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ORIGIN OF KANSAS GREAT PLAINS DEPRESSIONS

By
John C. Frye

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ABSTRACT

Undrained depressions of various sizes and shapes are a characteristic minor element of Kansas Great Plains topography. A review of depressions in all parts of western Kansas indicates that several processes of origin are required to explain the many diversified features. They are classed in two general groups: (1) solution-subsidence depressions where the soluble rock may be salt, gypsum, chalk, or limestone, and (2) nonsolutional features produced by variously differential eolian deposition or erosion, compaction, silt infiltration, and animal action.

INTRODUCTION

Undrained depressions of many sizes and shapes are characteristic of the topography of much of western Kansas (Schoewe, 1949, pp. 314-324). In some areas they are quite closely spaced and their aggregate number is counted in thousands. The Colby quadrangle (Fig. 1) is typical of upland areas in the High Plains section. Here, the density of shallow depressions is indicated by the 748 intermittent lakes shown in the 252 square miles covered by the map. Great Plains depressions have diameters ranging from less than 10 feet to several miles, and their depths range from barely perceptible to more than 100 feet (Pls. 1, 2). Many are symmetrically circular or oval in plan, whereas others are elongate or irregular. The side slopes range from very gentle to precipitous cliffs (Pl. 2). A few depressions hold permanent bodies of water (Pls. 1, 2) but most of them contain lakes only after rains, if at all. They occur in rocks of Permian, Cretaceous, Pliocene, and Pleistocene (including Recent) age.

Undrained and formerly undrained depressions are noted in some of the early geological reports on the High Plains section, particularly Haworth (1896, 1897), Johnson (1901), and Darton (1905). They have been called "sinkholes, or swales, or lagoons, sometimes filled with water" (Haworth, 1897, p. 19). The abundance and varied nature of Kansas Great Plains depressions have invited several conflicting hypotheses of origin (Schoewe, 1949, pp. 314-324). Also, they have been a subject of informal speculation and controversy among geologists concerned primarily with other aspects of Great Plains geology.

In connection with ground-water and stratigraphic studies during the past 12 years I have had opportunity to examine many of the widely distributed depressions in the Kansas Great Plains

