Pleistocene Geology of Kansas

By

JOHN C. FRYE and A. BYRON LEONARD

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State Geologist and Director of Research.

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PLEISTOCENE GEOLOGY OF KANSAS

by
John C. Frye and A. Byron Leonard

ABSTRACT

Deposits of Pleistocene age underlie much of the surface of Kansas. They contain more than 60 percent of the State's ground-water supplies, most of our sand and gravel and volcanic ash, and important deposits of ceramic materials. This report presents data on the general geology of Kansas Pleistocene deposits and is intended to serve as background for work by the Geological Survey and others on the utilization of these many materials and as an aid to soil scientists in their study and mapping of surface soils in Kansas.

A brief summary of the geologic processes that have produced the Pleistocene deposits is followed by a review of principles governing the classification and correlation of sedimentary strata. Stratigraphically, Kansas is the transition region joining three provinces: (1) the area of continental glaciation to the northeast, (2) the area of fluviatile and eolian deposits to the west and southwest, and (3) the Ozark province to the southeast. Kansas possesses representative deposits of each Pleistocene Stage with glacial deposits of Nebraskan and Kansan Ages. The Kansan Stage is appropriately the most extensive in Kansas, and the Wisconsinan Stage is characterized by extensive loess deposits. All Pleistocene stages in Kansas contain abundant faunas of fossil mollusks and more than 100 species are listed from more than 200 localities.

A review of the drainage history of Kansas describes the progressive evolution of the present stream pattern from a general southern drainage that existed in the central and west during early Pleistocene time. The existing landscape of Kansas is a result primarily of geologic processes operating during Pleistocene time.

INTRODUCTION

The Kansas landscape is largely a product of geologic processes operating during the last major segment of geologic time, the Pleistocene Epoch (or Quaternary Period). We now live in this segment of geologic time but conditions during much of it were strikingly different from those of the present. The existence of glaciers that advanced as far south as the northeastern corner of Kansas has given rise to the name "The Great Ice Age" which has come in popular writing to be almost a synonym for Pleistocene Epoch.

The profound importance of this most recent of major geologic intervals on our every day existence is emphasized by the facts that not only were the hills and valleys as we now see them produced by erosion and deposition, but the soils that support us were formed during this time, as were the sand and gravel deposits that contain most of our underground water supplies. Also, such usable substances as volcanic ash, molding sand, and ceramic clays were deposited during the Pleistocene.

During the past 15 years the State Geological Survey of Kansas has accumulated a great many data on the Pleistocene geology of the State. Much of this information has been acquired as a direct part of studies of ceramic raw materials, volcanic ash deposits, and particularly from investigations conducted cooperatively by the Federal and State Geological Surveys on groundwater resources. In addition, fundamental research projects on petrology, stratigraphy, and paleontology of these deposits have been carried out in order to give support to work of practical application. During this 15 years of coordinated attack the Pleistocene of Kansas has yielded many of its secrets, albeit there are many problems yet unanswered. Stratigraphic nomenclature has evolved from uncorrelated local systems to a uniform state-wide classification, and a consistent history, although not complete in all details, has been developed for Pleistocene events. It is the purpose of this report to review and summarize present knowledge of the Kansas Pleistocene in the hope that it will serve at once a convenient source of general data and as a starting point for future more detailed and complete regional studies.

Virtually every member of the staff of the State Geological Survey and cooperating Federal personnel has made some contribution to this undertaking, and several other agencies including the U.S. Soil Survey and official agencies in adjacent states have contributed importantly by their cooperation. A bibliography of literature dealing with Kansas Pleistocene geology is presented at the end of this report.

GEOLOGIC PROCESSES

It is the purpose of this report to present a discussion of the character, distribution, associated faunas, correlation, and significance of the many Pleistocene deposits of Kansas. General discussions of physical geology are presented in the many excellent textbooks in the field, and a detailed presentation of glacial geology is given in the recent textbook by Flint (1947). Nevertheless, it seems advisable to preface this description of Kansas Pleistocene with a brief summary of those physical processes that were of primary importance in the formation of the surficial deposits in the State and the shaping of the Kansas landscape. Although the Pleistocene geologist may wish to pass by this portion of the report, it is designed to furnish a background of understanding to the agriculturalist, the engineer, or the industrialist who has need for the specific data presented in the remainder of this bulletin.

The Pleistocene deposits of Kansas, of course, are entirely nonmarine but represent the full range of depositional environments that occurs on the continental interior. Deposits made by glaciers are present in northeastern Kansas and have lent distinction to the Pleistocene Series generally. Deposits formed by streams occur widely over the State, as do sediments produced by the action of winds. Smaller in quantity, but of real significance, are materials that accumulated in standing bodies of water, and others that were formed by mass movement, creep, or colluviation on slopes of various angles. The recognition and understanding of these several kinds of deposits requires some knowledge of the processes that produced them.

Furthermore, weathering has been the prime factor in the development, not only of the surface soil but also of the buried soils that are used extensively for correlation. Erosion in its many aspects has shaped much of the existing topography. The surface of Kansas is a direct result of physical processes operating throughout Pleistocene time.

Glaciation is discussed first because it played a controlling role, both by its abnormal prevalence during the Pleistocene Epoch and its control of cyclic pulses of stream sedimentation. Fluviatile or stream sedimentation logically follows glaciation, and as eolian sediments were in large part derived from flood plains of streams, a discussion of them follows. Modification of sediments by weathering is discussed next, and finally the destruction or modification of both Pleistocene deposits and older bedrock by erosion and pedimentation is described. The degree of agreement among geologists is less for the last three than for the first two of these topics. As this section is intended primarily for nongeologists, in some cases controversial subjects are treated somewhat arbitrarily and interpretations are given which we judge to fit best the objective data in Kansas.

GLACIATION

Although continental glaciation as a physical process has not been operative in Kansas since mid-Pleistocene time, it exerted a profound influence on the shaping of the Kansas landscape throughout the entire epoch. It is beyond the scope of this report to consider the controversial problem of the cause of continental glaciation (Flint, 1947). Suffice it to say that conclusive evidence demonstrates that during several segments of Pleistocene time the rate of snow accumulation exceeded the rate of melting at two major centers in Canada. These areas of principal accumulation, or dispersal, have been called the Keewatin center (west of Hudson Bay) and the Labradoran center. As the snow thickness increased in these areas, the lower layers were changed by overlying weight and by thaw and refreeze into granules of ice called neve or firn. The neve was converted at still greater depths into glacial ice. As these masses of ice attained sufficient thickness the weight induced a plastic flow of the lower part of the glacier, much the same as a mound of warm tar will flow outward in all directions if more tar is added at the center (a discussion of glacial motion is given by Matthes, 1942, and Flint, 1947). Continental glaciers continued to expand as long as the quantity of added winter snow, or nourishment, exceeded the quantity lost by melting during the summer season. The balance between nourishment and wastage fluctuated past the critical point and therefore the outer margin of the glacier fluctuated.

During two of the major glacial ages (Nebraskan and Kansan) continental glaciers that originated in the Keewatin center expanded to such an extent that they reached into northeastern Kansas. During early and late Wisconsinan time other continental glaciers reached into the central Missouri River basin although these failed by several hundred miles to reach the borders of Kansas.

The fact of continental glaciation was demonstrated beyond doubt more than a half century ago by the presence in the deposits (till) of stones transported across divides from distant sources, by the huge size of these erratic or "foreign" boulders, and by the general character of deposits and surface features. The name "till" is generally used to designate deposits made directly by glacial ice, and "drift" includes a wider range of associated fluviatile, lacustrine, and other deposits. In the Kansas tills pink quartzite is the most distinctive "foreign" rock and is found almost everywhere in our glacial materials. The nearest bedrock source of the pink quartzite found in the tills of Kansas occurs in southeastern South Dakota and northwestern Iowa. As this area is almost on a direct line from the inferred Keewatin center to northeastern Kansas the presence of these pink quartzite boulders confirms the conclusion that the glaciers that invaded Kansas originated in that center.

It seems obvious that the slow movement of several thousand feet of glacial ice across any area would produce radical changes in the terrain. The aspect of much of northeastern Kansas is the direct result of the action of continental glaciers. Glacial ice in motion has the capacity to erode the rock over which it passes; to transport rock fragments of large and small size; and to deposit the material or debris that it has carried. Glacial erosion is more vigorous in the interior part of a glacier where the ice is thickest but some erosion occurs locally even at the maximum limit of glacial extent as shown by striations (shallow grooves cut by stones held in the lower part of the ice) such as those that may be seen in the limestones that form the bluffs of Kaw Valley east of Bonner Springs. At other places (southwest of Atchison) the glacier "plowed up" evenly bedded water-deposited sand and silt, and at still other places shales of Pennsylvanian age were gouged out to various depths.

In contrast to these evidences of glacial erosion, observations indicate that in some places a continental glacier passed over an area without eroding it at all. A good example of the occasional failure of glaciers to erode underlying materials is afforded by the exposures in northeastern Doniphan County (Iowa Point section) where Kansas till rests on the top of an undisturbed soil in Nebraska till, which shows that the Kansan glacier here passed over the surface of this old soil without noticeably disturbing it.

Deposition rather than erosion was the predominant effect of the glaciers that invaded Kansas. Predominant deposition is characteristic of the terminal area of all glaciers. The presence of snails known to be adapted to temperate climates in ice-associated deposits and lack of frost features strongly suggest that the climate of Kansas was not conducive to glacial accumulation even at the climax of a glacial age. Therefore, glaciers existed in this area only because the rate of inflow from the north exceeded the rate of melting, in much the same manner that the end of a rod of ice can be maintained in an oven if it is pushed inward as fast as it melts at the end. Rock debris, produced by erosion farther north and incorporated into the glacial ice, was transported southward by the glacier and deposited at its terminus. Deposition by a glacier took place by "dumping" as the ice melted at its terminus; by decrease in carrying power as the glacier became thinner in the marginal area; by the stagnation of glacial segments; and by streams flowing on, within, and at the base of the glacier. Deposition occurred most rapidly at the edge of the glacier where its transporting power was lost. However, this terminal edge of the glacier fluctuated in position and during the waning phase of a glacial age it retreated toward the north and northeast.

A continental glacier may vacate an area either by becoming thin and impotent or by progressive retreat of the margin while the ice mass maintains active movement. Conditions intermediate between these two extremes, or perhaps combinations of them, may have been common in the many ice caps of the Pleistocene (Flint, 1947, chapter 9). Till thicknesses in excess of 300 feet at localities more than 50 miles from the ice limit (Frye and Walters, 1950) and the lack of ablation moraine or vertical differentiation in the till indicated that the Kansan glacier retreated from Kansas while maintaining forward motion all along its margin. The absence of a clearly recognizable terminal moraine in the State suggests that the glacier maintained itself at its maximum extent for only a short time although terminal moraine may have been eroded beyond recognition.

Deposits made by glacial ice are distinctive even though heterogeneous. The many specialized depositional land forms and their associated sediments common in regions covered by late Pleistocene glaciers, such as drumlins, eskers, kames, kame terraces, and recessional moraines, are not discussed here because they have not been recognized (or only doubtfully recognized) in Kansas. The till deposits of Kansas may be considered to be largely ground moraine. Except where modified by weathering, the till is calcareous, some hue of gray in color, and generally fine-textured even though it is locally quite coarse and contains boulders more than 6 feet in diameter. Test drilling shows that the till contains many lentils of sand and gravel. These inclusions of sand and gravel are judged to be polygenetic. They represent deposits of outwash made at the margin of the glacier and later overridden by a readvance of the ice front, englacial and subglacial stream deposits, and incorporation of masses of sand, silt, or gravel locally known to have been moved as frozen blocks into the till by the plowing action of the glacier.

Another effect of continental glaciers, unobservable today but of great importance to the development of our streams, was regional crustal warping caused by the weight of the glaciers. Flint (1947, chapter 19) has summarized the evidence of crustal warping, even now not fully compensated, that resulted from the last glaciation. As a load of several thousand feet of ice is applied to the surface of the earth the crust slowly yields and adjusts to the pressure; as the ice load is removed the crust slowly readjusts to its former position. Although it is not possible to obtain direct evidence that such isostatic adjustments resulted from the accumulation and dissipation of the Kansan glacier, it is inconceivable, since such movements were produced by the relatively small latest Pleistocene glaciers, that such movements did not occur as a result of the earlier and much more extensive Kansan glaciation.

FLUVIATILE SEDIMENTATION

Sediments deposited from currents of flowing water are quantitatively the most extensive of the Pleistocene materials in Kansas. Stream action has been a topic of study since the beginnings of geology as a science and the mechanics of the process are known in considerable detail (Gilbert, 1914; Rubey, 1938). Briefly stated, a stream (a) may transport its load of rock debris without net erosion or deposition; (b) may erode its channel and by so doing add to the quantity of material it is carrying; or (c) may give up or deposit some of the rock materials in transit and so decrease its load. Which of these three conditions obtains at any particular time or place is controlled by the interrelation of three measurable factors: (1) the quantity of water moving in the stream; (2) the quantity and character of the rock debris being transported by the stream and available to it, and (3) the velocity with which the water moves, mostly controlled by the stream gradient. The discussions of fluviatile sedimentation all relate themselves ultimately to the modification of one or more of these three controlling factors. For example, a sudden increase in the quantity of fine rock material furnished to a stream might change it from an eroding to a depositing one.

In the vicinity of continental or mountain glaciation each of the three major factors that control stream deposition is importantly affected by the activity of the glacier. Accelerated precipitation rates, retention of water in glacial ice, or its release by glacial melting influence water volume in streams. The burial of sediment sources under rapidly advancing glaciers, the discharge of debris at the margin of a stabilized glacial front, and the release of progressively greater areas of finely comminuted rock debris as a glacier front retreats influence the volume and character of the sediment load available to streams. Isostatic warping of the surface near the margin of a glacier may cause an increase, a decrease, or in special cases a reversal of the stream gradient which largely controls the velocity of the flowing water. In addition to these basic effects on stream action, the physical presence of a continental glacier, by blocking draingeways with ice, till, or outwash sediments, or by otherwise altering the load or flow, may importantly modify the regimen of streams. Furthermore, in the continental interior these glacial effects go far beyond the limits of glaciation and similar histories of erosion and deposition are found in separated stream basins that were not invaded by glaciers. The similar histories in unglaciated and glaciated river basins are judged to be due to the fact that many of these streams joined glacially headed streams in their lower courses and that the climatic fluctuations, particularly changes in precipitation rate, that were associated with episodes of glaciation were far-reaching in effect.

Another indirect effect of glaciation on stream deposition is by way of drainage changes. The action of glaciers disrupted drainage patterns and in some cases caused the breaching of former divides. Such disarrangement of drainage lines caused changes in gradients, volumes, and sediment loads.

In general, during the advancing phase of a continental glacier, precipitation rates must have been relatively high (or the glacier would not have been nourished), the available sediment was progressively diminished as the burial by ice protected progressively larger areas formerly subjected to stream erosion, and gradients may have been slightly increased near the glacial margin by isostatic "fore bulge" (Flint, 1947, p. 409) and were sharply increased in coastal areas by declining sea level. In other words, an increase in water volume, a decrease in available sediment load, and at least locally an increase of gradient combined to produce downcutting by streams during the early part of a glacial episode.

During the waning phase of a glacial episode the rock debris available as sediment load to streams was enormously increased by the uncovering of vast areas of glacial deposits and the removal of sediment by running water from the melting ice mass itself.

At least locally gradients were decreased by the subsidence of the isostatic "fore bulge" and rebound of the glacial floor and in coastal areas by the rise of sea level. The relative volume of water in streams during the early and late phases of glaciation is not known with certainty. It is possible that stream volumes decreased during glacial retreat, in spite of the large quantities released by melting of ice, because of decreased precipitation rates and rise in temperature (and resultant evaporation), but it is certain that the ratio of load to water volume in streams increased markedly. That is, marked increase of load and local decrease of gradient caused general stream alluviation during late glacial time.

In Kansas, Pleistocene stream alluviation was importantly influenced in all parts of the State by the episodes of glaciation. Sea level changes are judged to have had little if any effect on deposition or erosion in this continental interior region. The effect of sea level change on stream regimen must be projected headward along any stream by the migration of a steepened or flattened gradient and, other conditions remaining constant, the regimen of the stream above the migrating segment is unaffected by the change of sea level. The point in the channel where the gradient changes is called a "knickpoint" or interruption in the profile. If an oversteepened channel segment is working through loose alluvial materials it may move with considerable speed, but where relatively resistant rocks, such as the Pennsylvanian limestones of eastern Kansas, are being eroded it moves more slowly —requiring more than the allowable fraction of a glacial age to enter deeply into the State. The headward migration of a flattened segment of stream gradient is not controlled by local bedrock and may move more rapidly than an oversteepened segment. It is only remotely possible that an effect of rising sea level at the end of a glacial episode may be recorded in Kansas by the final deposition of silt that commonly concludes a glacial cycle of stream alluviation. Clearly, it is not necessary to call upon such an explanation to account for deposition of these fine sediments.

EOLIAN SEDIMENTATION

The deposition of eolian Pleistocene sediments in Kansas was directly controlled by the activity of streams to almost the same degree as stream deposition was controlled by glaciation, because alluvial materials were the source of all eolian deposits. The mechanics of wind erosion, transportation, and deposition have been discussed by Bagnold (1941) and are beyond the scope of this bulletin. The factors controlling erosion, transportation, and deposition by wind are much the same as those controlling water deposition—importantly modified by the lower density and viscosity of air and the lack of restriction of air currents to definite channels. Glacial ice is capable of transporting and depositing huge boulders; streams carry and deposit rock fragments more than 1 foot in diameter; but air currents transport only particles of sand size or smaller. Furthermore, the coarser particles carried by winds are rarely lifted far above the ground surface and are carried relatively short distances in any one "jump," whereas silt-size particles are carried tens or hundreds of miles as a suspension load.

Deposits made by winds fall generally into two classes: (1) well-sorted sand typically displaying a dune form at the surface, and (2) massive exceedingly well-sorted silt. In general eolian silts and sands are distinct and are not gradational, even though deposits intermediate in texture are known to occur. Eolian sands are commonly moved as traction load whereas silts are always moved as suspension load. Eolian sands generally occur geographically near to their source of alluvial sediments whereas eolian silts may be distributed over wide areas. The textural distinctiveness of these two types of eolian deposits, the lack of quantitatively important intermediate deposits, the stratigraphic interbedding of eolian sand with eolian silt, and their general relation to independent and distinct source areas lead to the judgment that sediment source is the factor exerting most important control on eolian deposits.

The major dune sand tracts in Kansas are located near Arkansas River or its Pleistocene courses, whereas loess is not abundant in that region. It is judged that these sands were derived from the rapidly alluviating stream channels during late Pleistocene glacial episodes. The facts that dune sands are prevalent in this region whereas loess (or eolian silt) is relatively insignificant and that the Pleistocene alluvial deposits consist predominantly of sand and coarser materials indicate that the sediment load of Arkansas River during late Pleistocene time consisted of coarse clastic materials with relatively little silt. This is compatible with the geology of the Arkansas Valley west of central Kansas as the outcropping rocks along it consist of shales, chalks, Pliocene alluvium, granite, and other crystalline rocks which would furnish the stream with abundant clay, sand, and gravel but with a small proportion of silt. Sands, once derived from the alluvial source by wind action and piled in hillocks, have moved in successive "spurts" of migration (Smith, 1940) perhaps a few tens of miles from their original source.

