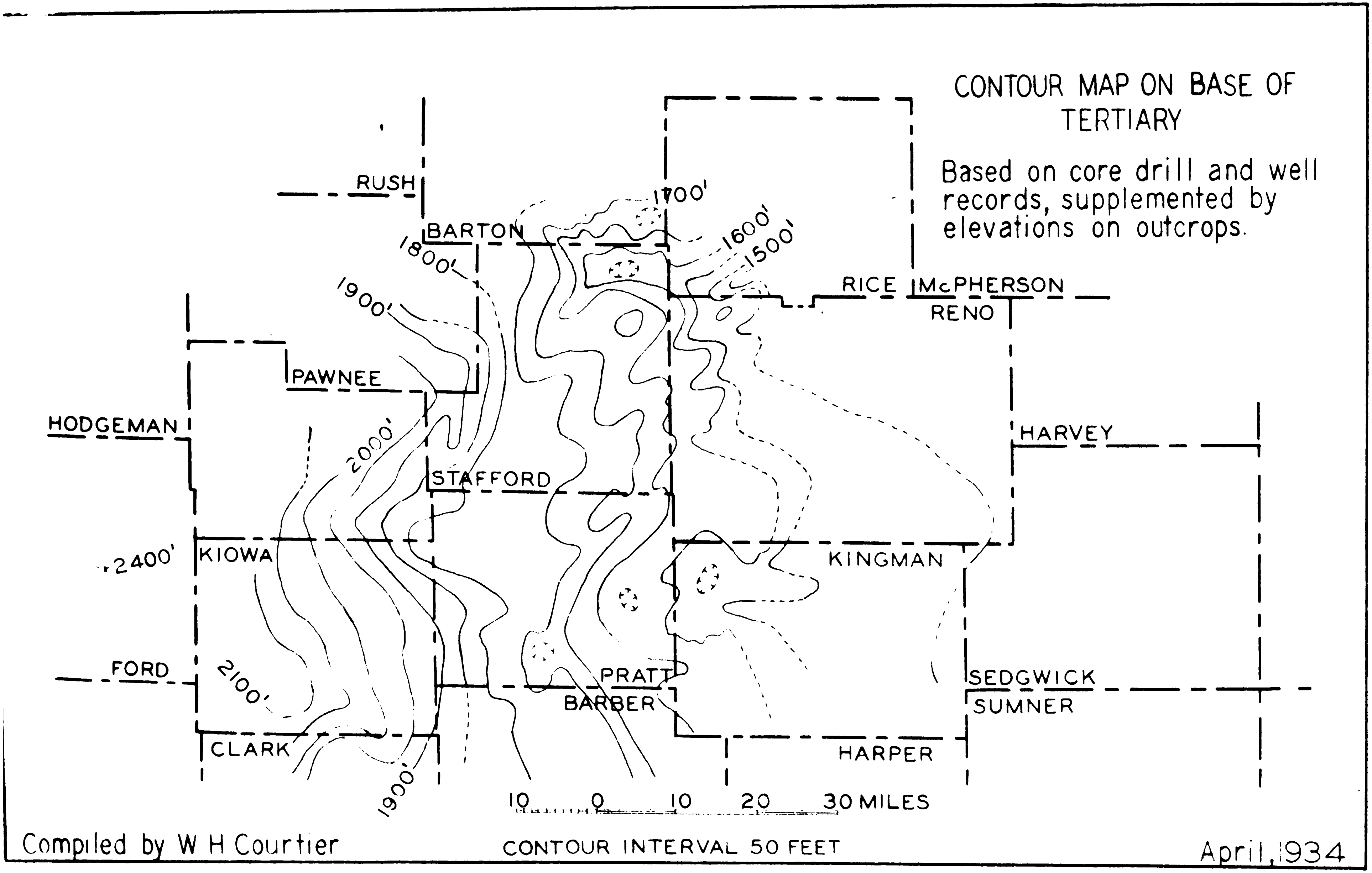
CONTOUR MAP ON BASE OF TERTIARY
Based on core drill and well records, supplemented by elevations on outcrops.
RUSH
BARTON
RICE
McPHERSON
RENO
PAWNEE
HODGEMAN
HARVEY
STAFFORD
KIOWA
KINGMAN
FORD
PRATT
BARBER
SEDGWICK
SUMNER
CLARK
HARPER
1700'
1600'
1500'
1800'
1900'
2000'
2400'
2100'
1900'
10 0 10 20 30 MILES
Compiled by W H Courtier
CONTOUR INTERVAL 50 FEET
April, 1934

Plate IV.

been made either by core drill in searching for structures favorable to the accumulation of oil or by oil wells. Water well information is of little value as it is not usually necessary to drill through the Tertiary for an adequate supply.