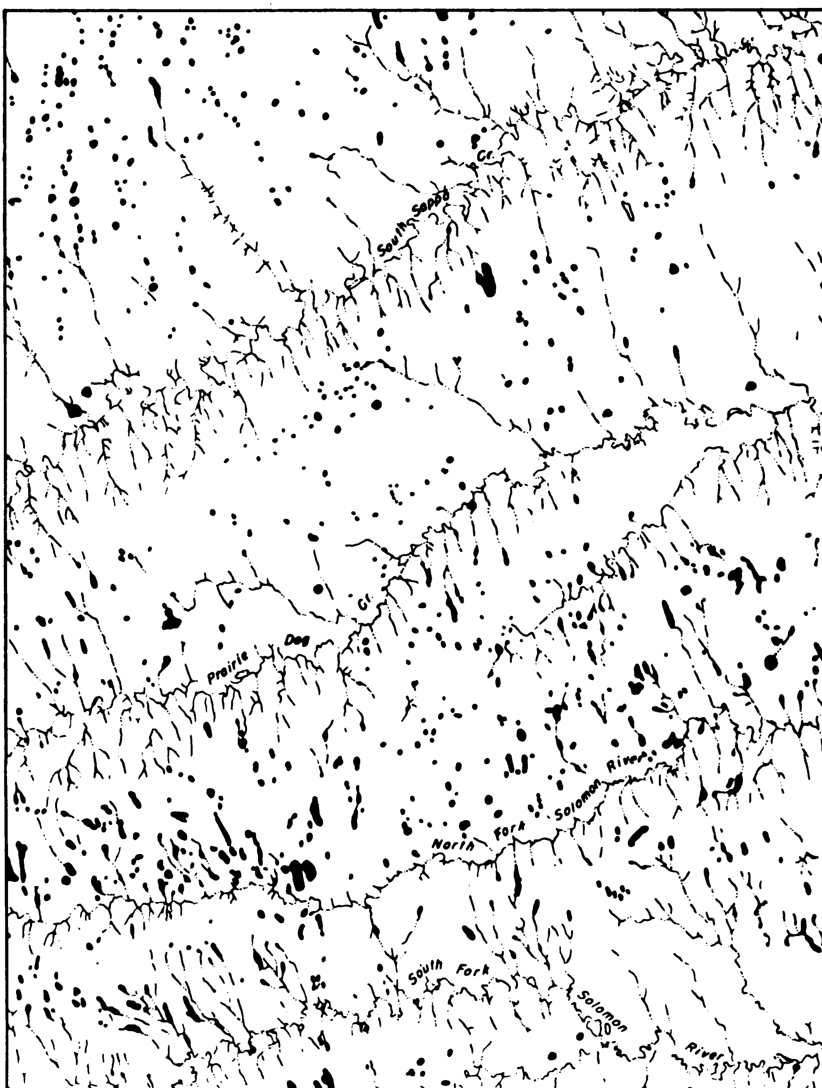

FIG. 1.—Drainage and intermittent ponds from the Colby 15-minute quadrangle, Thomas County, Kansas. Map by U. S. Geological Survey. Note the abundance of depressions, indicated by ponds, in the broad upland divide areas. These areas are underlain by about 30 feet of late Pleistocene loess 150 to 250 feet of Ogallala formation (Pliocene) and Pierre shale.

region. Field observations and subsurface data have led to judgment that the depressions in central and western Kansas represent several modes of genesis, and that some indicate effects of more than one process.

The present paper undertakes to review pertinent features of these depressions bearing on their origin and the hypotheses of formation so far advocated, and to outline additional processes that may have played a part in their development. Schoewe (1949, pp. 314-324) has recently described the appearance and distribution of variously sized basins in western Kansas. At least six distinct processes are judged to have played major or minor roles in the development of these basins. Therefore it is appropriate to classify the depressions according to presumed dominant mode of their origin as follows: (1) deep-seated solution of salt or gypsum with accompanying surface subsidence or collapse; (2) solution of carbonate rocks at intermediate depths and subsequent collapse; (3) differential wind deposition and erosion, in some places accompanied by compaction of eolian silts; (4) differential silt infiltration; (5) animal action; and (6) faulting.

Acknowledgments.—Thanks are expressed to R. C. Moore, whose criticisms have improved the manuscript, and to Ada Swineford and A. R. Leonard for helpful advice.

DEEP-SEATED SOLUTION

Depressions which seem to be explained best by deep-seated solution of Permian salt and gypsum characterize a large area in Meade and Clark Counties, Kansas, and in adjacent parts of Oklahoma. Half a century ago these depressions were noted by Haworth (1896, 1897) and Johnson (1901). Many are now drained. The Ashland-Englewood basin in southern Clark County is an area of coalescing partly filled and dissected depressions. In areal distribution the basins, or sinkholes, or sinks are sharply localized east of a prominent fault in central Meade County (Frye, 1942). Although the eastern side of the fault is upthrown, the regional dip of Cenozoic deposits, regional direction of ground-water movement, and general topographic slope are all easterly. In most of the dissected basins the rims expose Permian rocks capped with Ogallala beds of Pliocene age. Deep drilling has revealed the presence of salt and gypsum beds in the Permian rocks at depths less than 1,000 feet.