The mode of origin of massive silt deposits has, in recent years, been a highly controversial subject (Russell, 1944; Leighton and Willman, 1950). Deposits consisting predominantly of silt and superficially displaying the same appearance have been produced in several ways. Swineford and Frye (1951) made a regional study of the petrography of the Peoria loess (early Wisconsinan) in Kansas, and state concerning its origin (p. 317):

> Although some relatively structureless silts on slopes are derived colluvially from higher silt deposits (Elias, 1931) and some loess-like silts at low levels are water-laid, these studies have led to the conclusion that the extensive deposits of massive silts over thousands of square miles of upland and high-terrace surfaces are predominantly the result of eolian action. The facts contributing most importantly to this conclusion are (1) topographic position of loess on extensive divide areas, including highest elements in local topography; (2) textural similarity to that of modern wind-transported silt; (3) relatively uniform composition over an area of 30,000-40,000 square miles in Kansas alone, where the loess rests on various stratigraphic units of Pennsylvanian, Permian, Cretaceous, Pliocene, and Pleistocene age; (4) decrease in thickness and median grain diameter in directions away from major outwash-

carrying valleys; (5) regional persistence of distinct faunal zones characterized by terrestrial snails; (6) lateral persistence of buried soil profiles which lack evidence of erosion or creep; (7) gradational contact of overlying loess units on buried soils; and (8) lack of any other known agent capable of depositing uniform silts simultaneously on sharply discordant topographic levels. In view of these facts, an eolian origin of the Kansas Peoria loess is accepted without reservation and is implicit in further discussions of local source and distribution patterns.

Swineford and Frye (1951) demonstrate that the major sources of loess in Kansas are the Platte River Valley of western Nebraska, the Missouri River Valley, and the Republican River Valley. If we examine the geology westward along Platte River Valley we see that it sharply contrasts with that along the Arkansas (the major dune sand source) by the presence of thick and widespread deposits of Tertiary silts which contain a very high percentage of silt-size material similar to that found in loess. The Missouri River Valley was an important avenue for the discharge of glacial outwash during Wisconsinan glacial episodes and also had available large quantities of silt-size materials. In outwash-carrying valleys, such as the Platte and the Missouri, during the melting season of the year flood waters intermittently covered the entire valley floor. On the retreat of each flood a sheet of sediment extended from valley wall to valley wall and as soon as the surface of this fresh sediment was dry it constituted an almost ideal source of silt for eolian transport. As these valleys were being aggraded rapidly with outwash and flooded with sufficient regularity to inhibit the growth of permanent vegetation, winds had free access to the silt source. In the eastern areas the valley walls were heavily vegetated and served as near-by settling areas for the air-borne silt. In the High Plains, however, a short grass flora prevailed and the winds were less restricted in the long distance transport of their silt load (Swineford and Frye, 1951).

The bulk of the eolian Pleistocene deposits in Kansas, both sand and silt, accumulated during the retreating phases of glacial episodes as it was then that broad alluvial flats were continuously replenished with sediments. However, wind action is possible at any time and winds of strengths adequate to transport sands now regularly occur in the State. Eolian deposits may accumulate whenever and wherever suitable sediment sources exist.

WEATHERING

Weathering, unlike the three agents of deposition—glaciation, stream action, and wind action—does not directly contribute new deposits but rather affects modification of existing deposits. Weathering by mechanical processes produces fragmentation of rocks and minerals without appreciable change in the composition of the constituent minerals. Among the agents of mechanical weathering are temperature changes, freezing of water, crystal growth, plant and animal action, wetting and drying, abrasion, and corrosion. Chemical weathering is more complex and as it commonly affects a change in chemical composition and mineral species, it is more profound than mechanical weathering.

Chemical weathering results generally in the reduction of particle size, the addition of water, oxygen, and carbon dioxide, and the loss of soluble salts of some metals such as sodium and potassium. Clay minerals commonly result from chemical weathering in a temperate climate and the color and general appearance of a deposit may be markedly altered.

Many general reviews of weathering process (e. g., Reiche, 1945) are available in the literature, and the following discussion is concerned primarily with the effects of weathering that are observable and usable in the study of Kansas Pleistocene deposits.

Soil development.—The effect of weathering of all types has its most obvious expression in the development of surface soils. Soils are important to the Pleistocene geologist for several reasons, one of which is their use, when buried in a sequence of sediments, for stratigraphic classification and correlation. The nature, chemistry, and formation of soils have been discussed in a general way by Rice and Alexander (1938), Byers, Anderson, and Bradfield (1938), and Byers and others (1938), who have made the following statement concerning the nature of soil (p. 948):

> Soils are natural media for the growth of plants. They are mixtures of fragmented and partly or wholly weathered rocks and minerals, organic matter, water, and air, in greatly varying proportions, and have more or less distinct layers or horizons developed under the influence of climate and living organisms. The cross section of horizons from the surface to the parent material is known as the soil profile. The degree of profile development is dependent on the intensity of the activity of the different soil-forming factors, on the length of time they have been active, and on the nature of the materials from which

> the soils have developed. Soils are dynamic in character—they are constantly undergoing change—but they normally reach a state of near equilibrium with their environment, after a long period of exposure to a given set of conditions, and they may change but little during periods of hundreds or even thousands of years unless there is a change in the environment.

It is apparent from this statement that "soil formation" is intended to include the advanced stages of weathering produced by both physical and chemical processes of both inorganic and organic origin, acting on rock materials already fragmented by earlier stages of weathering. Therefore, "soil forming processes" are effective only on a surface that possesses sufficient stability to attain this advanced stage of weathering. More than 90 percent of the surface of Kansas at the present time possesses this degree of stability, where it is not disturbed by man's activities, and comparable conditions have obtained at intervals within Pleistocene time.

As the forces contributing to weathering and soil formation come in contact with rock materials at or near the surface, soil development proceeds downward from the surface, and, other things being equal, the greater the length of time involved the deeper the soil. This progressively downward development also produces zonation of the weathering effects. In Kansas till, for example, oxidation (accompanied by hydration) of iron-bearing minerals has proceeded to depths of 30 to 50 feet. This oxidation alters the color of the till from its original bluish gray to a tan or yellowish brown and reduces its toughness or "brittleness." In this same till, leaching of calcium carbonate has proceeded downward only 5 to 15 feet. This leached zone includes the soil of the agriculturalist whereas the deep zone of oxidized material below is classed as only slightly weathered or as "parent material."

The soil proper is divided into zones that are referred to as A, B, and C horizons. The A, or uppermost horizon, has the least resemblance to the original rock material from which the soil developed; it has lost soluble constituents and some colloids but has gained in organic material; it may be loose and friable and commonly contains a relatively small amount of clay. The B horizon, second down from the surface, may also show extreme change from the fragmented rock below; it has lost some of the soluble constituents such as calcium carbonate but is enriched in clay content by the alteration of feldspars and ferromagnesian minerals and perhaps also by the downward movement of colloids of clay produced by weathering in the A horizon above. B horizons display a wide range of structures which are in part controlled by the degree of dispersion of the clay colloids, and generally are tougher and more resistant to erosion than either the overlying A horizon or the underlying C horizon. In well-drained mature (or old) soils the B horizon is generally several times as thick as the A horizon. In dry to moderately dry climates calcium carbonate dissolved from the upper part of the soil accumulates as "caliche" in the lower part of the B horizon or upper part of the C horizon. The C horizon, which occurs below the B horizon, generally displays no distinct structure. It consists of fragmented rock that is commonly altered chemically only by oxidation and hydration. C horizons in unconsolidated deposits may be quite thick as in the glaciated area of the State, whereas in indurated rock they may be quite thin, as in the central Flint Hills area.

These described characters of a soil profile apply primarily to the zonal or normal soils. In soil science three orders of soils are recognized (Baldwin, Kellogg, and Thorp, 1938, p. 987), the (1) zonal or normal, (2) intrazonal, and (3) azonal soils. These three orders have been briefly characterized as follows:

> Thus the zonal soils include those great groups having well-developed soil characteristics that reflect the influence of the active factors of soil genesis—climate and living organisms (chiefly vegetation). These characteristics are best developed on the gently undulating (but not perfectly level) upland, with good drainage, from parent material not of extreme texture or chemical composition that has been in place long enough for the biological forces to have expressed their full influence.
>
> The intrazonal soils have more or less well-developed soil characteristics that reflect the dominating influence of some local factor of relief or parent material over the normal effect of the climate and vegetation. . . .
>
> The azonal soils are without well-developed soil characteristics either because of their youth or because conditions of parent material or relief have prevented the development of definite soil characteristics.

Of these three orders of soil only the zonal (normal) and intrazonal are usable by the geologist in his interpretation of conditions that existed on former surfaces now buried by younger sediments. During the present century, intrazonal soils on buried till plain surfaces have been studied extensively in the glaciated region of the upper Mississippi River basin. Wiesenboden (meadow soils) or humic-gley soils, and Planosols were described by Kay and Pearce (1920) as gumbotil and were used for stratigraphic correlation and as a basis for estimates of the duration of interglacial time. The morphology of these intrazonal soils is dominated by the effect of the one genetic factor—poor drainage. Where profiles of intrazonal soils are used for time estimates it should be remembered that the thickness of the gley layer (gumbotil) is influenced by minor details of microtopography, permeability of the till, position of water table, and other factors to such a degree that they may obscure the effects of time. Normal or zonal soils are developed in response to the balanced effects of many genetic factors and therefore are more indicative of regional conditions than are intrazonal soils. Within the range of buried Pleistocene soils in Kansas are to be recognized Chernozems, Prairie soils, Reddish Prairie soils, Brown soils, Chestnut soils, and other representatives of the great soil groups that are identified among the surface soils of Kansas.

The concept of the soil catena serves to emphasize the influence of surface features on the development of normal profiles. A soil catena has been defined as follows (Soils and Men, 1938, Glossary, p. 1164):

> A group of soils within one zonal region developed from similar parent material but differing in characteristics of the solum owing to differences in relief or drainage.

It is the position within the catena that most easily confuses the field geologist in his examination of a buried soil. Parent material, its texture, mineral content, calcium carbonate content, and permeability generally can be determined. Geographic location gives a clue to climate by analogy with existing climates. But without a three-dimensional reconstruction it is difficult to estimate the position within the former catena occupied by buried soil exposed in a cut or penetrated by augering.

In well-drained to moderately well-drained zonal profiles in upland situations the effects of climate, flora, and fauna are closely related and climate is the dominant factor. In situations of similar drainage in the buried Pleistocene soils in Kansas the greater the depth of profile the higher the rainfall rate or the greater the length of time of formation. In areas where precipitation now exceeds 35 inches annually caliche zones are not present or are at considerable depth and are discontinuous. Maximum development of caliche zones is in the 25 to 30 inch rainfall belt. In the area characterized by less than 20 inches of annual precipitation A horizons commonly retain some calcium carbonate even though a weak caliche zone occurs at a shallow depth.

A controversial factor in the interpretation of buried profiles is the significance of reddish overtones to the brown B horizons in areas where the top soil B horizon lacks a red component. Although it has been contended by some that a reddish cast is indicative of higher temperatures, field relationships suggest that development during a longer period of time under stable conditions in a moderate climate may produce the same effect.

Soil-forming intervals.—The formation of deep surface soils requires a relatively high degree of stability of the surface. The presence of such soil profiles at definite positions within the Kansas Pleistocene sequence of sediments indicates that conditions of relative surface stability have existed periodically throughout Pleistocene time. It is important for the interpretation of these sediments to know where within the glacial-interglacial cycle the "soil-forming intervals" occur.

Within the glaciated region soil formation obviously did not take place while glacial ice covered the area or in areas where its proximity gave rise to accelerated erosion or deposition. However, a till plain surface, far from an ice front or major drainageway, presents conditions well suited for continuous soil formation.

Till plains are crossed in various places by valleys cut into glacial deposits and bedrock and subsequently filled with water-laid sediments. At some places both the till and alluvial valley fills are overlain by the next younger till sheet. Although there are differences of opinion as to the age of these alluvial fills and the interval during which soils formed on them (Frye, 1951a), the relations of outwash fills to the glacial cycle described in previous sections indicate that the fills are latest glacial in age and that the soils on them formed during interglacial time. Thus, they are approximately equivalent to the till plain soils.

Stratigraphically, the water-laid sediments and ancient soils in many places can be framed between till sheets, indicating definitely that the period of soil formation preceded deposition of

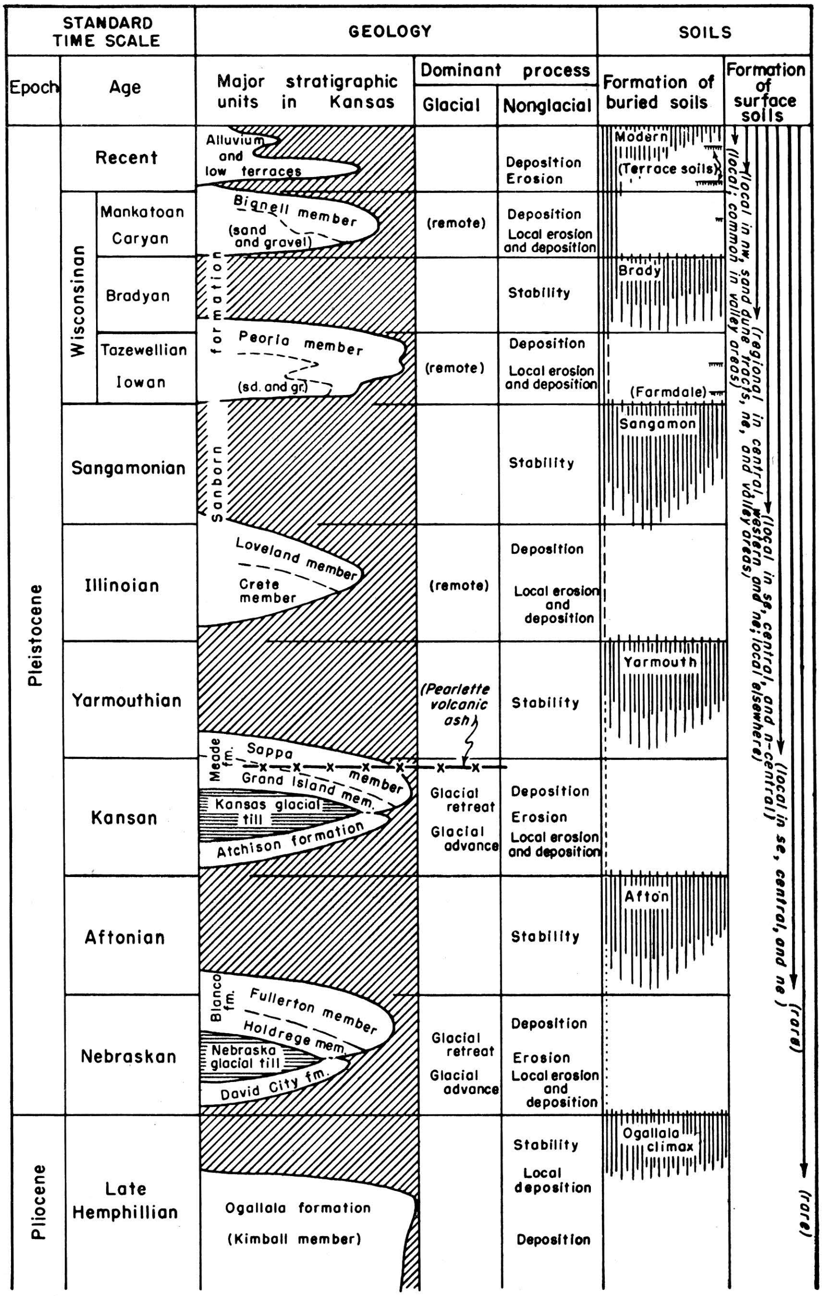


FIG. 1.—Chart showing cyclic arrangement of Pleistocene deposits in Kansas and major soil-forming intervals. The column at the right refers to surfaces that have been more or less continuously exposed to soil-forming processes. The vertical extent of each time division is arbitrary. (Frye, 1951, p. 406.)

the overlying till. The relation of Wiesenboden and Planosols (gumbotils) on till plain surfaces to filled valleys which are cut below their level has been taken as evidence that the valley incision occurred after development of the soils. However, poorly drained profiles are now forming on the undissected surface of young till plains, in some places within a few hundred feet of the steep walls of erosional valleys cut into the till plain. This suggests that earlier till plains may have been incised and valleys filled by stream action without materially affecting the progress of soil formation on the extensive interfluves. Furthermore, soils roughly comparable in development to the till soils are known to occur on some of these water-deposited sediments.

As most of Kansas lies beyond the glacial limit, we are particularly concerned with the placement of soil-forming intervals in the nonglacial sequence. As has been stated, evidence in Kansas indicates that valley incision was prevalent during glacial advance and maximum stand and alluviation during glacial retreat. Stratigraphically, cyclic units capped by a buried soil (Fig. 1) have been correlated from the Plains region with the glacial section and shown to possess the same succession as the tills.

Field data as well as theoretical considerations indicate that the interglacial intervals of the Pleistocene were times of soil formation and that glacial intervals were times of soil destruction or burial. Each cycle of glacial sedimentation is appropriately followed by soil formation. The Pleistocene stratigraphic sequence, as now known in Kansas, displays five major soil-forming intervals and several less distinct minor intervals (Fig. 1).

EROSION AND PEDIMENTATION

Erosion, as defined in Webster's New International dictionary, is "the general process of the wearing away of rocks at the earth's surface by natural agencies." In this broad sense erosion includes all processes of degradation discussed in previous sections and its results are generally well understood. In central and western Kansas, however, erosional forms classed as pediments or "flanking pediments" are common. These surfaces are commonly veneered with debris in transit and since they have proved to be a source of confusion in the mapping of Pleistocene deposits they merit special notice.

Pediments have been studied and described from desert mountainous regions for many years. Mountain pediment is defined by Bryan (1922, p. 88) as a

> . . . plain which lies at the foot of mountains in an arid region or in headwater basins within a mountain mass. The name is applied because the plain appears to be a pediment upon which the mountain stands. A mountain pediment is formed by the erosion and deposition of streams, usually of the ephemeral type, and is covered with a veneer of gravel in transit from higher to lower levels. It simulates the form of an alluvial slope.

Concerning the contrast of mountain slope to mountain foot plain Bryan (1922, p. 38) states:

> The angles of the mountain slopes range from 15° to almost 90° with the horizontal; those of the plain from 1° to 6°. Between these slopes there is usually no region of transition, either of intermediate slopes or of low foothills. In many ranges slopes that average 25° to 30° rise directly from the plain to the crest of the mountains. The factors which produced the mountain slopes must then differ radically from those which produced the plain.

He further states (Bryan, 1922, pp. 52-53):

> The normal mountain pediment has smooth slopes, broken only by scattered hills that rise abruptly from the plain and are more or less strung out in lines which are prolongations of the intercanyon ridges of the mountains.

It is clear from these statements that Bryan included in the term mountain pediment only the relatively gentle erosional slope, generally covered with debris, that meets the mountain slope at a sharp angle without transition. It is also clear that he considered the sharpness of this angle of juncture to be a function of climate as attested by the following statement (Bryan, 1940, pp. 260-261):

> In the transition into the semi-arid regions where perennial grass clothes the slope, the zone of rainwash changes more gradually into flow in channels. The base of slopes merges with the pediment in a short, graceful curve similar to but generally less gradual than the transition curve of humid regions.