In core drilling, the softer surface formations are rapidly drilled by "fishtailing" and no record is kept of materials penetrated. It was assumed, after talking with geologists of several oil companies, that the depth at which casing was set (and actual coring commenced) would coincide approximately with the pre-Tertiary surface. To this end, the writer obtained core drill information from various oil companies for over 600 holes. These records were supplemented by logs of wells drilled for oil and elevations on surface exposures of the base of the Tertiary (Ogallala). Using this information the writer constructed a topographic map (Plate IV) of the pre-Tertiary surface. However, it is necessary before any conclusions are drawn, to consider several things involving the information from which this map has been compiled.

It was assumed at first that the information was probably accurate within 10 feet. But, in two wells the writer found that Dakota sandstone had been included in the "sand and gravel" of the Ogallala on the drillers log. And where some core holes had shown Tertiary to be extremely thin, or even lacking in instances, the writer found evidence in the field that this information erred as much as 40 feet. Other core holes starting where the Tertiary was known to be thin logged an excessive thickness of Tertiary. Therefore it was decided that the smallest contour interval that could be used with a factor of safety was 50 feet. Only the core holes that were in good agreement with each other were used in constructing the map (Plate IV).

Evidently the direction of the slope of the surface in pre-Tertiary time was to the east as at present. It is probable that the amount of slope indicated by the map is greater than that existing before deposition of Tertiary materials began, due to eastward tilting after Tertiary time.

Two other features of this map merit notice; the existence of a remarkably flat area in Pratt and southern Stafford counties; and the north-south alignment of depressions east of this flat area.

According to G.L. Knight 1/ the Comanchean (lower Cretaceous) beds which lie on the Day Creek dolomite (near the top of the Cimarron) in Clark county progress-

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1/ Oral communication.

ively overlap older Permian rocks until in Barber county Comanchean rests upon the dolomite of the Dog Creek Shale, and the Dog Creek Shale rests upon the Flower Pot Shale in places. The writer learned that just west of Greensburg the Comanchean is at least 300 feet thick. But in northern Barber county it thins to practically nothing. It therefore appears probable that the rather flat area shown on the map in Pratt and Stafford counties is due to the presence of the dolomite in the Dog Creek Shale and the dolomite at the base of the Medicine Lodge Gypsum (the intervening gypsum members being cut out) at the surface.

The depressions are very likely due to solution and removal of salt below the Cedar Hills sandstone with consequent slumping of the overlying beds. Indications of other depression were found, but as these depended for evidence upon single core holes, widely spaced, the writer considered such occurrences to be questionable and omitted them.

Drainage features on this old erosion surface are poorly defined and appear unrelated to the present drainage, except, as already noted that the general slope of the surface was to the east, as at the present time.

1. Adams, George Irving, Physiographic divisions of Kansas: Kansas Acad. Sci. Trans. 18, pp. 109-123 (map), 1903.

2. Bass, N.W., Structure and limits of the Kansas Salt beds: Kansas Geol. Survey Bull. 11, pp. 90-95, April 15, 1926.

3. Bass, N.W., Geologic Structure of the Dakota Sandstone in Western Kansas: Kansas Geol. Survey Bull. 11, pp. 84-89, April 15, 1926, Am. Assoc. Petroleum Geologists, vol. 9, No. 6, pp. 1019-1023, Sept. 1925.

4. Beede, Joshua William, The McPherson Equus beds, Kansas: Kansas Acad. Sci. Trans., vol. 15, pp. 104-110, 1898.

5. Cragin, Francis Whittemore, Notes on the Geology of Southern Kansas: Washburn College Laboratory of Natural History, (Topeka) Bull. 1, pp. 85-91, 1885.

6. Cragin, Francis Whittemore, Tertiary in Harper County, Kansas: Kansas City Review of Sci. and Industry, vol. 8, pp. 678-682, 1885.

7. Cragin, Francis Whittemore, Geological Notes on the Region South of the Great Bend of the Arkansas: Washburn College Laboratory of Natural History Bull. 2, pp. 33-37, 1889.