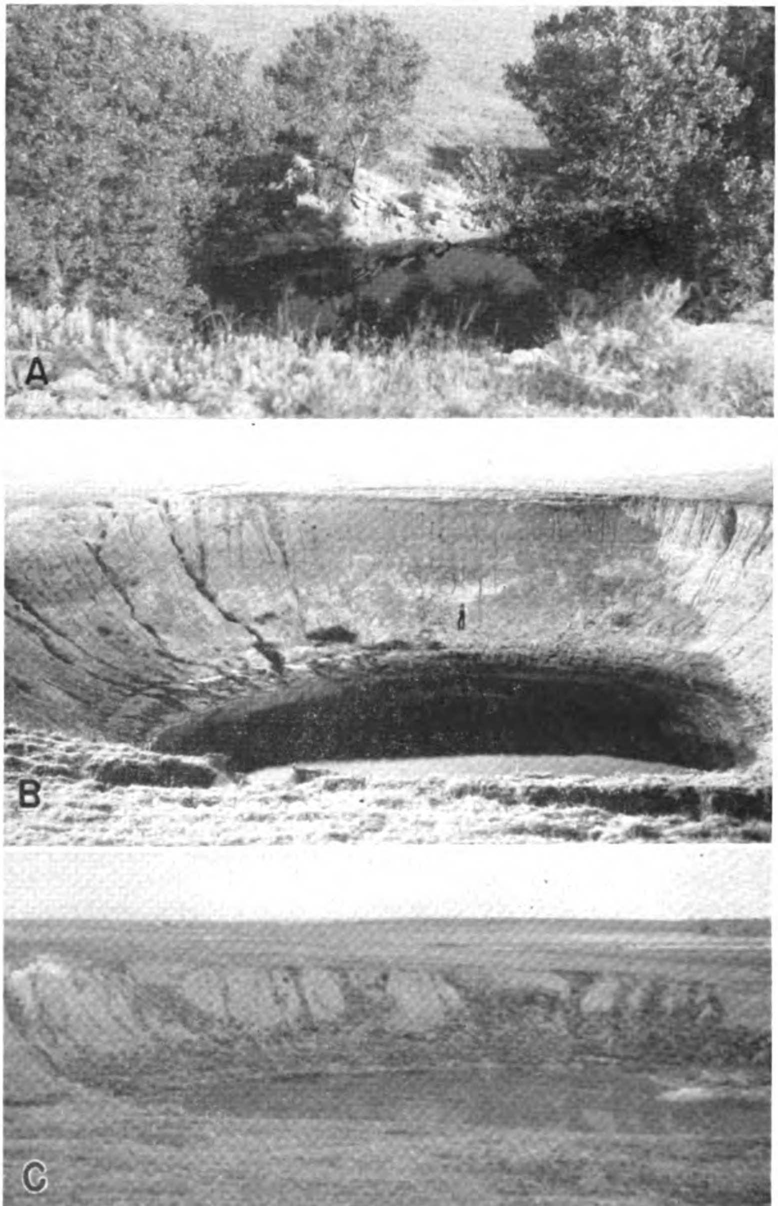

PLATE 1.—Solution-subsidence features. *A,* St. Jacob's well, west-central Clark County, Kansas, 1945. *B,* Meade "salt sink," 1½ miles south of Meade, central Meade County, Kansas. Photograph made in 1898 or 1899 by W. D. Johnson, U. S. Geol. Survey. This sink, which developed suddenly in 1879, is located just east of the Crooked Creek fault and is the result of deep-seated solution of Permian salt and gypsum. *C,* Meade "salt sink" as it appeared in 1939. Note erosion of sides and fill in sink bottom.

The age of the sinks in this area ranges from mid-Pleistocene to latest Pleistocene (Recent). The most recent subsidence, which formed across a cattle trail in March 1879 (Johnson, 1901, pp. 706-707), is located southeast of the City of Meade and just east of the Crooked Creek fault. Locally it is known as the "Meade salt sink" because it contained a pool of salt water immediately after the collapse (Pl. 1). In addition to "Meade salt sink," "Big Basin" and "St. Jacob's Well" (Pls. 1A, 4) in Clark County are relatively young as shown by their slightly dissected rims, lack of fill, and imminent piracy by surface drainage.

A particularly interesting partly filled and dissected sink is located mainly on the Jones Ranch about 10 miles southeast of Meade. The centripetal drainage pattern developed in the former sink is still evident in the headwaters of Sand Creek which now drains the area. East of the depression the walls of Sand Creek Valley expose Permian and Ogallala rocks dipping into the basin (Frye, 1942). The fill is dated as late Pleistocene in age.

Although the relatively small depressions are noted most commonly in the literature, large depressions are not lacking. The extensive Ashland-Englewood lowland in southern Clark County is the largest solution-subsidence feature in Kansas topography. Cimarron River enters this lowland from a narrow valley which is deeply incised in Permian rocks. The basin floor is marked by low ridges and hummocks of Permian redbeds projecting through 100 feet or more of late Pleistocene sediment. The crenulated escarpment that limits the basin to the north (Pl. 2E), west, and south is abrupt and exposes Permian redbeds capped by Ogallala formation. Frye and Schoff (1942) discussed the origin of these features and concluded that the Ashland-Englewood basin was formed by coalescence of solution-subsidence depressions, integrated by late Pleistocene (including Recent) erosion and sedimentation. In similar manner integration of solution-subsidence areas produced the valley of Crooked Creek east of the major fault. Erosional integration is still in progress and such isolated depressions as "Big Basin" and "St. Jacob's Well" eventually may be incorporated into the Ashland-Englewood lowland.