Although Bryan recognized the existence of pediment surfaces in semi-arid and even humid climates, such features have received little notice in Kansas literature. In 1942 Frye and Smith described features along parts of Cimarron and Smoky Hill River Valleys and referred to them as "pediment-like slopes." In this report, pediments of the semi-arid type developed along major and minor valleys in central and western Kansas are called "flanking pediments" from their flanking position with respect to the stream course.

Although genetically comparable to mountain pediments, the flanking pediments of relatively low relief of the Great Plains region of Kansas differ from them in their magnitude and their consistent control by the position of through-flowing streams. Flanking pediments present broad, slightly concave upward, smooth surfaces, locally marked by inselberge, which meet the steep valley-side wall with a more or less distinct transition curve. The several cycles of pedimentation that may be observed in southern Barber County and elsewhere show that the steep valley walls at the pediment heads retreat with essentially parallel slopes. These "pediment head" bluffs diminish in height as they migrate by projection of the pediment slope away from the stream course that serves as the controlling base level. In the High Plains section, and to a less marked degree farther east, the crest of the valley-side walls is sharp and the flat upland surface that stretches back from its crest is only slightly affected by erosion. Flanking pediments are developed in Permian, Cretaceous, Pliocene, and Pleistocene rocks, but have their most ideal expression in thick relatively homogeneous or massive rocks such as Permian redbeds and the Smoky Hill chalk member of the Cretaceous Niobrara formation (note Fig. 4).

The surface of a flanking pediment is commonly veneered with rock debris derived in large part from the steep valley-side wall at the pediment head. The pediment surface, although at least in its upper part being slowly lowered by erosion, serves as an avenue of transportation for rock material from the head slope to the stream channel. Rock debris as a sheet is transported across this surface by minor stream action, creep or lubricated creep, and rill wash. Lubricated creep is seemingly an important process in areas where the pediment is cut on rock of low permeability such as Niobrara chalky shales. The sheet of debris has a much higher permeability than the underlying bedrock which retards the downward percolation of water, and during periods of rainfall the lower part of the debris sheet is saturated. The flanking pediment veneers range in thickness from a trace to more than 20 feet and in texture from well sorted to very poorly sorted, but their lithology in all cases reflects the upslope source.

This sheetlike downslope transport of material across smooth relatively undissected surfaces has led to serious errors in mapping of Pleistocene sediments particularly in south-central Kansas. In parts of Barber, Harper, Sumner, Kingman, and other counties, gravelly Pleistocene deposits crop out in the steep valley-side walls at the heads of pediments cut in Permian shales and siltstones and have contributed arkosic gravels to the pediment veneer. Where these surfaces are undissected the gravelly veneer resting on eroded Permian gives the superficial appearance of extensive Pleistocene alluvial deposits. Hand augering on some surfaces that had been previously so mapped, however, revealed the veneer to be less than 10 feet thick. In this region the flanking pediments are quite young within the Pleistocene, and as the pediment veneer, in some places, is in intermittent transit it is judged more appropriate to consider these features as erosion surfaces. Therefore such deposits are not shown on the map of Kansas Pleistocene deposits (Pl. 1).

The term colluvium has been used in many areas of Kansas to include flanking pediment veneers where they are poorly sorted and are judged to be largely the product of creep or lubricated creep.

PRINCIPLES OF CLASSIFICATION AND CORRELATION

In order that a discussion of sedimentary strata be meaningful it is necessary that a system of classification be used so that various units may be designated and named for recognition. Also, these units must be correlated from place to place or the classification and description has significance only for an individual locality. These facts have been recognized since the beginning of stratigraphical geology and general principles applicable to the classification and correlation of marine strata have been developed and used by many workers.

In the case of glacial deposits the recognition of a significant stratigraphic sequence developed relatively late; and as these deposits were studied principally by observation of their physiographic expression, they were considered by many geologists to be unique in stratigraphy and not adapted for inclusion in the general framework of classification and correlation evolved for marine strata. Although such features as degree of dissection, intersecting end moraines, and other physiographic features have been used extensively, sound stratigraphic criteria also have been applied in the study of glacial Pleistocene sediments for more than 50 years. The number of localities exposing superposed tills, or tills and other sediments, is relatively small but a general understanding of the sequence of glacial events in the upper Mississippi River basin region has become well established.

A completely different approach to these young sediments existed in the region beyond the limits of glaciation or marine transgressions. While a Pleistocene chronology was being developed by the study of glacial deposits in north-central United States, fossil vertebrates were being collected at many other localities. The Great Plains of Kansas and adjacent states contributed importantly to these collections. A chronology, unrelated to the glacial sequence, developed from the study of these fossil vertebrates. It was based in part on evolutionary changes in land mammals, and later on attempted correlation of these vertebrate remains with described forms occurring in other continents. In this independent chronology, even though localities showing superposition of distinctive assemblages of fossil vertebrates are exceedingly rare, the definition, classification, and correlation of stratigraphic units rested almost entirely on the one criterion of fossil vertebrates. The lack of adequate assemblages of fossil vertebrates from known stratigraphic positions in the glacial sequence retarded a correlation of the two chronologies.

The zone of transition from the glacial province to the nonglacial province crosses several of the states in the central Missouri River basin. The specialized techniques of neither the vertebrate paleontologist nor the glacial geologist are usable in the other's province. These facts, coupled with expanded programs of ground-water and engineering geology, have prompted a relatively large number of workers in the Missouri River basin region to attempt to place the study of Pleistocene deposits on a sound, well-rounded stratigraphic basis; to remove these deposits from the "special" category; and to use bases and principles of classification and correlation generally accepted for use in other parts of the rock column. Techniques of correlation now in general use in this region include, in addition to physiographic expression, fossil vertebrates, and stratigraphic succession, three general types of evidence that cross the glacial boundary and occur abundantly in both the glacial and nonglacial provinces. These are fossil molluscan faunas, morphology and continuity of buried soils, and petrographically distinctive volcanic ash.

CATEGORIES OF STRATIGRAPHIC UNITS

In any classification system the units must be defined for consistent use. Unfortunately, as independent chronologies developed for the glacial and nonglacial Pleistocene deposits, conflicting philosophies have developed concerning the nature of stratigraphic units. Although these divergent viewpoints are rarely expressed in published papers, it becomes evident on critical examination of the literature that in dealing with glacial deposits many geologists accept lithologic continuity of till sheets as indicating contemporaneity throughout the traceable extent of the deposit, whereas many vertebrate palentologists are prone to use a formation name to include all deposits yielding similar fossils, regardless of lithologic differences. That is, while the glacial geologist may assign, quite properly, a formation name to a till sheet he often assumes improperly that the formation represents an identical unit of time throughout its extent. In contrast, some vertebrate paleontologists having collected similar fossils from several localities and presuming that the fossils establish a faunal zone that may be of the same age at the several localities, have assigned a formation name to the faunal zone and treated it in a manner appropriate to a lithologic stratigraphic unit. Obviously where these two practices are followed by different workers in the same area the resulting nomenclature becomes confused beyond comprehension.

The problem of classification is complicated in the nonmarine Pleistocene by the degree of subdivision and predominance of deposits reflecting several strongly contrasting nonmarine environments but the basic problem of definition of kinds of units is the same for these youngest sediments as for all strata of the rock column. This general problem has attracted attention in recent years and Moore (1947) has proposed in a recommendation to the American Commission on Stratigraphic Nomenclature that three kinds of units be recognized—time units, time-rock units, and rock units. He has further proposed that appropriate spellings be used to differentiate clearly rock units (written as nouns) from the units designating a time interval (written as adjectives). A consistent differentiation of these kinds of units serves to clarify the confusion that has resulted from conflicting bases of stratigraphic classification.

In the marine rocks, segmentation of the sequence for the establishment of time-rock and time units has commonly been based on unconformities, hiatuses in sedimentation, or marked change in adjacent faunas where physical evidence is lacking. As Pleistocene time is relatively short and includes the present, it is desirable to divide it into shorter and more sharply restricted units than are used for older time intervals of Epoch rank. Therefore mere recognition of unconformities in an individual section becomes inadequate for a full definition of the several Ages. Continental glaciation was the most distinctive event of the Pleistocene and glacial till the most distinctive lithology. The interval of time characterized by the active deposition of glacial till during an episode of continental glaciation is taken as defining the span of a glacial Age, and the interval of time separating two such episodes is taken as defining an interglacial Age. Deposits made during an Age constitute a Stage.

For example, a continuously traceable till sheet, such as the Kansas till, is a rock unit of formational rank and is called by the same name throughout a region extending hundreds of miles north and east from Kansas although it is known to have been made by a migrating ice margin and to be of somewhat different age at different places. The Kansan Age, on the other hand, is a unit of time that meets, without overlap or hiatus, comparable units of time called Aftonian Age and Yarmouthian Age below and above. The time, like the till sheet, takes its identity from the particular advance and retreat of a continental glacier that characterized or produced it, but unlike the till sheet it embraces the same interval of years everywhere regardless of the particular events of deposition or erosion at any one spot. Therefore the Kansas till at most places where it is observed represents only a fraction of Kansan time. Furthermore, stratigraphic units in addition to till were deposited during Kansan time.

In this report, as is standard practice in publications of the Kansas Geological Survey, lithologic units are named as nouns, while adjectival endings on names denote time and time-rock units.

All units of first rank subdivision of the Pleistocene may be considered, as proposed by Flint and Moore (1948), both time units (Ages) and time-rock units (Stages). In application to the interglacial intervals the term Age is quite appropriate; however, the application of Stage is not so clear because the physical record of much of this time is preserved in soil profiles that represent the alteration of earlier rocks. Nevertheless, as these profiles of weathering furnish a physical record of interglacial time, it is deemed appropriate to class these terms also as both Ages and Stages.

THE PLEISTOCENE TIME SCALE

The term "Pleistocene" is generally assigned to the last major unit of Series (Epoch) rank in the standard scheme of stratigraphical classification. Although the term is used on all continents, it has been unsatisfactory because of the striking inconsistencies in the defined span of time and rocks included within it in the various regions and depositional provinces. "Pleistocene" was introduced by Lyell in 1839 to apply to marine strata in the Mediterranean region that contain molluscan faunas, the species of which are more than 70 percent living. In the light of present knowledge such a definition would include much of the time now universally assigned to the late Tertiary. In 1846 Forbes used the word Pleistocene to apply to the "glacial epoch," thus giving a climatic implication—a redefinition to which Lyell agreed in 1873. A definition based on climatic change as evidenced by continental glaciation is almost universally used for Pleistocene in central and northern North America as indicated by the official usage of the U. S. Geological Survey (Wilmarth, 1925, p. 49): ". . . Pleistocene epoch includes the deposits of the Great Ice Age, as it is popularly known, and contemporaneous marine, fluviatile, lacustrine, and volcanic rocks. In some areas it also probably includes some preglacial deposits and some postglacial deposits older than those of the Recent epoch."

Nevertheless, in the typical region of the northern and western Mediterranean "Pleistocene" has been used in diverse ways. In recent years the disagreements among workers in this region have been reduced largely to two possible stratigraphic positions that might properly be regarded as the base of the Series, namely the top of the marine Calabrian (Gignoux, 1943) and its presumed nonmarine equivalent, Villafranchian, or at the base of these same units (Movius, 1949; Migliorini, 1950). As meaningful classifications of rocks must be based on a standard of reference (albeit our correlation with a type may be faulty), a resolution of this problem is vital.

At the 18th International Geological Congress in Great Britain (1948) a commission was appointed to make recommendations on the Pliocene-Pleistocene boundary line. The commission report, unanimously accepted by the Council of the Congress, was as follows (Oakley, 1950, p. 6):

> (1) The Commission considers that it is necessary to select a type-area where the Pliocene-Pleistocene (Tertiary-Quaternary) boundary can be drawn in accordance with stratigraphical principles.
>
> (2) The Commission considers that the Pliocene-Pleistocene boundary should be based on changes in marine faunas, since this is the classic method of grouping fossiliferous strata. The classic area of marine sedimentation in Italy is regarded as the area where this principle can be implemented best. It is here too that terrestrial (continental) equivalents of the marine faunas under consideration can be determined.
>
> (3) The Commission recommends that, in order to eliminate existing ambiguities, the Lower Pleistocene should include as its basal member in the type area the Calabrian formation (marine) together with its terrestrial (continental) equivalent the Villafranchian.

It is hoped, for sake of clarity and understanding among workers, that geologists generally will accept the decision of this international body. It is a particularly happy decision for workers in the United States (Moore, 1949) because both in Europe (Migliorini, 1950; Venzo, 1952) and, as will be shown later, in central United States this boundary coincides rather closely with the advent of the first major glaciation and thus matches the definition currently in use by glacial geologists.

The Kansas Geological Survey recognizes Tertiary and Quaternary as the Period-Systems within the Cenozoic Era. This rather outmoded usage is retained primarily because these terms are deeply rooted in the literature and they are in current use by many other official Geological Surveys. This has little bearing on the present discussion as in Kansas usage Quaternary Period covers the same time span as its only contained Epoch, the Pleistocene.

Subdivisions of Pleistocene time now in general use have evolved largely as the result of work in the glaciated region of the upper Mississippi Valley. Although arbitrary, the general framework developed in that area constitutes a usable Pleistocene time scale and, with minor modification of the Wisconsinan Sub-Ages, is accepted for use in Kansas. The time scale accepted as standard in Kansas is shown in Figures 1 and 2.

The earliest Age (Stage) is called the Nebraskan. Seventy years ago the concept of multiple glaciation was established in Iowa by the work of McGee (1878, 1879, 1881) and others and in 1894 Chamberlin (pp. 753-764; 1895) (also Calvin, 1896) applied the name Kansan to the lower of two tills in the Afton Junction-Thayer area of Union County, Iowa, on the basis of the supposed extent of this till into Kansas. In 1897 Bain (p. 464) stated: "A preliminary examination as far south as Kansas City seemed to show that the older drift did not come to the surface, and accordingly the upper drift at Afton Junction is presumably the surface drift of eastern Kansas, though the matter has not been fully studied." As a result of Bain's work the term Kansan was transferred to the upper drift in the Union County, Iowa, exposures and the name Albertan or sub-Aftonian assigned to the lower one (Calvin, 1897). The name Nebraskan was later proposed for this lower till by Shimek (1909) on the basis of its supposed westward extent in Nebraska, and this term has enjoyed general acceptance in the Missouri basin region.

The Aftonian Age (Stage), the second time unit in the Pleistocene, is an interglacial interval. This name first was proposed for sediments exposed in the Afton Junction, Iowa, region (Chamberlin, 1894a; Calvin, 1897) and has been generally used during the present century to designate the post-Nebraskan pre-Kansan interglacial interval.

The Kansan Age (Stage), the third segment of Pleistocene time and the second glacial interval, takes its name from the State of Kansas. Although the name Kansan was proposed originally for deposits in Union County, Iowa, the name was transposed from the lower to the upper of the two tills exposed there after southward tracing revealed that the upper till is equivalent to the surface till of northeastern Kansas. Therefore, it may be assumed that the Kansas region is the type locality for this Stage.

The Yarmouthian Age (Stage) is the interglacial interval next following the Kansan. The name Yarmouth was proposed by Leverett (1898b) to apply to the soil that served to separate the tills of Kansan and Illinoian ages in east-central Iowa. It is the oldest of the interglacial Ages to be based on a buried soil. The name Yarmouth is now used in Kansas for the buried soil in this stratigraphic position while the name Yarmouthian is assigned to the Age (Stage). In his description Leverett (1898b, p. 239) stated: "The presence of this soil horizon was first brought to the writer's notice by a well section at Yarmouth in Des Moines County, Iowa. For this reason, and because the name of this village is less likely to be confusing than names which are more common, it seems appropriate to apply the name Yarmouth to this weathered zone."

The Illinoian Age (Stage) is the glacial interval next following Yarmouthian. Leverett in 1899 proposed the name Illinois glacial lobe, from the State of Illinois, to include the drift sheet so extensively developed in that state. Subsequent usage has established the name Illinoian for this interval of Pleistocene time.

The Sangamonian Age (Stage) is the youngest of first-rank interglacial intervals within the Pleistocene. Like the Yarmouthian, the name was originally based on a buried soil, and similarly the name Sangamon is now used in Kansas to apply to the buried soil formed during this time. The name Sangamon was proposed by Worthen in 1873 for a soil developed in Illinois drift and overlain by Iowa loess in Sangamon County, Illinois. Leverett in 1898 used the term to denote the interval between the Illinoian and Iowan glacial episodes.

The Wisconsinan Age (Stage) is the fourth and last of the first-rank subdivisions of Pleistocene time that is characterized by continental glaciation. Unlike the preceding Ages, however, the Wisconsinan contains repeated glacial advances and retreats and has been subdivided into Sub-Ages (Substages). Kay and Graham (1943, p. 89) have summarized the early development of this classification in Iowa as follows:

> The name East Wisconsin was first used by Chamberlin in 1894 for the most recent of the glacial ages of the Pleistocene period. The following year at the suggestion of Upham the name was shortened to Wisconsin (Chamberlin, 1895). Soon two substages, early Wisconsin and late Wisconsin, were recog-

> nized. More recently Leverett (1929) described three substages, early, middle and late Wisconsin. The early Wisconsin drift was interpreted to have come from the Labradorean center, the Middle Wisconsin from the Patrician center, and the Late Wisconsin from the Keewatin center. Then in 1931, as a result of detailed field studies in Illinois, Leighton (1931) proposed a modification of the use of the name Wisconsin in Pleistocene classification. The change involved the elimination of the Peorian as an interglacial stage and the inclusion of the Iowan stage as the oldest substage of the Wisconsin. The evidence in Illinois had convinced Leighton and his associates that there was continuous deposition of loess, previously interpreted to belong to the Peorian interglacial age, from Iowan time until after early Wisconsin time; and furthermore, that the interval heretofore called Peorian was so short as to necessitate its elimination as an interglacial age from the classification of the Pleistocene. Moreover, Leighton proposed that since the Iowan glacial age cannot longer be recognized in Pleistocene classification as being independent in age from Wisconsin age, the usage of the name Wisconsin of our present classification be modified to include the Iowan as the earliest of its substages. He proposed also that the Wisconsin substages be named, from oldest to youngest, Manitoban (Iowan), Quebecan (Early and Middle Wisconsin), and Hudsonian (Late Wisconsin). Later he realized that the terms herein used were not appropriate. ... Leighton (1933) therefore proposed other names. .. They are, from oldest to youngest, the Iowan, the Tazewell (Early Wisconsin), the Cary (Middle Wisconsin), and the Mankato (Late Wisconsin).

The names proposed by Leighton in 1933 have been in general use since that date as the Substage names for the Wisconsinan. However, recent work in the Missouri River basin region has produced strong evidence indicating that the first two of these substages were closely linked, as were the last two, but that these two pairs of glacial episodes were separated by a significant time interval during which continental glaciers, if they were in existence, had small influence on the region of north-central United States. This grouping of events suggests that the recognition of three Sub-Ages—an early glacial Sub-Age, an intermediate interglacial Sub-Age, and a late glacial Sub-Age—might be appropriate. Such a reorganization would involve the introduction of three new Sub-Age names and reduce the refinement of the Pleistocene time scale, neither of which is judged to be appropriate at this time. Therefore an additional (interglacial) Sub-Age, Bradyan, has been proposed for use in the Kansas region (A. B. Leonard, 1951; Frye and Leonard, 1951; Frye, 1951). The Bradyan Sub-Age is between the Tazewellian and Caryan glacial Sub-Ages and is named for the Brady soil, extensively developed in the top of Tazewellian sediments in western Nebraska (Schultz and Stout, 1945) and in Kansas, and overlain at many places by the Bignell loess of presumed Caryan-Mankatoan age. Thus the Sub-Ages of the Wisconsinan as used in Kansas are, from oldest to youngest, Iowan, Tazewellian, Bradyan, Caryan, and Mankatoan.