8. Darton, N.H., Preliminary report on the Geology and Underground Water Resources of the Central Great

Plains: U.S. Geol. Survey Prof. Paper 32, pp. 433, 1905.

9. Darton, N.H. and others, Guidebook of the Western United States, Part C, the Santa Fe Route: U.S. Geol. Survey Bull. 613, p. 194, 1915.

10. Darton, N.H., The Structure of Parts of the Central Great Plains: Abst. Washburn Acad. Sci. Jour. 8, p. 503, 1918, U.S. Geol. Survey Bull. 691, pp. 1-26, 1918.

11. Elias, Maxim K., The Geology of Wallace County Kansas: Kansas Geol. Survey Bull. 18, April 1, 1931.

12. Elias, Maxim K., Grasses and other Plants from the Tertiary Rocks of Kansas and Colorado: Univ. of Kansas Bull. 20, May 15, 1932.

13. Elias, M.K., Paper in preparation.

14. Emmons, Samuel Franklin and others, Geological Guide Book of the Rocky Mountains Excursion: International Geol. Congress V. Washington 1891, pp. 443-449, 1893.

15. Fenneman, Nevin M., Physiography of Western United States (Great Plains province): New York McGraw Hill Co., pp. 1-91, 1931.

16. Gilbert, G.K., The Underground Water of the Arkansas Valley in Eastern Colorado: U.S. Geol. Survey Ann. Rept. 17, pt. 2, pp. 551-601, 1896.

17. Haworth, Erasmus, Underground Waters of Southwestern Kansas: U.S. Geol. Survey Water Supply Paper

vol. 6, p. 65, 1897.

18a. Haworth, Erasmus, Physiography of Western Kansas: Kansas Univ. Geol. Survey, vol. 2, pp. 11-49, 1897.

18b. Haworth, Erasmus, Physical Properties of the Tertiary: Kansas Univ. Geol. Survey, vol. 2, pp. 247-284, 1897.

19. Haworth, Erasmus, and Beede, J.W., The McPherson Equus Beds: Kansas Univ. Geol. Survey, vol. 2, pp. 285-296, 1897.

20. Hay, Robert, A Geological Reconnaissance in Southwestern Kansas: U.S. Geol. Survey Bull. 57, pp. 1-49, 1890.

21. Hay, Robert, The Geology of the Great Plains: Kansas Acad. Sci. Trans. vol. 13, pp. 3-6, 1893.

22. Hay, Robert, Geology and Mineral Resources of Kansas: Kansas State Board of Agriculture Biennial Rept. 8, pt. 2, pp. 99-162, 1893.

23. Hay, Robert, On the Eastern Extension of the Cretaceous Rocks in Kansas and the Formation of certain Sandhills: Trans. Kansas Acad. Sci., vol. 14, pp. 227-229, 1894.

24. Hay, Robert, Water Resources of a Portion of the Great Plains: U.S. Geol. Survey 16th Ann. Rept. pt. 2, pp. 541-588, 1894-1895.

25. Hay, Robert, A Bibliography of Kansas Geology:

Kansas Acad. Sci. Trans., vol. 14, pp. 260-278, 1896.

26. Hill, Robert Thomas, Summary of Physiographic Investigations made in connection with the Oklahoma-Texas Boundary Unit: Texas Univ. Bull. 2327, pp. 157-172, Aug. 1923.

27. Johnson, Douglas, Streams and Their Significance: Jour. Geol., vol. 40, No. 6, pp. 481-497, Aug. Sept. 1932.

28. Johnson, Willard Drake, The High Plains and Their Utilization: U.S. Geol. Survey 21st. Ann. Rept. pt. 4, pp. 601-741, 1901, No. 22, pt. 4, pp. 631-669, 1902.

29. Jones, Alfred W., The Flood of 1903 in Central Kansas: Trans. Kansas Acad. Sci., vol. 19, pp. 138-140, Nov. 1903.

30. Knight, G.L., Geology of Barber County Kansas: Kansas Geol. Survey, bulletin in preparation.

31. Landes, K.K., Volcanic Ash Resources of Kansas: Kansas Geol. Survey Bull. 14, 1928.

31a. Landes, K.K., Volcanic Ash in Kansas: Geol. Soc. America Bull., vol. 39, pp. 931-940, Dec. 1928.

32. Lee, Willis Thomas, Peneplains of the Front Range and Rocky Mountains National Park, Colo.: U.S. Geol. Survey Bull. 730, pp. 1-17, April 4, 1932.