In the Meade-Clark County region a combination of geologic factors has given rise to the extensive development of solution-subsidence depressions. Faults cut both Pliocene-Pleistocene sediments, which contain fresh water under hydrostatic pressure, and Permian strata containing numerous beds of salt and gypsum. As pointed out by Frye and Schoff (1942, p. 34), the local structure allows fresh artesian water to circulate down fault zones into Permian rocks at depth, and eastward to a point of discharge, which is lower in elevation than the area of water ingress (Fig. 2). This structure has localized the sinks east of the faults. Since the faults are dated as early Pleistocene, developments of the solution-subsidence features can hardly antedate mid-Pleistocene time.

SOLUTION OF CARBONATE ROCKS

The youngest depressions in western Kansas of sufficient size to attract regional notice developed in Wallace County in 1926 (Moore, 1926) and Hamilton County in 1929 (Landes, 1931). Origin of the Wallace County sink by solution of Cretaceous chalk at a depth of a few hundred feet and subsequent collapse of the near-surface rocks has been described by Moore (1926) and Elias (1930, 1931).

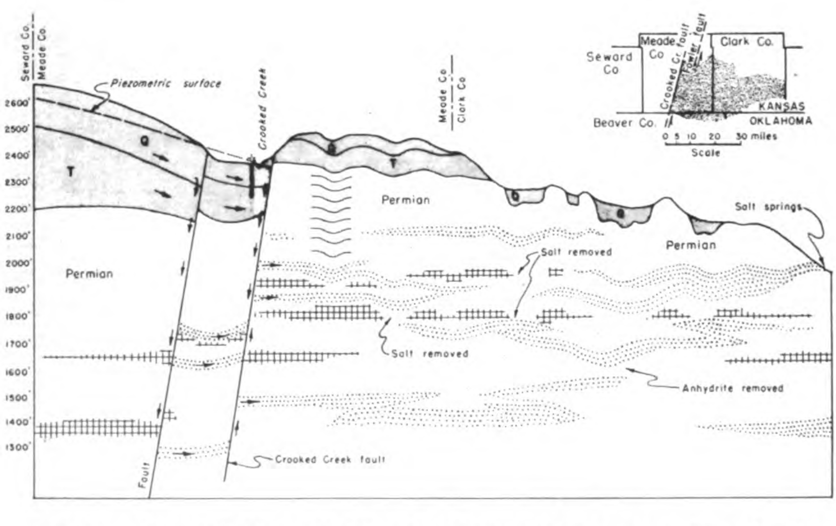

FIG. 2.—Generalized section through Meade basin and area immediately adjacent to east showing supposed course of circulating ground water and development of solution-subsidence features. Arrows indicate inferred directions of ground-water flow. After Frye and Schoff, 1942, p. 37. Insert map shows location of major faults in Meade County and the area principally affected by solution-subsidence features.

The development of this depression is described by Moore (1926, p. 130) as follows.

On the morning of March 9, 1926, a certain rancher, living about five miles east of the little town of Sharon Springs on the plains of western Kansas, chanced to see across the fields a dun-colored smoke. Hasty investigation revealed a newly formed, great yawning hole at the edge of the gently rounded bluff that here looks down on the dry sandy flat of Smoky Hill River. The cloud was dust. Excited word was broadcast by the press that the bottom was dropping out of Smoky Hill River, that a volcanic explosion of some sort was in full blast, or maybe a great gas blowout was in process of blowing.

According to reliable report the opening was at first something over fifty feet in diameter and appeared to be some hundreds of feet deep. Two streams of water from the underflow of Smoky Hill River were cascading into the depths sounding distantly on rocks below. . . .

A systematic series of soundings of the pond revealed a gradual increase in depth of water to about fifty feet, but in an area comprising about one seventh of the bottom the soundings increased very suddenly to 160 or 170 feet. A survey showed that the depression formed by the subsidence has a volume of a little over one and a half million cubic feet. Taking into account the volume which is occupied by the fallen rock debris, which by reason of its fragmentation may be assumed to fill a space at least 20 to 30 per cent. greater than its original volume, the size of the cavity under ground must be large. The depth from the original surface to the top of the material filling the deeper part of the hole is 245 feet; the depth to the bottom of the original cavity may be 500 feet, although this is only an approximate estimate.