The Recent Age (Stage), predominantly comparable in character to an interglacial interval, is the last major subdivision of the Pleistocene and includes the time since the Mankatoan glaciers ceased to exert a recognizable influence in the central interior region of North America. The term Recent was first used in a geologic time sense by Lyell (1833, pp. 52-53) to designate the interval during which man has inhabited the earth. Since Pleistocene has come to be a virtual synonym for "glacial period" Recent has been generally used to designate the post-glacial interval. This should not be construed to mean that Recent time has been lacking in climatic changes or geologic events. It may be that a minor episode of continental glaciation (Cochrane) occurred during this Age and sediments in Nebraska have been correlated with this event (Schultz, Lueninghoener, and Frankforter, 1951). However, the Recent was predominantly a time free of important effects of continental glaciation and for usage in Kansas has not been subdivided into named Sub-Ages (Substages).

CYCLICAL UNITS IN THE KANSAS PLEISTOCENE

The foregoing discussion of the subdivisions of Pleistocene time shows at once a cyclic repetition of events. Recognition of this cyclic arrangement is not new and has been emphasized by classification schemes used in Iowa and Illinois. In the continental interior this cyclic arrangement of sediments, even far beyond the glacial margins, is clearly due to the alternate advance and retreat of continental glaciers. An indirect effect of glaciation —sea level fluctuation—may have exerted a major influence on sedimentation and erosion in coastal areas but is judged to have had slight effect on the Kansas region.

A Pleistocene cycle in the glaciated region and in an extensive marginal belt consists of a glacial and an interglacial interval. It is characterized by (1) valley cutting in the early part of the glacial interval plus some local sedimentation caused by the disruption of former drainage by advancing glaciers; (2) deposition of till and outwash in the glacial region at the glacial maximum; (3) deposition of coarse-textured outwash beyond the glacial limit, and in shallow valleys cut across the till plains as the ice margins retreated; (4) deposition of progressively finer alluvial materials as the glaciers shrank and finally disappeared; and (5) development of mature soil profiles over much of the region that presented surface conditions of essential equilibrium. As the major source of loess was the flood plains of outwash-carrying streams, these deposits occur in positions 2, 3, and 4 of the cycle. It can be seen then that the greatest volume of sediments of a Pleistocene cycle is not evenly distributed through the time of either a glacial or interglacial age but is concentrated primarily in the time span extending from about the midpoint to the end of a glacial Age, and perhaps into the very early part of the succeeding interglacial Age. The soils that typify the interglacials formed during a time span extending from early in an interglacial Age to approximately the beginning of the next succeeding glacial Age (Frye, 1951).

In the Kansas region evidence is lacking concerning the deposition of sediments during the early part of a glacial Age beyond the limits of the Kansan ice sheet. Therefore beyond the ice margin the cyclical unit of sediments represents an age extending from mid-glacial to very early interglacial. However, the formation of normal soil profiles was probably terminated early during the following glacial Age by the sharp acceleration of stream erosion.

In Iowa and Illinois the Pleistocene is classed as a Period (System) and four Epochs (Series) are used to include a glacial-interglacial pair each. These are Grandian (Nebraskan and Aftonian), Ottumwan (Kansan and Yarmouthian), Centralian (Illinoian and Sangamonian), and Eldoran (Wisconsinan and Recent). Of these units each of the first three essentially coincides with a glacial cycle; however, present data indicate that the youngest (Eldoran) includes two distinct cycles, each of which is complex within itself. These terms have not been adopted for official use in Kansas partly because of this inconsistency and partly because the retention of Quaternary as the System-Period with Pleistocene as its contained Series-Epoch would force the erection of a new category of names to include these terms and thus produce a further complication of the classification system.

STRATIGRAPHICAL CLASSIFICATION OF PLEISTOCENE DEPOSITS

The practical field geologist, the person concerned with securing water supplies, ceramic clays, volcanic ash, or sand and gravel deposits, or the soil scientist investigating parent materials of soils, is primarily concerned with the classification of rocks and only secondarily with the classification of time. Although on the map and cross sections in Plates 1 and 2 the Pleistocene deposits of Kansas are shown by Stages, for detailed geologic mapping and the several fields of applied geology the investigator deals with physical entities or rock units, commonly classed as formations, members, and beds or lentils. In principle the recognition of units of rocks is based on physical characters observable in the field and the assignment of a specific exposure to such a rock unit does not necessarily imply that it is contemporaneous with other exposures so classed. It has been recommended (Ashley and others, 1933) that a formation be a unit of rocks mappable by ordinary field methods on maps of conventional scale. Members may also be mappable units but beds rarely are.

It should not be construed, however, that age is of no value in field mapping. As the sediments of the Pleistocene consist of repeated cycles of sediments that have much in common, their physical appearance may have striking similarities. Therefore placement within a Stage by paleontological or other means may be necessary before final specific formational or member assignment is possible.

As has been described, the most striking arrangement of Pleistocene deposits in Kansas is in cyclic bundles and these bundles are in general comparable to Stages. The primary physical basis for classifying these sediments is therefore the buried soils that cap each cyclic bundle or the period of erosion which was the opening episode of the next succeeding cycle and which in many places destroyed the soil profile that had developed during the preceding interglacial Age.

Rock units of formational rank ideally have lithologic unity and contrast with contiguous formations. Thus the Kansas till is predominantly ice-deposited till, but it contains zones or beds of water-laid sand and gravel which were deposited as outwash during minor fluctuations of the ice margin, or by englacial streams, or by incorporation into the till from the deposits overriden by the glacier. It has stratigraphic continuity over a wide region and contrasts strongly with the underlying Atchison formation (silt, sand, and gravel) and the overlying Meade formation. At such places where it rests directly on an older unit of similar lithology (Nebraska till) it is separated from it by a buried soil, or an erosion surface. While a till sheet, because of its relatively sharp and easily recognizable top and bottom, is readily mappable, comparably sharp limits are not present in some sequences of alluvial deposits. For example, the Nebraska Geological Survey classes both the Sappa and Grand Island as formations. It is true that the Sappa commonly overlies the Grand Island but it is also true that the two units are gradational nearly everywhere they occur and any boundary drawn between them must be purely arbitrary. A boundary line drawn arbitrarily within a gradational series from gravels to silts can hardly be used as an objective field basis for mapping as several observers cannot be expected to draw such a line at the same place. For that reason the two units are classed as members in Kansas terminology and the Meade formation is used to include the entire gradational sequence which does have clearly recognizable limits at top and bottom. Such a practice retains lithologic similarity for the formational unit from place to place while establishing recognizable limits.

Stratigraphic continuity cannot be construed to have the same meaning in alluvial deposits as it does in marine strata. Glacial till and loess each transgress divides and have regional continuity. Fluviatile deposits, on the other hand, are restricted to the valleys that contain them and do not normally possess such regional continuity. Deposits within several drainage basins, if they possess the same lithologic character, such as a gradational sequence of gravel, sand, and silt, are nevertheless placed in the same formation when it is possible to demonstrate that they resulted from the same regional cycle of alluviation. In many places physical continuity of alluvial deposits can be demonstrated for hundreds of miles along an individual valley system. This practice seems required for Pleistocene deposits in order to avoid a maze of comparable names and because the complexities of drainage adjustments would otherwise extend names of older units across present divide areas while requiring several names for comparable age sediments in some existing valleys (note section on drainage history).

Names are not commonly assigned to beds or lentils (subdivision of a member) in Kansas Pleistocene deposits. A striking exception to this general practice is the Pearlette volcanic ash bed which occurs within the Sappa member of the Meade formation. In this case the unique character of this bed requires a formal name for proper reference.

The assignment of a name to a buried soil is a problem rarely encountered in sediments older than Pleistocene and does not fall clearly within the accepted practice of stratigraphic nomenclature. These soils are developed in the top of a stratigraphic unit and so are included entirely within sediments that are assigned a proper name. For example the soil in the top of the Kansas till is entirely within the Kansas till formation even though it may be called the Yarmouth soil. Therefore named buried soils do not become formations or members but their upper surface may be taken as the boundary between units of any rank. It has been general practice by some workers to assign to a buried soil the name of the formation or member in which it is typically developed (Loveland soil, or Kansan gumbotil). This practice becomes awkward when such a buried soil is found developed on another formational unit, such as "Loveland soil" on the Crete member, or even on Greenhorn limestone of Cretaceous age.

It has become standard practice in Kansas to use, as a noun, the name of the Age during which a buried soil developed as the proper name for the buried soil, and to consider these soils not as stratigraphic units but as bearing the same relation to rock units as a combined faunal zone and unconformity. This is particularly appropriate as most interglacial Ages have been named for buried soils and much of our knowledge of these intervals of time is derived from the corresponding soil. In this usage the Sangamon buried soil is known by the same name where it is developed in Loveland loess, Crete sand and gravel, or any one of the several older units on which it has been observed.

CRITERIA USED IN PLEISTOCENE CORRELATION

Stratigraphic correlation is essentially the matching of rock or time-rock units from one place to another. As these two categories of units are different there are philosophically two kinds of correlation. However, in the Pleistocene the unit of regional correlation is generally the Stage and therefore several basically different types of evidence may with propriety be brought to bear on a correlation problem. These types are: (1) lines of evidence establishing physical continuity from place to place, such as the tracing of a till sheet, a loess sheet, or a terrace surface; (2) evidence of synchronous deposition, usable only by the recognition of separated deposits made by the same volcanic ash fall; (3) evidence from the matching of similar assemblages of fossil organisms; (4) the matching or tracing of weathering effects on a former surface; and (5) the matching of similar stratigraphic or physiographic sequences. Although all may constitute an integrated team each of these methods actually correlates different things. Tracing of a lithologic unit correlates physical continuity but these physical features may be of slightly different ages from place to place; provable simultaneous deposition establishes contemporaneity of date from place to place but says nothing about the continuity of the containing sediments; fossil faunas (if the assemblages are adequate) establish similarity of animal populations which may imply a correlation of time or environment or perhaps both; the use of buried soils, if performed by the matching of morphological types, establishes a similarity between environments, but if performed by tracing (physical continuity) falls in the same category as the first group; and the fifth method matches similarity in sequence of events, but unless the matched sequence is sufficiently long and intricate these matched events may be similar but are not necessarily contemparaneous.

Lithologic continuity.—Continuous tracing of a bed, or soil, is the most direct means of correlating stratigraphic units from place to place. The continuous tracing of units, however, is rarely possible in the field. In some areas in north-central Kansas individual loess sheets and their associated soils can be traced continuously for tens of miles. What workers usually mean by the "tracing" of beds or soils is the observation of such units at closely spaced intervals, either in surface exposures or by penetration in test holes. This method is used extensively in Kansas and is particularly applicable to correlation of loess sheets and tills in the hundreds of test holes that have been drilled by the cooperating Geological Surveys.

Petrographically distinctive volcanic ash.—A method of establishing synchroneity of date from place to place has resulted from the discovery that fresh volcanic ash deposits of the rhyolitic type can be distinguished petrographically from other ash falls of different ages (Swineford and Frye, 1946). Bentonite, or altered volcanic ash has been used in many parts of the rock column as means of correlation but petrographically distinct fresh volcanic ash deposits have been used for interregional correlation only in the Pleistocene deposits west of Mississippi River and east of the Rocky Mountain Front Range. Only one such bed of ash (the Pearlette bed, Sappa member, Meade formation) occurrs extensively in the Kansas Pleistocene and therefore this method is effectively limited to the establishment of one time line. This bed has been studied from more than 100 localities in the State. The validity of the method has been summarized as follows (Frye, Swineford, and Leonard, 1948, p. 514):

> Such properties as the refractive index, specific gravity, and shape of shards depend not only upon the chemical composition of the magma but also upon such highly variable factors as the temperature of quenching, pressure, and gas content. Glass from acid magmas in particular may show much variation because of a wide range in temperature and other conditions at eruption (E. F. Osborn, oral communication). Therefore, it is unlikely that the glass shards from several different ash falls will have the same characteristics.

The particular petrographic features that are usable in distinguishing the Pearlette volcanic ash bed from other volcanic ash deposits of the region have been summarized as follows (Frye, Swineford, and Leonard, 1948, p. 513):

> 1. The color includes certain light shades of orange-yellow, which are not characteristic of fresh ash described from the Pliocene.
>
> 2. The refractive index is consistently 1.499-1.501.
>
> 3. The shape of the shards is characteristically sharply curved, with thickened glass at the bubble junctures, which are commonly curved and branching at wide angles. Fibrous shards are present in all samples.
>
> 4. Many shards have groups or clusters of elongate vesicles which are seldom found in ash of Pliocene age.
>
> 5. The percentage of iron oxide is less than 2 . . . whereas in . . . Pliocene ash the Fe_2O_3 content ranges from 1.66 to 3.09 . . . .
>
> 6. The specific gravity ranges from 2.21 to 2.32, whereas in the Pliocene ash it ranges from 2.33 to 2.37.

Molluscan faunal assemblages.—Assemblages of fossils are useful in determining the relative age and stratigraphic sequence of deposits only under rather rigidly controlled conditions. First of all, the vertical sequence and range of distinctive assemblages must be ascertained, and as far as practicable, the areal extent of each assemblage must be learned. Finally, of course, a correlation of established faunal zones with the standard stratigraphic sequence must be made, without which any sequence of faunal assemblages lacks meaning to the geologist.

In Kansas, a distinctive molluscan faunal assemblage is associated with each of the major cycles of Pleistocene deposition, and in the case of the complex Wisconsinan cycles, a stratigraphic sequence of faunal zones occurs. Fortunately, in the midcontinent region, the association of a distinctive molluscan assemblage with the petrographically unique Pearlette volcanic ash provided a key to the correlation of the succession of molluscan faunal assemblages with the accepted stratigraphic sequence. Once such a correlation has been made, molluscan faunal assemblages become a useful tool with which to identify sediments in situations where the stratigraphic sequence is not clear. Occasionally, assemblages of fossils may be useful in the correlation of units of deposits which are not subdivisible by lithologic or other standard criteria of the stratigrapher. The correlation of the massive Peoria silt member of the Sanborn formation with the Farmdale, Iowa, and Tazewell loesses of the glaciated region is an example of this use of fossils.

Morphology and continuity of buried soils.—Buried soil profiles have been used in two distinctly different ways as tools of stratigraphic correlation. These two techniques are (1) matching or contrasting degree or type of profile morphology and color and (2) the tracing of a soil by many closely spaced observations in much the same way as a rock unit is traced. The end product of these two methods is quite different and for either method to have validity a worker must understand the genetic implications of the many soil types. Of the three orders of soil recognized in soil science (Baldwin, Kellog, and Thorp, 1938) only zonal (or normal) and intrazonal soils are of stratigraphic value as the azonal soils do not exhibit distinct vertical zonation and therefore cannot be interpreted in a sequence of clastic sediments.

The matching of physical characteristics of soils over wide regions is extremely precarious unless it is known that all factors affecting the development of the soil were the same. Most prominent among these factors are parent material, climate, drainage conditions, floral cover, and animal population. Of these factors only the nature of the parent material can be determined with certainty by the geologist by examination of a sequence of sediments containing a buried profile. Therefore, this technique should be used, in stratigraphic correlation, with great caution and over short distances. Even more precarious is the use of profile morphology of surface soils to date the immediately underlying sediments. Although of value in establishing relative ages of adjacent surfaces with similar topographies, this method has not been used regionally in Kansas. The present surface soils that extend east-west across Kansas, if examined at localities where they are developed in materials of similar type and age, illustrate this point. They range from Brown soils and Chestnut soils in the northwest through Chernozems and dark Planosols to Prairie soils and Prairie-Forest soils in the northeast.

The tracing of a buried soil is a valuable tool to stratigraphic correlation and this method is not beset with the principal dangers involved in the matching of profile morphology. The Sangamon soil, in spite of its progressive change in morphology, has been traced virtually the entire 400 miles east-west across Kansas.

Stratigraphic succession.—The measurement of a sequence of rocks, noting physical appearances and distinctive characters, constitutes one of the earliest techniques of stratigraphic correlation. It is essentially the tracing of rock units by moderately to widely spaced observations, and as a group of associated contrasting rock units is being traced simultaneously stratigraphic placement can be maintained by the particular sequence. In other words, this method relies on the consistence of a sequence of past events that resulted in distinctive rock layers. When dealing with widespread tabular bodies of rock (loess sheets, till sheets) the method has a high degree of reliability. However, where it is applied to alluvial sediments it should be used with caution as deposits of restricted geographic distribution may be easily confused with other cyclic units which display similar physical appearance.

Physiographic expression.—The physiographic character of tills has been used for many years as a means of correlation, particularly of the younger tills. In the Kansas region this technique is not applicable in the glaciated region as Kansas till everywhere overlaps Nebraska till and younger tills do not occur in the State.

Topographic form is quite usable as an aid to correlation, however, along the valleys flanked with alluvial terraces, particularly in the northern part of the State. The tracing of an alluvial terrace is much the same as the tracing of a rock unit, and in effect the deposits under the surface of an alluvial terrace constitute a lithologic unit. Many special problems arise in using terraces for correlation purposes. Perhaps the most persistent problem is the determination of the erosional history of the particular valley along which the terraces are being traced. The presence of a sequence of terraces is evidence that erosion has been predominant over deposition in the valley system. In Kansas valleys, erosional histories have not been consistent and in some valleys a physiographic or inverted sequence displays the several Pleistocene Stages in descending steps. In other valleys most of Pleistocene time was typified by predominant alluviation and only Wisconsinan terraces occur. In still others, Nebraskan terraces occur at high levels, Kansan sediments are overlain by Illinoian sediments under an intermediate terrace surface, and a complex of low terraces and flood plain are of Wisconsinan and Recent age. Obviously a terrace sequence cannot be projected with safety from one valley to another.

Other problems of terrace correlation are inherent in the technique. Along some valleys terrace levels converge or diverge and in some areas in Kansas former stream gradients cross. Influence on former stream gradients by resistant units in the bedrock may cause alternate divergence and convergence of the same pair of terraces when traced along a valley. Even the recognition of a terrace surface may be rendered difficult by erosion of the outer margin, and local deposition on the inner part of the terrace surface. In general, physiographic expression is a valuable tool in Pleistocene correlation when used in conjunction with other techniques in relatively local areas.

KANSAS IN RELATION TO THE MID-CONTINENT REGION

As preface to a discussion of the stratigraphy of the Pleistocene deposits in Kansas it is desirable to review briefly the stratigraphy of these deposits in the midcontinent region of which this State is a part. It is especially desirable to do so as the Pleistocene deposits of Kansas occur in three distinct provinces which are in some cases more closely related to the stratigraphy of adjacent states than to that of the other Kansas regions. Glacial deposits are extensive in northeastern Kansas and are similar to deposits in Iowa and eastern Nebraska. In east-central and southeastern Kansas locally derived stream-deposited gravels are the predominant Pleistocene sediment and show little direct effect of glaciation. In central and western Kansas stream-laid and eolian sediments are closely related to similar deposits in the states to the north and south and indirectly to glacial events in the area to the northeast and to the west.