33. Mead, J.R., A Dying River: Kansas Acad. Sci. Trans. (1893-94), vol. 14, pp. 111-112, 1896.

34. Meinzer, O.E., Ground Water for Irrigation in

the Vicinity of Wichita, Kansas: U.S. Geol. Survey Water Supply Paper 345-A, pp. 1-9, 1914.

35. Moore, R.C., Geology of Kansas: Kansas Geol. Survey Bull. 6, pt. 2, 98, 1920.

36. Moore, R.C., Surface Features of Kansas, Map 1930.

37. Moore, R.C. and Landes, K.K., Underground Resources of Kansas: Kansas Geol. Survey Bull. 13, 1927.

38. Mudge, Benjamin Franklin, Geology of the Arkansas: Kansas State Board of Agriculture Trans. 1872, pp. 408-410, 1873, Kansas Acad. Sci. Trans. 1, pp. 50-53, 1895.

39. Mudge, Benjamin Franklin, Pliocene Tertiary of Western Kansas: Kansas Acad. Sci. Trans., vol. 31, 1874, pp. 17-19, 1875, Kansas Acad. Sci. Reprint, pp. 113-117, 1896, Kansas State Board of Agriculture, Ann. Rept. vol. 3, pp. 351-353, 1875.

40. Mudge, Benjamin Franklin, Notes on the Tertiary and Cretaceous Periods of Kansas: U.S. Geol. and Geog. Survey of the Territories (Hayden) Bull. 2, pp. 211-221, 1876, U.S. Geol. and Geog. Survey of the Territories (Hayden) Ann. Rept., pp. 277-294, 1877.

41. Newberry, John Strong, Geological Report:- in J.N. Macomb, Report of the Exploring Expedition from Santa Fe, New Mexico, to the junction of the Grand and

Green rivers of the Great Colorado of the West in 1859: U.S. Army Engineering Dept. Washington, D.C., pp. 9-118, 1876.

42. Parker, Horatio Newton, Quality of the Water Supplies of Kansas: U.S. Geol. Survey Water Supply Paper 273, p. 375, 1911.

43. Perrine, Irving, Geological Conditions in Central Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 2, pp. 70-97, 1918.

44. Slichter, Chas. S., The underground flow in Arkansas Valley in Western Kansas: U.S. Geol. Survey Water Supply and Irrigation Paper 153, pp. 7-88, 1906.

45. Smyth, B.B., The Age of Kansas: Kansas Acad. Sci. Trans., vol. 9, pp. 129-136, 1885.

46. Todd, James Edward, Aqueous Loess: Kansas Acad. Sci. vol. 29, pp. 115-116, 1920.

47. Twenhofel, W.H., Treatise on Sedimentation: The Williams and Wilkins Co., Baltimore, Md., 1932.

48. Webster, Wilfrid, Physiographic Map of Kansas: The Geographical Press, Columbia Univ. New York, 1931.

49. Williston, Samuel Wendell, The Pleistocene of Kansas: Kansas Univ. Geol. Survey, vol. 2, pp. 299-308, 1897, Kansas Acad. Sci. Trans., vol. 15, pp. 90-94, 1898.


Plate V.
GEOLOGIC MAP OF SOUTH-CENTRAL KANSAS
By William H. Courtier
Geologic boundaries obtained through field work and from unpublished maps of the Kansas Geological Survey
Base from U. S. Geological Survey maps.
APRIL, 1934
Scale
10 MILES
QUATERNARY
Qal Alluvium
Qds Dune sand
Qsb Sanborn formation (In part as old and perhaps older than Qt)
Qt Terrace deposits (including McPherson formation) (Sands, gravels, silts, clays.)
TERTIARY
To Ogallala formation
CRETACEOUS
K Cretaceous undifferentiated
PERMIAN
Pc Cimarron
Pw Wellington
BARTON
PAWNEE
STAFFORD
EDWARDS
FORD
KIOWA
PRATT
KINGMAN
RENO
McPHERSON
SEDGWICK
SUMNER
BUTLER
CLARK
BARBER
CHEYENNE BOTTOMS
ARKANSAS RIVER
GREAT BEND
LARNED
HUTCHINSON
WICHITA
DODGE CITY
PRATT
ST. JOHN
LYONS
McPHERSON
KINSLEY
GREENSBURG
KINGMAN
Ellinwood
Sterling
Stafford
Macksville
Nickerson
Halstead
Cheney
Clearwater
Derby
Mulvane
Medicine Lodge