Although insoluble Pierre shale underlies the surface of much of central Wallace County, it is immediately underlain by 700 feet of Niobrara chalk and chalky shale. Furthermore, in addition to the subsidence of 1926, several other depressions occur in the same areas and these display different stages of destruction by erosion. That their age may not be great is suggested by the observed rapid rate of rim erosion in the 1926 sink hole.

Cavern development in chalk is not a commonly described feature but in central westernmost Kansas the evidence of chalk solution, probably aided locally by circulation along fault zones, as postulated by Moore and by Elias seems conclusive. The requirements for sink development of this type include a section of thick Cretaceous chalks overlain by no more than a few hundred feet of insoluble shales and a structural setting that would permit adequate circulation of fresh waters through beds generally displaying extremely low permeabilities. In areas where the

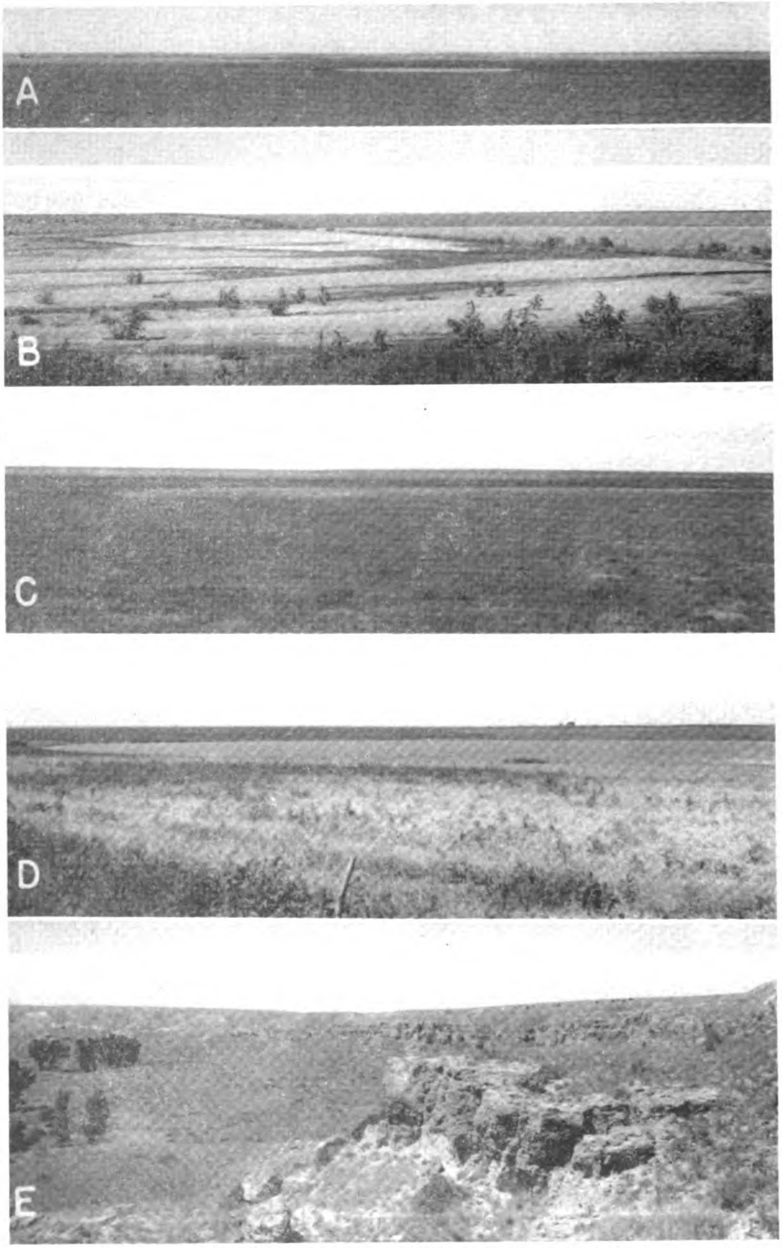

PLATE 2.—Great Plains depressions. *A,* Temporary pond in very shallow High Plains depression, north-central Thomas County, Kansas, 1943. *B,* Temporary lake in large High Plains depression, north of Sappa Creek, north of Levant, Thomas County, Kansas, 1943. *C,* Small High Plains depression on the Thomas-Logan County line (SE¼ sec. 36, T. 10 S., R. 34 W.). This is one of the depressions where test drilling revealed no reflection of