Northeastward from Kansas, in the upper Mississippi valley region of Iowa, Illinois, Minnesota, and Wisconsin, there are extensive deposits made by continental glaciers. It is within this area that the generally accepted glacial sequence was worked out. The history of this work has been summarized by Kay and Apfel (1929, pp. 71-73) as follows:

> In the year 1837, Louis Agassiz, then living in Switzerland, put forward the theory that there had been continental glaciation in Europe. This somewhat startling interpretation stimulated investigation of mantle rocks both in Europe and in America. Soon in both countries abundant evidence had been found to place Agassiz's views of continental glaciation upon a firm basis. From that time glacial phenomena have been studied by many geologists, and year by year as investigations have continued, more and more of the complex phases of the history of the deposits which were made by glaciers during the Pleistocene or Glacial Period have been unraveled. Nor has finer work been done anywhere than by students of the glacial deposits of the Mississippi Valley. At first it was believed that all the phenomena could be explained in relation to the advance and retreat of a single ice sheet. But soon evidence was found which indicated to some geologists that there had been two ice sheets separated by a long interglacial epoch. This evidence consisted in many places of a forest bed or buried soil separating two tills. For instance, buried soils between tills were described in Illinois as early as 1868 by Worthen. In a report of the Ohio Geological Survey for 1869 but published in 1871 Orton called attention to a buried peat near Germantown, Ohio. Moreover, in the report of the Geological Survey of Ohio, Volume I, written in 1872, Orton stated that the interglacial stage was coming to be clearly recognized both in Europe and

in America. Another interesting early reference to the significance of vegetable material in relation to till was made by N. H. Winchell in 1873. He stated that he found leaves and wood in clay in the midst of tills in southeastern Minnesota, and expressed the view that the clay "may consist of the remains of a previous glacial sheet, upon which rested vegetable growths of the surface, accumulating between the periods of glacial epochs." In the 3rd and 4th Annual Reports of the Geological and Natural History Survey of Minnesota, published in 1875 and 1876, respectively, Winchell described occurrences of two tills separated by peat, and in Geology of Minnesota, Volume I, 1884, he stated that in southeast Minnesota the peat separates an "old" drift or upper drift from an "older" drift or lower drift. At this time he recognized also in other parts of Minnesota a "younger" drift which is younger than his "old" drift.

Between the years 1875 and 1886 Chamberlin published several important papers in which differences in topographic form and degree of alteration were emphasized as bases for differentiating tills. In fact he put greater emphasis upon the significance of these features than upon the forest beds. He recognized two tills in Wisconsin separated by a long interglacial interval. He called the older till the First Glacial and the younger the Second Glacial. In 1886 he stated that the subdivisions within each of these glacial epochs remained to be worked out but that some evidence of the older drift area pointed to a dual division of the first epoch.

From these splendid beginnings, investigations have continued year after year to the present time. As a result of these studies many chapters of the whole story of the Pleistocene of the Mississippi Valley have now been clearly outlined.

Concerning the early work in Iowa, Kay and Apfel, (1929) state that McGee made the first important contributions during the period 1878-1891 by recognizing two distinct tills separated by a forest bed. During the last decade of the last century work by McGee, Chamberlin, Bain, and Calvin led to the recognition of essentially all the major glacial units now known in Iowa. In 1897 Calvin presented a classification of Iowa Pleistocene deposits that is strikingly similar, in spite of altered names, to the accepted classification over 50 years later. A summary of Calvin's (1897) classification is as follows:

10. The recent stage, since the retreat of the Wisconsin ice.
9. Fifth glacial stage, Wisconsin.
8. Fourth interglacial stage, Toronto (?).
7. Fourth glacial stage, Iowan.
6. Third interglacial stage (unnamed).
5. Third stage of glaciation, Illinois.
4. Second interglacial stage, Buchanan.
3. Second glacial stage, Kansan.
2. First interglacial stage, Aftonian.
1. First stage of glaciation, Albertan.

Although it is the work in central and eastern Iowa, Illinois, and Wisconsin that served to define the standard glacial sequence on which the subdivision of Pleistocene time is based, it is with deposits of the Missouri Valley region in western Iowa and eastern Nebraska that the glacial deposits in Kansas have been correlated. The existence of glacial deposits of Nebraskan and Kansan age have for more than 50 years been known to occur along the Missouri River valley of Iowa and Nebraska, and recently it has been demonstrated (Smith and Riecken, 1947) that the Iowan glacier crossed this valley into northeastern Nebraska. Younger Wisconsin tills occur farther north in South Dakota and to the east in north-central Iowa. Deposits of all the major episodes of continental glaciation except the Illinoian are known to occur along Missouri River Valley northward from Kansas.

The late Pleistocene loesses are also well developed in this area. The Loveland loess (Illinoian) was described by Shimek (1909) from exposures in the Missouri Valley bluffs at Loveland, Iowa. Peoria loess has been studied extensively along this segment of valley, and the Bignell loess has been described from exposures at Sioux City, Iowa, and several localities in eastern Nebraska.

The exact placement of deposits of sand, gravel, silt, and volcanic ash that occur at several places along the valley is important to regional correlations. This is particularly so as the volcanic ash has been determined petrographically to be the Pearlette bed and is associated with an important molluscan fauna (Frye, Swineford, and Leonard, 1948; A. B. Leonard, 1950) which establish these deposits as age equivalents of the Grand Island and Sappa members of the Meade formation of Kansas terminology. The evidence bearing on the placement of these beds in the glacial section has been discussed by Frye, Swineford, and Leonard (1948) who concluded that they occur above Kansas till and below Loveland loess. The principal formational units described from the midcontinent region and their correlation with the Kansas section are shown in Figure 2.

The east-central region of Kansas Pleistocene is genetically and physiographically related to southern Missouri and northeastern Oklahoma. No detailed studies of Pleistocene deposits have been made in either of these adjacent areas and although the term "Lafayette gravels" has been applied to some deposits by a few workers, a formal stratigraphic nomenclature is not in existence. As the deposits of Pleistocene age in these areas are quite thin and discontinuous the problems are primarily physiographic rather than stratigraphic. Furthermore, the available evidence in Kansas indicates that some of the gravel veneers on relatively high levels are late Tertiary in age.

The Pleistocene geology of western Kansas is closely related to the stratigraphy of adjacent areas in the High Plains—western Oklahoma, northwestern Texas, and western Nebraska. The High Plains of northwestern Texas are far removed from continental glaciation or the direct effects of these glaciers. However, episodes of erosion and deposition are judged to have taken place in this region essentially synchronously with erosion and deposition farther north in the High Plains. The Pleistocene geology of this area has been reviewed by Evans and Meade (1945). They describe the Blanco formation (and equivalent Rita Blanca deposits) and conclude that this formation is Nebraskan in age is unconformable on Pliocene sediments, and that it accumulated in basins. The Tule formation (and probably equivalent Spring Creek deposits) unconformably overlies the Blanco formation. Although Evans and Meade do not give a definite age assignment to the Tule formation, work on volcanic ash petrography and fossil molluscan faunas by Frye, Swineford, and Leonard (1948) shows clearly that this formation is equivalent to the Meade formation (Sappa and Grand Island) of Kansas classification, and is late Kansan and early Yarmouthian in age. Deposits of Illinoian age have so far not been recognized in northwestern Texas, but Peoria loess with a distinctive pre-Bradyan Wisconsinan snail fauna has been described in the northern part of the panhandle area (Frye and A. B. Leonard, 1951). Evans and Meade (1945, p. 495) proposed the name Tahoka clay for young basin deposits that occur at several localities in this part of Texas and adjacent New Mexico. They conclude on the basis of stratigraphic relations, fossil vertebrates, and artifacts, that the Tahoka formation is Wisconsinan in age.

In the Nebraska region work in the western part of the State has in general been coordinated with studies of the Pleistocene deposits in the eastern (glaciated) area. Attention was drawn to the early Pleistocene deposits of western Nebraska by the naming and description of the Broadwater formation (Schultz and

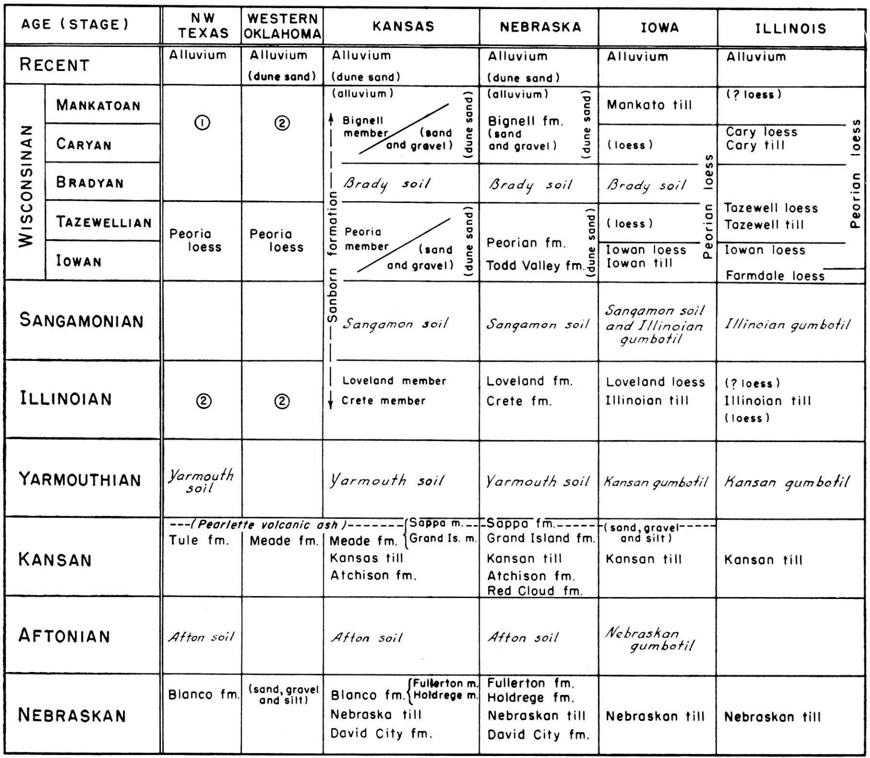
Stout, 1945, p. 232) and its fossil vertebrate fauna. This formation, recognized only in western Nebraska, occurs unconformably on Ogallala formation in a high terrace position along the North Platte Valley, has been correlated in part with the Holdrege and Fullerton formations which occur farther east (Condra and Reed, 1950), and is considered to be Nebraskan and Aftonian in age.

Several general summaries of the Pleistocene stratigraphy of Nebraska have been published (Lugn, 1935; Condra, Reed, and Gordon, 1947; Condra and Reed, 1950; Schultz, Lueninghoener, and Frankforter, 1951) and the formations now recognized by the Nebraska Geological Survey are listed on Figure 2. For the most part the formational names in current use in Nebraska appear also in the Kansas nomenclature as members or formations. As they will be described in some detail in the following section of this report, they will not be discussed here. Two important Pleistocene regions in Nebraska should be mentioned, however. These are the vast sand hills tract which lies north of the Platte River Valley in north-central Nebraska and the extensive region of thick loess in southwestern Nebraska. These two areas and the southward extension of the loess cover into Kansas present an expanse of thick and virtually continuous Wisconsinan deposits that rivals even the Wisconsinan till plains province of Ohio, Indiana, Illinois, Wisconsin, and Minnesota. In this northern High Plains area these late Pleistocene sediments approach 200 feet in thickness and dominate the surface of a region extending more than 300 miles both north-south and east-west.

It is apparent that Kansas lies across the boundaries separating three distinctly different Pleistocene provinces. This geographic circumstance is at once the frustration and the challenge to the Pleistocene geologist working in the State. It renders inoperative some commonly used techniques of Pleistocene correlation but those correlations that have been possible serve to link dissimilar chronologies and nomenclatures.

PLEISTOCENE STRATIGRAPHY IN KANSAS

Knowledge of the character and distribution of Pleistocene deposits in Kansas is based largely on work during the past two decades by the Federal and State Geological Surveys and cooperating agencies. In this period the surface geology, including Pleistocene units, has been mapped in all or parts of 40 counties, and samples of Pleistocene materials from more than 1,000 test holes drilled by the cooperative Ground-Water Division of the Federal and State Geological Surveys and from several hundred hand auger holes bored to shallower depths have been studied. Although the work so far accomplished fails to provide all desired details concerning the character of Pleistocene strata, it has furnished us with an adequate basis for the development of a state-wide nomenclature and reconnaissance map of Cenozoic deposits in Kansas shown in Plate 1. The topographic re-



AGE (STAGE)		NW TEXAS	WESTERN OKLAHOMA	KANSAS	NEBRASKA	IOWA	ILLINOIS
RECENT		Alluvium	Alluvium (dune sand)	Alluvium (dune sand)	Alluvium (dune sand)	Alluvium	Alluvium
WISCONSINAN	MANKATOAN	①	②	(alluvium) Sanborn formation Bignell member (sand and gravel) (dune sand)	(alluvium) Bignell fm. (sand and gravel) (dune sand)	Mankato till	(? loess)
	CARYAN					(loess) Peorian loess	Cary loess Cary till Peorian loess
	BRADYAN			*Brady soil*	*Brady soil*	*Brady soil*	
	TAZEWELLIAN	Peoria loess	Peoria loess	Peoria member (sand and gravel) (dune sand)	Peorian fm. Todd Valley fm. (dune sand)	(loess)	Tazewell loess Tazewell till
	IOWAN					Iowan loess Iowan till	Iowan loess Farmdale loess
SANGAMONIAN				*Sangamon soil*	*Sangamon soil*	*Sangamon soil and Illinoian gumbotil*	*Illinoian gumbotil*
ILLINOIAN		②	②	Loveland member Crete member	Loveland fm. Crete fm.	Loveland loess Illinoian till	(? loess) Illinoian till (loess)
YARMOUTHIAN		*Yarmouth soil*		*Yarmouth soil*	*Yarmouth soil*	*Kansan gumbotil*	*Kansan gumbotil*
KANSAN		---(*Pearlette volcanic ash*)--- Tule fm.	Meade fm.	Meade fm. {Sappa m. Grand Is. m.} Kansas till Atchison fm.	Sappa fm. Grand Island fm. Kansan till Atchison fm. Red Cloud fm.	(sand, gravel and silt) Kansan till	Kansan till
AFTONIAN		*Afton soil*		*Afton soil*	*Afton soil*	*Nebraskan gumbotil*	
NEBRASKAN		Blanco fm.	(sand, gravel and silt)	Blanco fm. {Fullerton m. Holdrege m.} Nebraska till David City fm.	Fullerton fm. Holdrege fm. Nebraskan till David City fm.	Nebraskan till	Nebraskan till

1. The Tahoka clay may be in part of this age
2. Deposits known to be of these ages have not been described from these areas

FIG. 2.—Chart showing proposed correlation of Pleistocene units in Kansas with principal described units in other states of the mid-continent region and the classic section of the upper Mississippi Valley region.

lations of these sediments in the central and eastern parts of the State are shown by cross sections in Plate 2. A summary of present knowledge of the character, distribution, and correlation of Pleistocene sediments in Kansas is presented in this report.

NEBRASKAN STAGE

The Nebraskan Stage includes the sediments genetically related to the first major cycle of Pleistocene glaciation and the deposits of equivalent age beyond the limits of glaciation. In Kansas these deposits are classed in three formations: the David City formation, the Nebraska till, and the Blanco formation (which includes the Holdrege and Fullerton members). Nebraskan sediments are distributed discontinuously over the State and are generally less well exposed than the succeeding stages. Nebraskan glacial sediments are exposed only in extreme northeastern Kansas, particularly in Doniphan County; chert gravels of this age occur as high terrace remnants along Cottonwood and Neosho Valleys in east-central Kansas; and Nebraskan alluvial deposits form the lower part of the fills of former valleys in central and southwestern Kansas. In the northwestern part of the State the Nebraskan Stage is virtually unknown.

DAVID CITY FORMATION

Definition.—The David City formation was described by Lugn in 1935 (pp. 38-40) from the records of sand and gravel with some silt and clay in wells near David City, Nebraska. In the type area the David City formation rests on bedrock, is overlain by Nebraska till, attains a maximum thickness of 150 feet, and is considered by Lugn (1935, p. 38) to be ". . . outwash fluvio-glacial material carried into old pre-Pleistocene valleys and other depressions on the bedrock in front of the Nebraskan glacier, and the inwash sediment carried by streams from other directions, whose valleys were dammed up by the ice itself or by debris washed from the melting ice sheet." Lithologically it has been described as resembling Platte River gravel, and as a fine- to medium-textured gray sand.

Character and distribution.—The term David City formation is applied in Kansas only to water-laid deposits occurring below and genetically related to Nebraska glacial till. Its geographic distribution is therefore restricted to the three northeastern counties—Doniphan, Atchison, and Brown. It has been studied in surface exposures only along the Missouri Valley bluffs in Doniphan County and is best exposed in excavations in the NE¼ SE¼ sec. 6, T. 2 S., R. 20 E. At this locality, referred to as the "Iowa Point section" and described in the following measured section, 10 feet of sand, gravel, and cobbles which rest directly on Pennsylvanian limestone are overlain conformably by Nebraska till. The excavations also expose in ascending order Kansas till and the Loveland, Peoria, and Bignell members of the Sanborn formation (Frye and A. B. Leonard, 1949). The David City formation consists of cobbles (of pink quartzite, igneous and metamorphic rocks, and a predominance of limestones of several types) interbedded with sand and gravel (consisting predominantly of quartz grains but containing some grains of limestone and igneous and metamorphic rocks) and a small amount of silt. The entire thickness displays cross bedding and some of the well-sorted sand lenses in the upper part contain shells of small clams and several species of aquatic snails. Some shells have been collected at the contact with the overlying till, and the entire thickness of the formation is calcareous with local cementation by calcium carbonate.

Iowa Point section, measured in quarry face and auger holes, NE¼ SE¼ sec. 6, T. 2 S., R. 20 E., Doniphan County, Kansas.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
Bignell silt member (Wisconsinan Stage, Caryan-Mankatoan Substages)	
7. Silt, massive, structureless, buff, gray, and tan; exposed in vertical face of quarry. Three to 4 feet at top and bottom partly leached of $CaCO_3$ but containing some etched snail shells; remainder of interval effervescent in dilute HCl, fossiliferous. Upper half distinct faunally from lower half	38.0
Peoria silt member (Wisconsinan Stage, Iowan-Tazewellian Substages)	
6. Silt, massive, structureless, gray and tan. Well-developed **Brady soil** at top, represented by a few feet gray leached silt, grading downward to a more compact zone, faint reddish-buff in color and locally containing abundant large caliche nodules in lower part; 12 to 15 feet thick. The lower 16 feet contains two weakly calcareous zones containing typical Peoria fossil snails, separated by a leached zone 2 feet thick.	29.0

Loveland silt member (Illinoian Stage)	
5. Silt, massive, reddish-buff. All but lower 0.5 foot leached and included in the **Sangamon soil** profile lower B horizon. Lower 0.5 foot calcareous. In adjacent exposures etched shells occur in the basal part of the Loveland. In contrast to the overlying loesses the Loveland displays a joint system with limonite concentrations along joints.	7.5
Kansas till (Kansan Stage)	
4. Till; matrix of clay and silt containing pebbles and cobbles of limestone, pink quartzite, and igneous rocks. Irregular masses of brown sand are incorporated in the till. Gray and yellow mottled. Lower 7 feet calcareous; upper 2 feet leached and containing nodules of caliche in lower part, judged to be the lower part of truncated **Yarmouth soil** profile. A few fossil snail shells found imbedded in the bottom few inches of Kansas till and sand.	9.0
Nebraska till (Nebraskan Stage)	
3. Till; matrix of clay and silt with pebbles and cobbles of limestone, igneous rocks, and a few of pink quartzite. Irregular masses of sand and gravel incorporated in till. At top a well-developed humic-gley **Afton soil** profile, darkened layer more than 2 feet thick and leached of all limestone pebbles to a depth of more than 3 feet. Quartzite pebbles occur throughout soil. The dark layer grades downward into a medium-gray to light-brown leached and oxidized zone, which in turn grades downward into gray calcareous till. A few fossil snail shells found imbedded in bottom few inches of till.	7.0
David City formation (Nebraskan Stage)	
2. Gravel, cobbles, boulders, sand, and silt; limestone, igneous rocks, and quartzite, moderately well-sorted sand common in upper part, iron-stained, calcareous; locally cemented with $CaCO_3$, local concentrations of fossil snail shells and small clams in well-sorted sands in the upper part.	10.0
PENNSYLVANIAN—Virgilian	
Deer Creek limestone and Calhoun shale	
1. Limestone and shale exposed in quarry face to level of Missouri River flood plain. Approximately	30.0
Total thickness exposed	130.5

Nonglacial gravels judged to be pre-Nebraskan in age occur at this same stratigraphic position in northeastern Kansas (Todd, 1920; Frye, 1941). These pre-glacial gravels consist entirely of chert and limestone pebbles, obviously derived from cherty limestones within 100 miles west of Missouri River, and a minor amount of quartz sand. Unlike the David City gravels, from which they are readily distinguishable, these pre-glacial gravels are totally lacking the rock types indicative of a northern or northeastern glacial source.

Topographically the David City occurs in contact with bedrock more than 30 feet above the level of the Missouri River flood plain whereas the pre-glacial gravels, at all localities known in this area, occur on higher bedrock.

Test drilling in northeastern Kansas (Frye and Walters, 1950) has failed to reveal this formation beyond the limits of Doniphan County although the overlying Nebraska till may extend into adjacent Brown and Atchison Counties. The David City formation is quantitatively a minor element of the Pleistocene deposits in Kansas.

Age and correlation.—The David City formation in Kansas is considered to be early Nebraskan in age and equivalent to the subsurface type in Nebraska because it is lithologically similar to the overlying Nebraska till with which it is conformable. It is strongly dissimilar to the nonglacial gravels in a comparable stratigraphic position. The David City gravels were deposited during the advance of the Nebraskan glacier, but were subsequently overridden by the advancing ice mass. Locally, age equivalents to the David City may be included within the Blanco formation in southwestern Kansas, but if so, are not recognizable.

NEBRASKA TILL

Definition.—In the last decade of the past century the existence in southern Iowa of a till below the one now called Kansas became well established. This earliest Pleistocene glacial unit was variously called Kansan, pre-Kansan, sub-Aftonian, Albertan, and Jersyan. The typical description of this earliest glacial deposit was based on exposures in Union County, Iowa. In 1909 Shimek proposed the name Nebraskan for this drift because he concluded that it extended westward into the State of Nebraska and subsequently this name has been generally accepted in the Missouri Valley and upper Mississippi Valley regions. The Nebraska till is the earliest recognized glacial deposit in Kansas. It comformably overlies the David City formation and is overlain unconformably by Kansas till.

Character and distribution.—Nebraska till has been recognized with certainty only in Doniphan, Atchison, and Brown

Counties in the extreme northern part of the State, and surface exposures are restricted to the Missouri Valley bluffs in Doniphan and Atchison Counties. Evidence has been cited for the presence of Nebraska till along Kansas River Valley east of Lawrence (Schoewe, 1927) and this suggests the possibility that another lobe of Nebraskan ice crossed the present site of Missouri River between Kansas City and Leavenworth. Test drilling in the glaciated area (Frye and Walters, 1950) has not been sufficient to settle this question but it is adequate to restrict clearly such a lobe—if it did exist—to a relatively small area in Leavenworth County and the Kaw Valley to the south of that county.

Where it has been studied in outcrop sections the Nebraska till is indistinguishable lithologically from the much more widespread overlying Kansas till. It consists of boulders and cobbles of pink quartzite, conglomeratic quartzite, igneous rocks, metamorphic rocks, and predominantly limestone, in a matrix of clay, silt, and sand. Where unweathered it is calcareous and gray in color. It commonly contains lenses and zones of well-sorted sand. Its recognition is based on the stratigraphic relationship which is demonstrated conclusively in exposures at the Iowa Point section (Frye and A. B. Leonard, 1949) in Doniphan County (NE¼ SE¼ sec. 6, T. 2 S., R. 20 E.). At this locality the Nebraska till, 7 to 10 feet thick, is characterized by a well-developed Wiesenboden, or humic-gley, Afton soil in the upper part. Although part of the A horizon of the Afton soil was removed by the overriding Kansan glacier, most of its thickness is preserved and is not distorted by later glacial scour or by frost action. The upper 2½ feet is darkened by organic material and is leached of carbonates including limestone pebbles, although quartzite pebbles occur sparsely throughout its thickness. The dark-gray to black zone grades downward into a less intensely weathered gray-tan zone which in turn is gradational with calcareous till containing limestone pebbles in the lower part of the exposure. The Afton soil at this locality is similar in appearance to material called Nebraskan gumbotil in Iowa and Nebraska.

Thin Nebraska till may occur locally below the Atchison formation southwest of the City of Atchison (Frye, 1941). In this area, however, Afton soil has not been found in the top of the Nebraska till.

Although test drilling in northern Atchison County and Doniphan and Brown Counties has not been adequate to furnish the desirable details (Frye and Walters, 1950) it is judged that Nebraska till is discontinuous under the Kansas till in this area, occurring on relatively high bedrock surfaces. Nebraska till was not recognized in test holes south of the prominent bedrock sag trending east-west through southern Nemaha County, or west of Brown County.

Age and correlation.—There is no inherent characteristic of the Nebraska till that permits its correlation with the type to the north. Rather, its correlation rests on its stratigraphic position and regional relationships to the north and northeast. Detailed work in that region (Kay and Apfel, 1929; Kay and Graham, 1943; Condra and Reed, 1950) has shown that only two major glacial advances approached Kansas. The presence of the well-developed Afton soil, which demands a significant interval of time for its development, separating two tills in northeastern Kansas requires the correlation of the lower till of this area with the Nebraska till of the type area.

BLANCO FORMATION

Definition and subdivisions.—The name "Blanco Canyon beds" was first used by Dumble (1890) and by Cummings (1891). The exposures along Blanco Canyon of White River north of Crosbyton, Crosby County, Texas, and the vertebrate fossils from these deposits have also been discussed by Gidley (1903), Osborn (1903), Baker (1915), and Matthew (1925). Recently the Blanco beds have been described in detail by Evans and Meade (1945, pp. 491-493) and the contained fossil vertebrates have been discussed by Meade (1945). Typical exposures of the Blanco formation occur near Mt. Blanco, near the juncture of Crawfish Draw with Blanco Canyon, approximately 10 miles north of Crosbyton, Texas. Here the Blanco formation consists of gravel and sand in the lower part, with gray to white silts, sands, and clays with some diatomaceous marl and fresh-water limestone in the upper part. The formation is unconformable on Pliocene Ogallala formation. The contact truncates the Ogallala beds at a low angle and abraded pebbles and cobbles of Ogallala "cap rock" locally form the lower few feet of the Blanco.

In the upper part of the Blanco, nodular caliche which is judged to represent the buried Afton soil commonly occurs in a zone ranging up to 2 feet in thickness. Sand, silt, and volcanic ash unconformably overlie the Blanco in this area. The volcanic ash has been determined on the basis of petrographic characters to be the Pearlette bed (Frye, Swineford, and Leonard, 1948). The Pearlette ash commonly occurs in the Tule formation in this region of the Texas High Plains. It has associated with it fossil vertebrates and a large molluscan fauna, features which serve to establish correlation of the Tule formation with the Sappa member of the Meade formation in Kansas and the Sappa formation in Nebraska.

In Kansas, as in other areas of the Great Plains, deposits correlated with the Blanco formation commonly are coarse-textured in the lower part and grade upward into finer-textured clastics. Although conformable and gradational these contrasting lithologies merit recognition as named members. In Nebraska, equivalent units are named Holdrege and Fullerton formations (Lugn, 1935; Condra and Reed, 1950); in Kansas these names are used to designate the comparable members of the Blanco formation.

The name Holdrege formation was applied in Nebraska to sands and gravels reported in the log of a test well drilled for oil near the Cen. SW¼ sec. 23, T. 6 N., R. 19 W., 2 miles north and 4 miles west of the City of Holdrege, Phelps County, Nebraska (Lugn 1935, p. 92). This test is reported to have penetrated 71 feet of Holdrege sand and gravel resting on 129 feet of Tertiary Ogallala formation and overlain by 30 feet of Fullerton formation silts, sandy silts, and clays.

The Fullerton formation was described and named from exposures about 1 mile northwest of Fullerton, Nance County, Nebraska (Lugn, 1935, pp. 83, 98). The Fullerton silts, here 20 feet thick, occur as the lowest exposed unit of the Fullerton, or "Lover's Leap" section. This section exposes Peorian and Loveland loesses, Crete formation, Sappa formation, Grand Island formation, and Fullerton formation (Nebraska classification). Holdrege formation sand and gravel below the Fullerton has been penetrated in near-by wells. Lugn (1935, p. 98) states that although the Fullerton formation is exposed only at the type locality and in the northern part of Nebraska, it is known from subsurface data to occur over a wide area.

Character and distribution.—In Kansas the Blanco formation is quantitatively important only in the central and southwestern parts of the State (Pls. 1, 2). The Blanco formation is unknown in the glaciated area except for a few small and inconclusive deposits of chert gravels which contain a minor percentage of pebbles common to the glacial deposits (Davis, 1951).

In east-central Kansas thin deposits of chert gravels that occur on disconnected high terrace remnants are judged to be age equivalents to the Blanco formation. These gravels consist entirely of siliceous grains, ranging in size up to several inches in diameter, that are similar to the chert contained in the upper Pennsylvanian and lower Permian rocks of east-central Kansas and the Flint Hills belt. No pebbles that could not have been derived from the Permian Herington limestone and rocks occurring stratigraphically lower have been found in these deposits. It is obvious that the source of these gravels (Pl. 3A) is quite local. The red clay matrix which fills the interstices of these gravels and the absence of limestone pebbles demonstrate that they have been subjected to prolonged weathering. In most exposures examined this red clay matrix persists through the entire thickness of the gravel and might be classed as the overthickened B horizon of an ancient soil.

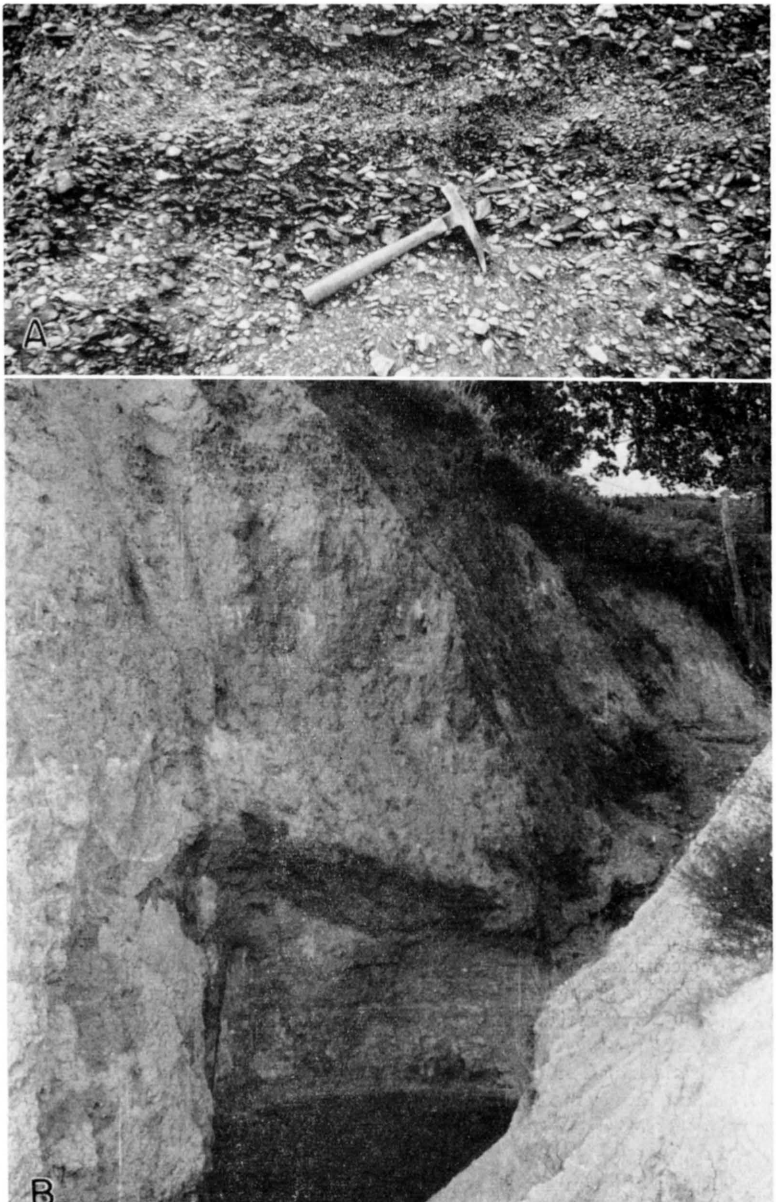
These terrace deposits are considered to be equivalent to the Blanco formation because of the advanced degree of weathering and their physiographic setting. A persistent terrace, called the Emporia terrace by H. G. O'Connor (personal communication) and dated as late Kansan by the presence of Pearlette volcanic ash, occurs at a height of 35 to 40 feet above the flood plain. The Emporia terrace gravel consists predominantly of chert but contains in the lower part a significant percentage of limestone pebbles and in the upper part a red clay zone. The Nebraskan age terrace remnants occur at a height of 75 to 105 feet above flood plain level along this same valley system. Chert gravels in this terrace are well exposed in several quarries (for example: northwest of the City of Emporia, and in the NE¼ sec. 5, T. 19 S., R. 12 E., Lyon County; SW¼ sec. 13, T. 19 S., R. 8 E., Chase County). Remnants of a still higher terrace, veneered with chert gravels indistinguishable lithologically from the Nebraskan gravels, occurring at heights of 150 to 200 feet above the same flood plains, are judged to be late Tertiary in age.

Terrace gravels of the same lithologic type which may also be Nebraskan in age occur adjacent to Elk River (for example: in the NW¼ sec. 13, T. 31 S., R. 11 E. and sec. 12, T. 30 S., R. 10 E., Elk County), Fall River (well exposed at right end of Fall River Dam), and Marais des Cygnes River.

In central Kansas the Blanco formation has been described by Fent (1950, pp. 64-65) who proposed the name Chase Channel formation, containing Holdrege and Fullerton members, for these deposits in Rice County. The log of a test hole through the formation is given below. In this area the formation is known primarily from test hole data. It forms the lowest part of the fill of buried valleys such as Chase channel, which are cut more than 200 feet below adjacent uplands capped with remnants of Pliocene Ogallala formation. Here the Holdrege gravels consist predominantly of locally derived rocks and grade upward into tan silts with soil caliche in the upper part. The Blanco is overlain by the late Kansan Meade formation which contains, at the site of some test holes, the Pearlette volcanic ash bed.

Log of Kansan and Nebraskan sediments penetrated in a test hole drilled in the filled Chase channel, SW¼ SE¼ sec. 10, T. 20 S., R. 9 W., Rice County, Kansas. (Fent, 1950, p. 128)

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Post-Kansan sediments	70	70
Meade formation (Kansan Stage)		
Sappa member		
Silt, calcareous, light-tan, and white clay; contains much volcanic ash	9	79
Volcanic ash (Pearlette bed), white; contains a few fine quartz grains	5	84
Sand, very fine, and silt, light-gray; contains many shell fragments	30.5	114.5
Grand Island member		
Sand, fine to medium	11.5	126
Blanco formation (Chase Channel formation of Fent) (Nebraskan Stage)		
Fullerton member		
Silt, calcareous, light-gray	14	140
Silt, buff, and fine sand	10	150
Holdrege member		
Sand, medium to fine	16	166


A
B

Gravel, fine to coarse, and sand	10	176
Silt, calcareous, buff; contains much coarse to fine sand	2	178
Gravel, fine to coarse, and sand	12	190
PERMIAN—Leonardian		
Harper sandstone		
Siltstone, dark-red	4	194

South and southeast of Rice County in central Kansas the Blanco formation crops out along the valleys of Arkansas, Chikaskia, and Ninnescah Rivers in Harper, Kingman, Reno, and Sedgwick Counties. In this area the Blanco is thin and the Holdrege gravels are comparable to the deposits of the filled valleys in Rice County in that they consist largely of rocks derived from bedrock formations that occur to the north and west in central Kansas. An exposure of Holdrege gravel resting on Permian occurs in a road cut in the SW¼ sec. 6, T. 27 S., R. 7 W., in northern Kingman County. Here these gravels consist predominantly of pebbles of Cretaceous rocks but also contain chert, some quartzite, and a few granitic pebbles. Gravels have been traced by test drilling northward from this locality across Reno County to an area where they occur incised below Ogallala (oral communication from O. S. Fent).

The strong reflection of local source in the lithology of the Holdrege gravels is clearly shown by the northward tracing of these deposits into northern Barton County and westward along the Smoky Hill Valley. In the vicinity of Galatia in northern Barton County and in adjacent southwestern Russell County (Latta, 1950) Holdrege gravels occur on a gentle sag on the Arkansas-Smoky Hill River divide high above the Kansan terrace of the Smoky Hill Valley. Here they contain a significant percentage of granitic pebbles. Farther north, on the north side of the Smoky Hill River, they are exposed in a similar topographic position in an abandoned pit and road cut about 1 mile northeast of Gorham in Russell County, several miles to the west in Ellis County, and at Antonino in southern Ellis county. At these localities the Holdrege gravels resemble the gravels of the Ogallala formation which occurs near

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PLATE 3. **Blanco formation. A,** Chert gravels capping high terrace remnant and assigned to Blanco formation; NW¼ sec. 5, T. 19 S., R. 12 E., Lyon County. (1949.) **B,** Blanco formation resting on erosion surface on Permian and overlain, in adjacent exposures, by Grand Island member of Meade formation. Large molluscan fauna collected from the upper part of this exposure. SE¼ SW¼ sec. 12, T. 29 S., R. 8 W., Kingman County. (1951).

by at higher elevations. In sharp contrast, the Holdrege gravels in central Ellis County, in a tributary position to the major Nebraskan streams and deriving their sediment principally from the Fort Hays limestone (Cretaceous, Niobrara formation) escarpment, consist largely of pebbles of chalk.