near-surface insoluble beds are several hundred or more feet thick this type of sink probably cannot occur. Such judgment is confirmed by test drilling in an area where 500 to 700 feet of Pierre shale overlies Niobrara chalk in Thomas County (Frye, 1945). In that area the Pierre shale floor does not reflect the depressions that occur on the surface. Perhaps Wallace, Logan, and Hamilton (Smith, 1940) Counties are the only areas in western Kansas where depressions have been produced by solution of Cretaceous chalks.

Solution cavities of sufficient size to cause surface depressions in western Kansas are possible only in Cretaceous chalks and Permian salt and gypsum. In western Texas and eastern New Mexico thick beds of caliche or limestone occur in the upper part of the Ogallala formation (Pliocene) and it has been suggested that some depressions in that area are produced by solution of this Pliocene caliche. In western Kansas, however, most of the calcium carbonate in the Ogallala formation consists of cement in sand, silt, and gravel beds. Limestone beds occur in the formation at only a few localities and at all observed occurrences such beds are quite thin; therefore, it is judged that large solution cavities could not be formed in the Ogallala.

EOLIAN ACTION

Localized deflation and deposition by wind action is a common occurrence in many semiarid and arid regions. In the sand-dune tracts south of Garden City and in the Great Bend region, hundreds of undrained depressions have been produced by wind action in shifting sand (Smith, 1940). Such blowouts and interdune depressions are clearly recognized and adequately described; they need no further comment here.

The effect of wind action on silt-mantled uplands is not so clearly understood. Much of the Kansas High Plains surface, mantled by late Pleistocene loess, is dotted by hundreds of shallow saucer-shaped depressions (Fig. 1; Pls. 2A, B, C, D). Although these shallow depressions may have diverse modes of origin, it seems probable that wind action has played an important role.

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the feature in the Pierre shale surface at depth. 1943. *D*, Temporary lake in upland depression in sec. 25, T. 6 S., R. 35 W., Thomas County, Kansas, 1943. *E*, Rim of Ashland-Englewood basin showing Permian redbeds capped with Ogallala formation, north of Ashland, central Clark County, Kansas, 1940.

PLATE 3.—Differential silt infiltration sinks. *A*, Surface of Arkansas alluvial plain on which the sinks developed, near Hutchinson, Kansas. *B* and *C*, Sinks that have filled in to within a few feet of the surface; August 1948. **Photographs furnished by Mr. T. J. Cambern.**

In the Texas High Plains comparable features have been attributed to wind scour (Evans and Meade, 1945). The depressions in the Texas plains commonly are accompanied by a low dune on the lee side and this association strongly suggests that the dune is formed by material derived from the basin floor. Although recognizable lee dunes are rare on the High Plains of Kansas, those which occur (Frye, 1946) probably have a similar origin.

Elongate troughs found on the upland surface in Cheyenne County, Kansas, contain strings of shallow depressions on their floors. The floors are immediately underlain by Ogallala rocks and the ridges are composed of Peoria and Bignell loesses. Since these features are localized near a probable loess source, and since some of the troughs are not occupied by through drainage, they may be the result of localized loess deposition in the form of longitudinal loess dunes.

At some places in northwestern Kansas where the upland mantle of late Pleistocene loess is thick, shallow depressions may be due to minor irregularities of loess deposition on a slightly dissected surface; to initial loess drift into shallow, pre-existing valleys; and to differential compaction of thicker loess deposits over shallow former valleys. Locally, alignment of shallow depressions roughly parallel to existing tributary drainage suggests partial control by earlier erosional valleys. That these northwestern Kansas features are not due to solution-subsidence is indicated by the large thickness of insoluble rock (1,000 feet of Pierre shale) above the shallowest soluble Cretaceous rocks, by the relatively low content of soluble material in the Ogallala formation, and by test drilling (Frye, 1945) which shows no reflection of the depression in the Pierre shale surface. Small depressions that may be the result of compaction of water-laid silt over former small valleys occur along the north side of Smoky Hill Valley in Ellis County.