As the direction of flow of the major Nebraskan streams was north-northwest to south-southeast whereas the principal stream now flows east-southeast across Rice, Reno, and western Sedgwick Counties (Pl. 2), the topographic position of the Holdrege rises eastward across this area. In eastern Harvey and Sedgwick Counties thin Blanco deposits cap the low scarp along the east side of the Arkansas alluvial plain and in southern Sedgwick County they cap the relatively low upland west of Arkansas River Valley where the major stream swings toward the south-southeast. Exposures are meager in this slightly dissected upland but the Fullerton member is well exposed in the SW¼ SW¼ sec. 16, T. 27 S., R. 2 W., Sedgwick County, where 8 feet of gray to greenish-gray silt and sand rests on Permian shale exposed along a cut bank of Dry Creek. Here the Fullerton is overlain by red sandy silts and silty sands tentatively classed as Crete-Loveland. The upper 3½ feet of the Blanco contains a heavy accumulation of nodular caliche judged to be the combined results of Afton and Yarmouth soil development, but the A horizon and the upper part of the B horizon have been removed by erosion. The silts below the caliche zone contain abundant fragments of snail shells but few identifiable shells are to be found. In this area the contact of Blanco on Permian is more than 200 feet higher than the bedrock floor under the Arkansas Valley no more than a mile to the east.

South of Great Bend in Stafford and Pratt Counties the Blanco formation forms the lowest part of the fill in valleys now overlain by sediments of Kansan, Illinoian, and Wisconsinan ages. The formation is here known primarily from test hole data (Pl. 2). In the southern part of Kingman County and northern Harper County, however, dissection by Chikaskia River and adjacent streams affords more ample exposures. In the SE¼ SW¼ sec. 12, T. 29 S., R. 8 W., Kingman County, Blanco deposits are well exposed in a road-side gully (Pl. 3B). Here pink-tan silty clay and gray sand and silt with a heavy nodular caliche zone in the top occur in an erosional valley in the Permian cut below the level of adjacent contact of Kansan deposits on Permian. This exposure has yielded a large fauna of fossil mollusks.

A comparable exposure of Blanco occurs along road cuts in the SW¼ sec. 35, T. 31 S., R. 10 W., northern Barber County. At this locality partly cemented fine sands, silts, and sandy silts, gray and gray-green, occur on the Permian surface below the level of extensive Grand Island gravels (Meade formation) to the north. Nodular caliche occurs in the upper part and fragments of fossil snail shells are scattered throughout the exposure.

Quantitatively the Blanco formation has its maximum development in Kansas in the southwestern area, where the formation attains a maximum thickness of more than 250 feet. In this area Smith in 1940 (p. 95) described and named the Rexroad formation from exposures (now classed as Blanco formation) on the Clarence Rexroad ranch in sec. 22, T. 33 S., R. 29 W., Meade County. In 1941 Frye and Hibbard (p. 407) redescribed these beds as the Rexroad member of the Ogallala formation. They state concerning these deposits in central Meade County (Frye and Hibbard, 1941, pp. 407-408):

> . . . the thickness and character of the member are known only from test-hole samples and well logs. Where the entire member is present it is about 200 feet thick, but in the deepest part of the basin it may attain a maximum thickness of 250 feet, and east of the Crooked creek fault it is only about 30 feet thick. On the basis of data from test holes, the lower 175 feet of the Rexroad member may be described as comprising alternating beds of sand, silt, and clay. . . . Two well-defined snail zones were encountered in the test drilling. . . .
>
> The upper beds of the Rexroad member, which are exposed at the surface, consist of blue-gray, tan, and gray sand, silt and clay. At many places a bed of soft sandy caliche occurs at the top of the member and at a few localities a thin bed of peat occurs 20 to 30 feet below the top. The Rexroad member of the Ogallala formation is overlain unconformably by the basal sand or gravel of the Meade formation of Pleistocene age.

The anomalous overthickened Blanco deposits in central Meade County are the result of post-Ogallala, pre-Nebraskan movement along the Crooked Creek fault (Frye, 1942) which extends in a south-southwesterly direction across central and southern Meade County into Beaver County, Oklahoma. Blanco deposits in southwestern Kansas occur principally in the area west of the Crooked Creek fault and east of a prominent fault revealed by test drilling in Stanton, Hamilton, and Kearny Counties (Latta, 1942; McLaughlin, 1943). These sediments extend northward across Arkansas Valley and into the "Scott-Finney depression" (Latta, 1944; Waite, 1947) of northern Finney County and north through central Scott County (Pl. 1).

Throughout southwestern Kansas the Blanco formation closely resembles the Ogallala formation lithologically, having been derived in large part from those Pliocene sediments. In general it contains sands and gravels in the lower part, grading upward into reddish-tan sandy silts and silts which contain nodular caliche. In this region the Blanco, known almost entirely from subsurface data (Frye, 1942; Latta, 1944; McLaughlin, 1946; Byrne and McLaughlin, 1948) is exposed along Crooked Creek Valley in central Meade County and Cimarron River Valley in southwestern Meade County, Seward County, and southern Grant County. The upper part is well exposed at the Rexroad type locality where it has yielded large faunas of fossil mollusks and vertebrates (Hibbard, 1944), in several road cuts west of the City of Meade, in Wolf Canyon and adjacent canyons south of Cimarron River in southwestern Meade County where it has yielded both fossil mollusks and vertebrates (Hibbard, 1944, 1944a, 1949b, 1950, 1951) and along canyon walls on the north side of Cimarron River Valley in southwestern Meade County where fossil vertebrates have been collected.

Age and correlation.—The placement of the Blanco formation within the standard time scale has been a question for debate among vertebrate paleontologists for many years. Suggested correlations, based on fossil vertebrates, have been made with other localities of fossil vertebrates in North America and Europe and not with the glacial time scale of the Mississippi Valley—although some writers have referred to the glacial age terms. General agreement seemingly exists among paleontologists concerning the similarity of faunas classed as Blancan in Texas, Kansas, and Nebraska. Early in the present century the Blanco beds were considered to be middle Pliocene in age (Matthew, 1925) and a decade ago they were placed as late Pliocene (Wood and others, 1941; Hibbard, 1937b, 1941a, 1941b; Frye and Hibbard, 1941). Recently (McGrew, 1944; Evans and Meade, 1945; Meade, 1945; Schultz and Stout, 1941, 1945, 1948) evidence from fossil vertebrates has been cited in support of an early Pleistocene (Nebraskan or Aftonian) age for the same localities in the three states.

The lack of fossil vertebrates in the glaciated region has prevented correlations with the glacial sequence based on vertebrate evidence. Therefore assignment of age to the Blanco and its equivalent was based on correlation with fossiliferous beds in southern Europe. Evidence has been presented that the Blancan faunas are equivalent in age to the fauna of the Villafranchian (McGrew, 1944, p. 47; Stout, 1950) or Villafranchian and Astian (G. G. Simpson, 1947, p. 623) or the Calabrian which is judged to be equivalent to Villafranchian (Schultz and Stout, 1948) of southern Europe. As the International Geological Congress which met in London in 1948 expressed unanimity (Moore, 1949; Oakley, 1950, p. 6) concerning the placement of the Calabrian (Villafranchian) as earliest Pleistocene it seems evident that the Blanco formation should be classed as early Pleistocene.

Since the Pleistocene time scale generally accepted as standard in interior North America is based on the sequence of glacial deposits, it is more significant to our problems to examine the evidence establishing correlation with the glacial section. Three independent kinds of evidence, exclusive of fossil vertebrates, demonstrate that the Blanco formation in central and southwestern Kansas and in northwestern Texas, is a product of the Nebraskan cycle of deposition and should be classed within the Nebraskan Stage. These are (1) the contained fossil mollusks, (2) stratigraphic framing between the conclusively correlated Sappa member of the Meade formation above (based on Pearlette volcanic ash, fossil mollusks, buried soil, and physiographic position) and the Pliocene Ogallala formation below, and (3) regional physiographic history.

Fossil mollusks occur abundantly in the Blanco formation in southwestern and central Kansas, as well as in Nebraskan sediments (David City formation and Nebraska till) at the Iowa Point section in the glaciated region of Kansas. Of the species common to the glacial and nonglacial sections of Kansas, 5 species are restricted to the Nebraskan Stage and do not occur in the stratigraphically higher Kansan fauna (65 species, 29 localities) in the mid-continent region.

Stratigraphic framing is perhaps the most conclusive single line of evidence demanding a Nebraskan age for the Blanco formation. At the type locality and west of Channing, Texas, in central Meade County, Kansas, and in Rice County, Kansas, Blanco beds are overlain by the Meade formation (in Texas classed as Tule) including the Sappa member with the Pearlette volcanic ash bed, and at several localities an associated large molluscan fauna. At all of these localities unconformable relation of the Blanco to the Pliocene Ogallala formation is clear. The stratigraphic position of the Pearlette volcanic ash and associated fauna has been established in the glacial section of the Missouri Valley region (Kansas, Nebraska, Iowa, and South Dakota) as late Kansan or earliest Yarmouthian (Frye, Swineford, and Leonard, 1948). Furthermore, the unconformity at the top of the Ogallala and below the Blanco is of profound regional importance, representing an episode of erosion throughout the entire mid-continent region—the first such regional erosional unconformity after the initiation of Ogallala deposition. (Frye, 1948; Elias, 1948). These data establish the Blanco as the cycle of deposits next preceding the Kansan and following regional erosion after the culmination of Ogallala (Pliocene) deposition.

Physiographically the Blanco overlain by Kansan and younger sediments occurs in erosional channels cut more than 200 feet below the adjacent top of the Ogallala in central Kansas (Fent, 1950, 1950a); on the downthrown side of the Crooked Creek fault in Meade County in a position indicating more than 150 feet of post-Ogallala, pre-Blanco displacement (Frye, 1942); as high terrace remnants below adjacent Ogallala and more than 100 feet above Kansan sediments overlain by Illinoian gravels in a lower alluvial terrace along Smoky Hill Valley (A. R. Leonard, 1952); and as high terrace remnants above a Kansan terrace in east-central Kansas. Only a Nebraskan age will satisfy all these physiographic positions.

AFTONIAN STAGE

The culmination of deposition of the Blanco formation may have extended into earliest Aftonian time and to that extent it might be assignable in its upper part (upper Fullerton member) to the Aftonian Stage. It is our judgment, however, that deposition of the Blanco was completed in the Kansas region by the time the Nebraskan ice sheet ceased to be active. If such were the case, a record of Aftonian time in Kansas is provided only by the Afton soil.

In the glaciated area a well-developed Wiesenboden or humic-gley soil (gumbotil) on Nebraska till and overlain by Kansas till has been studied only at the Iowa Point section. At this locality an exceptionally well-preserved soil, developed as a poorly drained profile, is exposed. The absence of limestone and granitic pebbles (common in the underlying till) from the upper part of the profile while quartzite pebbles occur throughout the old soil, attests to a long period of weathering.

Outside the glaciated region eroded remnants of Afton soil have been observed at localities in Kingman and Meade Counties and northern Barber and Harper Counties but an A or upper B horizon has not been observed. Eroded remnants of Afton soil have been penetrated in test drilling in Rice, Barton, Stafford, and Pratt Counties. The eroded lower part of a composite soil that had its initial development in Aftonian time has been studied in the SW¼ SW¼ sec. 16, T. 27 S., R. 2 W., Sedgwick County, and in the NW¼ sec. 36, T. 15 S., R. 26 W., Gove County, where nearly a complete profile underlies the surface of a dissected remnant of a high Nebraskan terrace. A soil that may be Afton and younger occurs below Peoria loess on eroded Ogallala in the SE¼ NE¼ sec. 33, T. 10 S., R. 28 W., Sheridan County.

In a wide region of the High Plains, particularly Greeley and Wichita Counties and northern Hamilton, Kearny, and Finney Counties, the depositional top of the Pliocene Ogallala formation is essentially uneroded and occurs under a cover of Wisconsinan loesses. In the many auger holes that have been bored through the loess in this region a heavy calcareous soil has been encountered at the top of the Ogallala. Soil-forming processes were operative on this surface for an undeterminable length of time after completion of Ogallala deposition and prior to Blanco deposition but it seems certain that Aftonian, Yarmouthian, and Sangamonian weathering all affected this surface.

Although data on the Afton soil are less adequate than for any of the succeeding Pleistocene buried soils, it seems probable that the degree of development of the Afton soil is comparable to the Yarmouth and Sangamon soils and is stronger than the Brady soil.

KANSAN STAGE

The Kansan Stage, which appropriately takes its name from Kansas, is quantitatively the most important of the Pleistocene stages in the State. During Kansan time a continental glacier advanced to a position far beyond the limits of the earlier Nebraskan ice and reached the south side of the Kaw Valley as far west as the mouth of Vermillion River. This glacier extended westward across the valley of Little Blue River south of the Nebraska state line. During the retreat of the Kansan glacier water-laid deposits of gravel, sand, and silt accumulated in most of the major valleys in eastern and central Kansas, as an alluvial plain in the Great Bend region, and in minor quantities in the valleys in the northwestern part of the State. The volume of glacial and fluvial sediments assigned to the Kansan Stage far exceeds that of any other Pleistocene stage in Kansas, although eolian sediments of this stage are virtually nonexistent. An event of paramount significance to Pleistocene stratigraphy occurred in latest Kansan time—the distributioin over the State of shards of glassy volcanic ash now recognized as the Pearlette bed from a source to the southwest. The Kansan Stage contains the Atchison formation, the Kansas till, and the Meade formation which includes the Grand Island sand and gravel member at the base and the Sappa member with the Pearlette volcanic ash bed.

ATCHISON FORMATION

Definition.—The name Atchison formation was proposed in 1951 by Moore and others (p. 15) from exposures in the vicinity of Atchison, Kansas, and particularly the deposits exposed along the creek bank in the SE¼ SW¼ sec. 2, T. 6 S., R. 20 E., Atchison County. A measured section at the type locality is given below. Earlier these deposits had been referred to as pro-Kansan sands (Frye and Walters, 1950, p. 149) and also as Aftonian sands and silts (Frye, 1941). The same deposits had previously been described in this area by Schoewe (1938) and in exposures along the Missouri Valley bluffs north of the City of Atchison by Todd (1920).

In their definition of the Atchison formation Moore and others (1951, p. 15) stated that the formation, which was not recognized beyond the limits of Kansan glaciation, comprised pro-Kansan

Kansas till and Atchison formation at type locality of Atchison formation. Exposed in creek bank in the SE¼ SW¼ sec. 2, T. 6 S., R. 20 E., Atchison County, Kansas.

	Thickness, feet
QUATERNARY—Pleistocene	
Kansas till (Kansan Stage)	
4. Till; clay, silt, sand, gravel, and boulders of limestone, igneous rocks, and pink quartzite, calcareous, tan, with streaks of blue-gray in lower part. The till thickens sharply to the southwest and upstream along the creek bank	8.0
Atchison formation (Kansan Stage)	
3. Sand, fine to very fine, thin-bedded, well-sorted to extremely well-sorted, light-tan	47.0
2. Sand, coarse to fine, thin-bedded to cross-bedded, tan streaked with orange-brown	15.0
1. Sand and gravel, cross-bedded, locally cemented with calcium carbonate. From water level in creek	8.0
Total thickness exposed	78.0

outwash of early Kansan age. At the type exposures (Pl. 4A, 4B) 70 feet of Atchison is exposed and a maximum of nearly 100 feet has been penetrated in test holes farther west (Frye and Walters, 1950).

Character and distribution.—The Atchison formation consists of silts, sand, and some gravel. At some localities, for example north of Atchison and in Marshall County (Pl. 4C), the coarse silts are extremely well sorted and thin-bedded to laminated. More than 90 percent of some samples of fine sands in the upper part of the type section fall into one Udden grade. Although it is not possible to obtain detailed information from cuttings from fish-tail hydraulic drilling, some samples from the subsurface of southern Nemaha County indicate a comparable lithology. In contrast, coarse gravels occur locally in the formation.

The relation of the Atchison formation to the Kansas till that everywhere overlies it indicates that this formation is genetically related to and only slightly older than the till. No evidence of weathering between the two units has been observed and at some localities till actually interfingers with water-laid sands. These relations suggest that the Atchison was deposited as outwash and lacustrine deposits in pro-glacial lakes produced by the advancing Kansan glacier. As the ice moved across an uneven topography it later overrode these associated water-laid de-

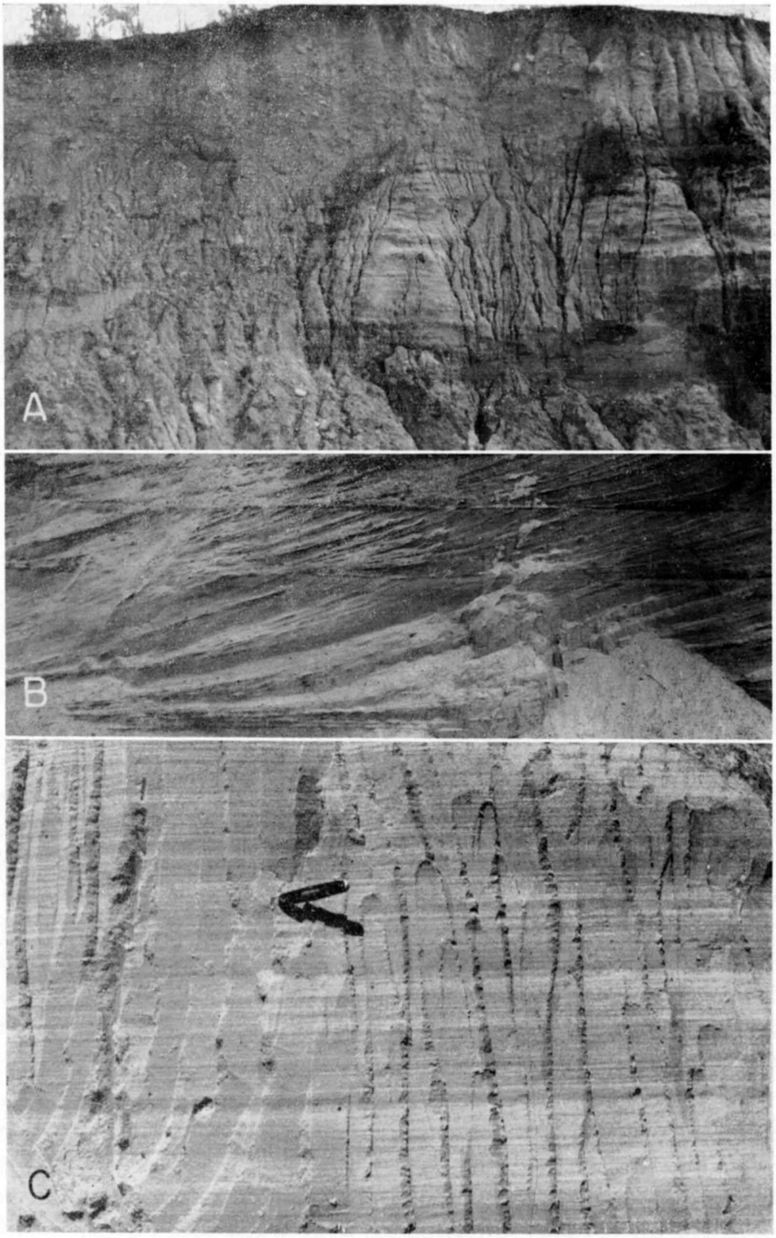

Plate 4. **Atchison formation. A,** Type section of Atchison formation, Kansas till at top of exposure; SE¼ SW¼ sec. 2, T. 6 S., R. 20 E., Atchison County. (1951.) **B,** Cross-bedded sand and gravel in lower part of Atchison formation, location of A. (1951.) **C,** Laminated fine sand of Atchison formation exposed in creek bank; Kansas till in adjacent exposures; Cen. E. line sec. 13, T. 5 S., R. 10 E., Marshall County. (1951.)

posits. At a few localities, exposures are adequate to show the effect of scour of these soft deposits by the overriding glacier and to demonstrate incorporation of Atchison sands as blocks and streamers in the overlying till (Pl. 5).