North of Great Bend and east of Hoisington in Barton County is located Cheyenne Bottoms, considered by some workers (Schoewe, 1949, p. 296) to be the result of solution at undetermined depth and subsequent subsidence. This depression, perhaps the most controversial in Kansas, is 10 miles across and occurs north of the Arkansas River. The area has been described by Schoewe (1949, pp. 294-296). In 1897, Haworth (pp. 43-45) suggested origin by drainage changes and unusual deposition.

Fent (1950) discussed the Pleistocene drainage history of south-central Kansas and proposed that the Cheyenne Bottoms are the result of the placement of thick late Pleistocene alluvial fill in an earlier Pleistocene valley. The abnormal alluviation resulted from Wisconsinan captures by the Arkansas River. Fent is of the opinion that the low ridge on the southeastern side of Cheyenne Bottoms is the result of accumulation of dune sand and loess on the surface of the alluvial plain. Fent's hypothesis fits well the observed facts and places this depression in the category of initial depositional features.

DIFFERENTIAL SILT INFILTRATION

In Johnson's discussion (1901, p. 702; note also Haworth, 1897, pp. 19-21) of High Plains basins, argument is given that solution-subsidence, such as is demonstrable in the area of Permian outcrops, was not sufficient elsewhere to account for origin of observed basins. He discounted wind scour because the low places were observed to contain intermittent ponds. Johnson thought that such depressions should be places of deposition rather than erosion. He did not recognize an eolian origin for the upland silts and did not consider initial irregularities on a depositional surface as more than points of localization for other processes.

Johnson's hypothesis of the origin of the High Plains basins is as follows (1901, pp. 703-704).

> Appearances indicate basining of the alluvial surface as a consequence, first, of rain water accumulation in initial faint unevenness of the plain; second, of percolation of this ponded surface water downward to the ground water in largely increased amount from these small areas of concentration, rather than from over the whole surface uniformly, with the result that the alluvial mass is appreciably settled beneath the basins only. The inference is at once suggested that this settlement takes place as the combined effect of mechanical compacting of the ground particles and chemical solution of the more soluble particles. Finally, these effects should be cumulative, resulting in the growth noted, since, with enlargement of the basins, concentration of rain water within them will be on an increased scale.
>
> Over comparitively small areas surface effects should be symmetrical, but beneath basins of great breadth—and some have breadths of several miles—the depths of settlement at points wide apart within the same basin, as well as the conformation of the basin rims, should reflect the broader variations of structure beneath. Depths should be least above beds of clay and greatest over areas of coarse channel deposits.

Although the mechanics of compaction are not clearly defined by Johnson, a process leading to formation of small depressions which has been observed on alluvial surfaces in central Kansas suggests a modification of his hypothesis. For lack of a better name, the process is called "differential silt infiltration."

On the alluvial plain of the Arkansas, and to a lesser degree the Smoky Hill Valley of central Kansas, numerous small inclosed depressions have formed since the areas have been under cultivation. Some of the larger basins have been attributed to a solution of subjacent Permian salt but the relation of others to the salt section and the history of their development exclude such an origin.

Data concerning a group of small sinks on the alluvial plain near Hutchinson were furnished to me by Mr. T. J. Cambern (of Howard, Needles, Tammen, and Bergendoff, Kansas City, letter dated Aug. 20, 1948). In this area, as in others, the small sinks have developed where the surface layer of alluvium is composed of silt, about 12 feet thick, which rests on well-sorted, unconsolidated sand and gravel. Rain water flows through openings which develop in the surficial silt so as to reach the sands and gravels below. This flow washes silt from the sides of passageways in the surficial material into the interstices of the coarser deposits beneath. Such inwashing of silt can continue as long as the passageways remain open or until enough silt has been carried into the coarse materials below to reduce their permeability and inhibit further inwash. After termination of silt inwash into the gravels the cavity is slowly filled and the initially steep sides of the sink reduced in slope. Localization of the initial point of inwash may be due to burrowing by rodents, decay of roots, or holes made by man. In the Hutchinson area the sinks were observed to be localized in an alfalfa field and were not found in adjacent wheat fields. As the water table in the area was about 15 feet below the surface, it seems probable that the dehydrating effect of alfalfa on the silt produced contraction joints which permitted inflow of rain water to the pervious sands and gravel below. The shallow root systems of wheat had little effect at depth.

It is possible that some of the depressions on the High Plains surface have been formed by differential silt infiltration, in spite of the greater thicknesses of sediment and greater depths to water table. During dry seasons sod cracks several inches wide have

been observed on the High Plains surface and have been probed to depths of 5 or 6 feet. Coarse, pervious gravels are known to occur at many places below an upper layer of silt, and although it is not possible with available data to establish this mechanism as effective in upland areas, it should be considered a possible mode of origin of the basins in some places.

ANIMAL ACTION

Darton (1905, pp. 36-37) referred to some of the depressions on the High Plains surface as "buffalo wallows" and explained their origin by the action of buffalos and wind. He believed the depressions were started by buffalos, either at wet, salty, or alkali spots, and that they were excavated by trampling hoofs followed by wind scour and also by mud sticking to the feet and shaggy coats of the animals during wet periods.

Although it seems quite plausible that the action of buffalos, as Darton describes, may have had importance in modifying or enlarging depressions, it could hardly have been effective in producing the initial low place that served to localize the wet spot, or other feature that attracted the buffalo. The effect of large animals, although possibly important locally in a secondary role, cannot be classed as a prime cause of Great Plains depressions. The effect of burrowing rodents in localizing rain water inflow, eolian scour, etc., may have been greater than that of the large animals.

FAULTING

Surface expression of faults is found in western Kansas only in Meade County. Faults cutting Permian and Cretaceous rocks are known to occur at many other places in the western part of the State and may have localized ground-water circulation and influenced the development of depressions, but fault scarps are commonly not reflected in the topography. In Meade County, however, the Crooked Creek fault (Frye, 1942) presents a distinct, though dissected, scarp along the east side of Crooked Creek

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Plate 4.—Aerial photograph of Big Basin and St. Jacob's well, in western Clark County, 1938. Photograph from U. S. Agricultural Adjustment Administration, reprinted from Smith, 1940, p. 239. These depressions are of the solution-subsidence type and are just north of the series of integrated basins making up the Ashland-Englewood lowland.

Valley for about 15 miles and has less striking topographic expression on into Oklahoma.

It has been pointed out that the Crooked Creek and associated faults, by controlling the circulation of ground waters, have an important bearing on the development of solution-subsidence depressions in southwestern Kansas. The total movement along the Crooked Creek and Fowler fault planes occurred during early to middle Pleistocene time and they have importantly affected the topographic basin northeast of the City of Meade and the trough occupied by Crooked Creek south of that city. In these areas it is impossible to differentiate effects produced primarily by movement along faults from those formed secondarily by solution at depth. The topographic youth of the major fault scarp at some places is indicated by the series of minor stream piracies being accomplished along its crest and the close conformity of the scarp's position to the trace of the fault plane.

An area superficially suggestive of fault control is the elongate north-south trough through central Scott and northern Finney Counties (Latta, 1944; Waite, 1947; Schoewe, 1949). Test drilling (Waite, 1947) has revealed that the trough is a filled and abandoned early Pleistocene valley and that the secondary depressions, such as Modoc or Scott basin and Shallow Water basin, are developed in the Pleistocene sediments filling the abandoned valley.

CONCLUSIONS

A review of topographic depressions in the Great Plains of Kansas emphasizes that several modes of basin formation have been operative. Depressions developed in Permian or Cretaceous rocks (with or without an incidental veneer of Pliocene or Pleistocene sediment) seem clearly to be the result of solution of salt, gypsum, or chalk at various depths below the surface. Solution was followed by sudden collapse of surface rocks or by a slow progressive subsidence with downwarping of surface rocks. In central Meade County, subsidences may be due in part to movement along fault planes.

The smaller, shallower, but far more numerous upland depressions of west-central and northwestern Kansas are judged to be developed entirely in Pliocene and Pleistocene sediments by processes other than solution-subsidence. Depositional irregularities of late Pleistocene loess, in part controlled by pre-existing topography, wind scour, differential compaction in relatively thick loess blankets possibly controlled by former shallow valleys, and differential silt infiltration, may all have played a part. At least one large depression, Cheyenne Bottoms, may have been enclosed by eolian deposition on the surface of an alluvial plain. Action of buffalo and other plains animals, although not a prime cause of basin development, may have modified surface expression importantly.

Thus, western Kansas depressions may be arranged in two groups. The larger more striking basins are mostly solutional sinks. The smaller, more numerous basins are nonsolutional depressions.

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