Exposures of the Atchison formation are not numerous. The formation is well exposed in the vicinity of the City of Atchison; in Marshall County (Cen. E. line sec. 13, T. 5 S., R. 10 E.; Cen. E. line sec. 13, T. 4 S., R. 10 E.; NW¼ SE¼ sec. 21, T. 3 S., R. 9 E.); and along the Menoken terrace of the central Kansas River Valley (Davis, 1951; Davis and Carlson, 1952). However, subsurface data indicate that the formation has considerable extent as the lower part of the fill in a pre-Kansan valley that extends from southeastern Marshall County, across southern Nemaha County (where it is overlain by as much as 300 feet of Kansas till), northeastern Jackson County, and central Atchison County (Frye and Walters, 1950). This extensive buried valley, which occurs under a present divide area, is judged to have been cut by a stream localized near the southern margin of the Nebraskan glacier and to have formed a basin of temporary pro-glacial lakes as the Kansan glacier advanced diagonally across it.

Age and correlation.—The Atchison formation is by definition pro-glacial outwash and therefore is a stratigraphic unit of different ages at different places. As the Kansan glacier advanced pro-glacial lakes were formed and overridden, and other lakes were formed. Therefore, the Atchison at the type locality may be in its entirety slightly older than the formation where it is exposed in Marshall County and in the central Kaw Valley. In areas at the margin of the glacier the Atchison formation may be inseparable from the earliest phase of retreatal Kansan outwash.

In the plains region of Nebraska beyond the glacial limit, deposits assigned an early Kansan age and approximately equivalent to the Atchison formation have been called the Red Cloud formation (Schultz, Reed, and Lugn, 1951, pp. 547-549; Schultz, Lueninghoener, and Frankforter, 1951). It is named from exposures in Red Cloud Township, E½ sec. 28, T. 2 N., R. 11 W., Webster County, Nebraska. Although at a few localities in central and western Kansas local deposits may be comparable to the Red Cloud of Nebraska, as yet no deposit in Kansas has been firmly correlated with this Nebraska formation. Deposits of questionable correlation have been classed with the Grand Island member of the Meade formation.

The age assignment of the Atchison formation to early Kansan is based on (1) its interfingering relationship to the overlying Kansas till, (2) the universal lack of evidence of weathering in its upper part, (3) its lacustrine bedding and sorting, (4) its merging with retreatal outwash in marginal areas, (5) its lithologic similarity to water-laid material interstratified with the till near the margin, (6) its common occurrence on low bedrock below the expected position of Nebraska till, and (7) the questionable occurrence of eroded Nebraska till below the Atchison deposits at one locality in Atchison County.

KANSAS TILL

Definition.—The name Kansan drift was first applied by Chamberlin (1894, 1895) to the lower of the two tills in the vicinity of Afton Junction, Union County, Iowa. Subsequent work by Bain (1897) showed the upper rather than the lower of the two tills in the Union County area to be the one that extends southwestward and forms the surface till of northeastern Kansas. Chamberlin later (1896) transposed the name Kansan drift to the upper till. Although the original description of this formation was based on exposures in southern Iowa, the transposition of the name clearly implies that the surface drift of northeastern Kansas is the type for the unit.

Kansas till, as here used as a stratigraphic unit of formation rank, includes the deposits made directly by the Kansan glacier and some water-laid sediments interstratified with the till. It does not, however, include the pro-glacial silts, sands, and gravels deposited in front of the advancing glacier (Atchison formation) or the outwash deposits from the retreating glacier (Meade formation). A type locality within Kansas has not been specified for the Kansas till and the erection of a type section seems unnecessary after more than 50 years of acceptance of the unit. Appropriate sections of reference within the type area may be considered as the exposures in cut banks approximately one-half mile southwest of the type locality of the Atchison formation (Pl. 5), exposures north of Atchison along the Missouri Valley bluffs (Todd, 1920), and the Iowa Point section in Doniphan County.

PLATE 5. **Kansas till southwest of Atchison, Kansas. A** and **B,** Exposures in the NE¼ sec. 10, T. 6 S., R. 20 E., Atchison County, west of type section of Atchison formation. The blue-gray Kansas till is quite uneven in texture and contains contorted "streamers" and "blocks" of well-sorted tan sand and silt, judged to have been derived from the plowing of the underlying Atchison formation by the overriding Kansan glacier. (1951.)

Character and distribution.—Kansas till occurs in the State over much of the area north of Kansas River and east of Little Blue River (Pl. 1). Here, Kansas till, which constitutes the predominant surface material, is extensively exposed in road cuts and natural exposures, except in the parts of Brown and Doniphan Counties where it is mantled with thick loess. In the part of the area eastward from central Marshall County and eastern Pottawatomie County little bedrock is exposed and the till is as much as 300 feet thick (Frye and Walters, 1950). At a few localities the Kansas till and the Atchison formation have a combined thickness of approximately 400 feet (Pl. 2).

The area of thick Kansas till terminates abruptly toward the west some distance within the glacial boundary. The deep accumulations of Kansas till are judged to have been importantly influenced by the bedrock surface over which the glacier advanced. A pronounced bedrock sag extends eastward across southeastern Marshall County, southern Nemaha County, northeastern Jackson County, and west-central Atchison County. This bedrock sag, generally containing Atchison formation sands and silts in the bottom and buried beneath the thickest Kansas till in the State, is now a general divide area. Another striking discontinuity in thickness occurs at the eastern scarp of resistant lower Permian limestones in Marshall County and eastern Pottawatomie County. The flat upland divides of north-central Pottawatomie County are mantled locally with 5 to 50 feet of till (for example, NE¼ NE¼ sec. 11, T. 7 S., R. 8 E.) consisting of a rubble of locally derived chert in the lower part (Pl. 6B) resting directly on bedrock, whereas to the north and east till thicknesses on lower bedrock beyond the east-facing scarp are generally from 100 to 200 feet. In northeastern Pottawatomie County thick till is "banked" against the east-northeast face of such a scarp whereas the upland flat west of the scarp is only thinly veneered with till.

Westward from central Marshall County, Kansas till is also generally thin and discontinuous. It is exposed west of Little Blue River Valley on the uplands (NW¼ NW¼ sec. 32, T. 3 S., R. 5 E.; SE¼ SW¼ sec. 13, T. 4 S., R. 4 E.) in Washington County. Near the Nebraska state line the westernmost exposure of Kansas till in the State occurs in road cuts in the SE cor. sec. 10 and the SW cor. sec. 11, T. 1 S., R. 4 E., Washington County. Here the till, which overlies sand, silt, and gravel that rests on Permian shale, is interstratified with sand and gravel. The upper part of the deposit contains boulders more than 2½ feet in diameter.

Southward from northern Jackson County the Kansas till thins toward the Kaw Valley and at many places along the north valley wall has been removed by erosion. A particularly important area for correlation purposes is north-central Shawnee County. Here the Kansas till forms a continuous mantle from the uplands down the valley side where it interfingers with the water-laid deposits of the Menoken (Kansan) terrace of the Kansas River Valley (well exposed in gravel pit in the SW¼ sec. 9, T. 11 S., R. 15 E.).

Exposures of Kansas till south of Kansas River are rare and the till that occurs on the uplands is thin and discontinuous (Pl. 1). At a few places in northern Wabaunsee County and northwestern Shawnee County there are surface concentrations of glacial boulders, but inconclusive evidence indicates that the till, nevertheless, is relatively thin.

Lithologically, the Kansas till is quite similar to the Nebraska till. It ranges from coarse bouldery till to clayey till with dispersed pebbles. Davis (1951) in the course of his studies of the lithology of various sand and gravel deposits in northeastern Kansas, analyzed the 4 to 8 mm size fraction of the Kansas till. He made the following statement as a result of this study (Davis, 1951, pp. 183, 187):

> The coarser fraction was washed from four samples of unleached till and one sample of highly weathered till. One count was made of boulders which had been washed by rain from unleached till in an old gravel pit. The lithology of rock fragments in the till varies considerably; however, all unleached samples retained the same general characteristics. Fragments of pebble size and larger constitute less than 5 percent of the volume of the samples. The limestone group is the dominant constituent in the sizes investigated and the shale-sandstone group is next in abundance in the smaller fractions. The total amount of locally derived rocks in the unleached till is in excess of 70 percent. A diagnostic feature of the 4 to 8 mm size pebbles in glacial till and outwash is that the granitic group and the combined dark igneous, miscellaneous metamorphics, and pink quartzite groups occur in roughly equal abundance.

On the basis of 61 pebble analyses from 29 localities in northeastern Kansas Davis was able to recognize significant differ-

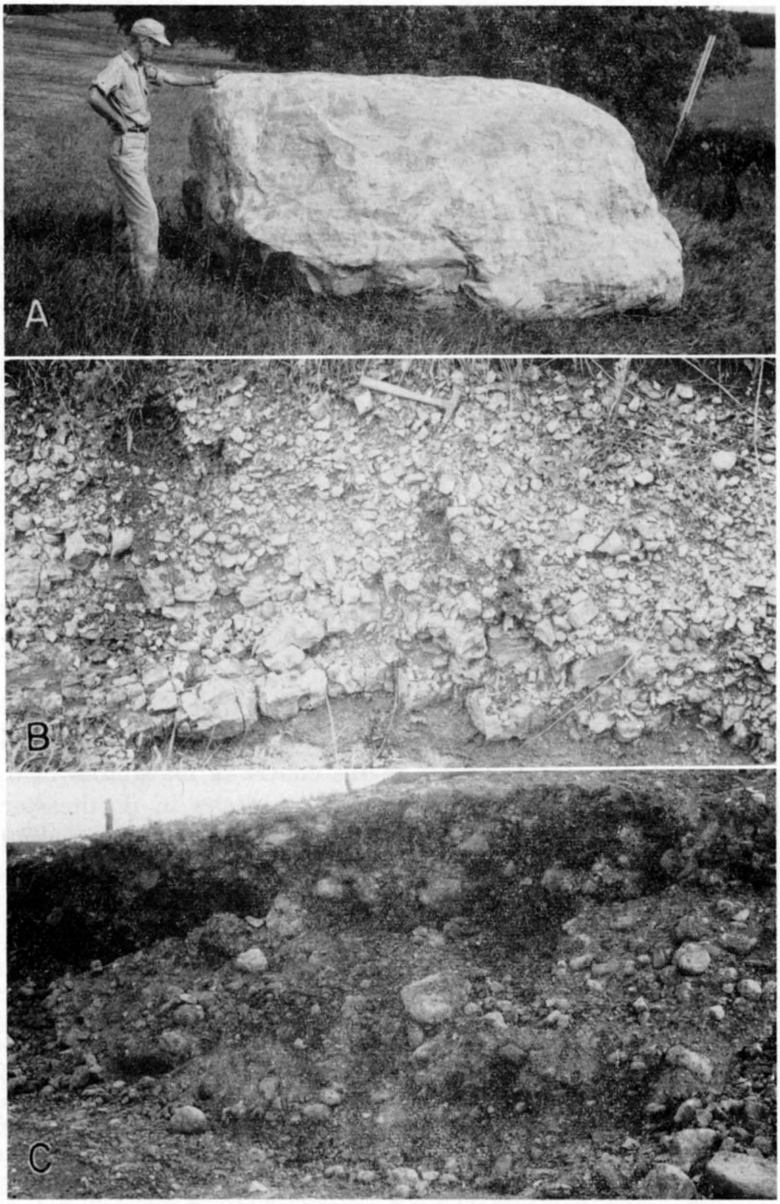

PLATE 6. **Kansan deposits in northeastern Kansas. A,** Large boulder of pink quartzite from excavation in Kansas till; sec. 33, T. 3 S., R. 9 E., Marshall County. (1951.) **B,** Chert rubble in base of Kansas till on upland in NE¼ NE¼ sec. 11, T. 7 S., R. 8 E., Pottawatomie County. Till rests on Florence flint. (1951.) **C,** Kansan outwash (Meade formation) exposed in gravel pit east of Big Blue River Valley; SW¼ SE¼ sec. 16, T. 3 S., R. 7 E., Marshall County. (1951.)

ences in deposits derived from several sources. He stated the following conclusions (Davis, 1951, p. 191):

> Gravel lithology in eastern Kansas varies systematically with the mean diameter of the gravel; therefore, studies of gravel lithology must utilize carefully sized material to obtain the most satisfactory results.
>
> The four most significant gravel types studied were pre-glacial gravel, glacial outwash gravel of Kansan age, gravel from Kansas till, and gravel of Illinoian to Recent age which was transported by Kansas River. The unleached pre-glacial gravel is characterized by a predominance of chert and limestone with lesser amounts of limonite, siltstone, and sandstone. Gravel in unleached Kansas till and in the unleached outwash associated with the till varies considerably in lithology from one locality to the next. However, both retain the following characteristics in the 4 to 8 mm grade size: (a) more than 70 percent of the pebbles are derived from local rocks; (b) limestone is the most abundant rock; (c) granitic rocks are the most abundant erratics; (d) pink quartzite constitutes less than 2 percent of the sample; and (e) the granitic group approximately equals in abundance the combined pink quartzite, miscellaneous metamorphics, and dark igneous groups.
>
> Gravel transported by Kansas River has the following characteristics: (a) the dominating lithologic group in grade sizes larger than 16 mm is chert; (b) the granitic group is dominant in grade sizes between 2 and 8 mm and reaches a maximum of about 60 percent of the sample in the grade size between 4 and 8 mm; and (c) igneous and metamorphic rocks exclusive of the granitic group do not constitute more than 6 percent of any sample.
>
> It is certain that the high percentage of granitic rock in post-Kansan sediments is due not to the introduction of glacial detritus but to the introduction of detritus from the Ogallala formation of western Kansas and southwestern Nebraska. This introduction of Ogallala detritus was initiated by drainage basin enlargements associated with the Kansan glaciation.

Although constituting a relatively minor part of the till volumetrically, pink quartzite resembling the Sioux quartzite of South Dakota is perhaps the most distinctive "marker stone" of the glacial deposits. The pink quartzite fragments are commonly of cobble to boulder size and some very large ones have been observed in areas near the glacial margin (Pl. 6A).

In areas where the Kansas till is thick it is commonly interstratified with sand and gravel deposits as shown by the log of a test hole in Nemaha County, given below. At a few localities (for example, NE¼ NE¼ sec. 14, T. 1 S., R. 10 E., Marshall County; SW¼ NW¼ sec. 27, T. 6 S., R. 14 E., Jackson County, shown in Pl. 7A) water-deposited sand and gravel interstratified with Kansas till is exposed. The sands and gravels at these localities are judged to be deposits of englacial streams or outwash deposited in response to minor oscillations of the ice front. Water-deposited sands of another origin also occur within the body of the Kansas till and are well exposed southwest of the City of Atchison (Pl. 5). Here "streamers," "wedges," and "blocks" of well-sorted sand occur in the till. As the material resembles the subjacent Atchison formation and shows evidence of distortion or movement it is considered to have been incorporated by the overriding glacier from the underlying Atchison deposits.

Kansas till penetrated in test hole drilled by State and Federal Geological Surveys in the NE¼ NW¼ sec. 31, T. 4 S., R. 13 E., Nemaha County, Kansas. Samples studied by Kenneth Walters.

	Thickness, feet	Depth, feet
QUATERNARY—Pleistocene		
Kansas till (Kansan Stage)		
Clay, silty, noncalcareous, light-gray	6	6
Clay, silty, noncalcareous, gray mottled with black	7	13
Clay, silty, highly calcareous, gray and tan; contains a few caliche nodules	4	17
Clay, silty, with a small amount of sand and gravel, calcareous, tan with reddish-tan	46	63
Clay, silty, and sand and gravel with pebbles of quartzite, calcareous, tan	9	72
Sand, fine, with some silt and clay, tan	8	80
Silt and clay, sandy, calcareous	5	85
Gravel, coarse to fine; contains chert and dark igneous rocks; quartz sand	15	100
Clay, silty, gravel, and quartzite pebbles, slightly calcareous, tan	10	110
Clay, silty, calcareous, tan	7	117
Clay, silty, gravelly, calcareous, blue-gray	6	123
Sand, medium to coarse, and gravel containing limestone, quartz, and dark igneous grains	7	130
Sand, gravel, and clay, tan, calcareous	5	135
Clay, silty, sand, gravel, and pebbles of limestone, quartz, and igneous rocks	70	205
Gravel, medium to coarse; contains pebbles of pink quartzite, limestone, and dark igneous rocks; some blue calcareous silty clay	10	215
Clay, silty, and gravel of dark igneous rocks and limestone, calcareous, blue-gray	17	232
Gravel, coarse to fine; contains dark igneous rocks and limestone	6	238
Clay, silty, with some medium gravel, calcareous, blue-gray	6	244
Gravel, fine, and silty clay, calcareous, blue-gray	6	250

Clay, silty, with limestone gravel, calcareous, blue-gray	50	300
PENNSYLVANIAN—Virgilian		
Shale, calcareous, blue-gray	10	310
Shale, sandy, calcareous, gray-green	19	329
Limestone, light-gray	1	330

The upper part of the Kansas till is commonly deeply weathered. Test drilling indicates that the depth to which calcium carbonate has been leached from Kansas till varies widely, but commonly does not exceed 10 to 15 feet. At most places the till is oxidized to a tan or brown color at depths considerably below the zone of leaching. A few test holes have penetrated 50 to 60 feet of oxidized till which grades downward into blue-gray unoxidized calcareous till. In many areas where the surface topography is gently rolling and the till is thick, well-developed joint systems occur to considerable depth in the till. These joints commonly have oxidized brown rinds and at many localities a concentration of calcite along the joint (Pl. 7B). This calcium carbonate accumulation has been observed to be as much as 2 inches thick.

Locally at the upland level in southwestern Atchison County, northern Shawnee County, Jefferson County, and Jackson County, a massive clay layer overlies the Kansas till. This clay layer has been informally referred to as the "Nortonville clay" from exposures in the NE¼ sec. 12, T. 7 S., R. 18 E., Atchison County, along road cuts north of the City of Nortonville. At this locality it is a light-gray massive plastic clay nearly 30 feet thick. It rests on oxidized and calcareous till with nodules of caliche and is overlain by a few feet of leached Peoria loess. Although largely noncalcareous to the acid bottle, it contains a few nodules of caliche and some scattered sand grains in the lower part. It is framed stratigraphically between the Kansas till below and the Peoria loess above, and therefore its possible age is late Kansan to Sangamonian. Although its exact age and mode of origin are not known, present data are judged to indicate that these clays were deposited in slight initial depressions on the surface of the newly formed Kansas till plain as the Kansan ice front retreated, and perhaps in some places in ice margin lakes on the flat areas between outwash spillways. Sup-

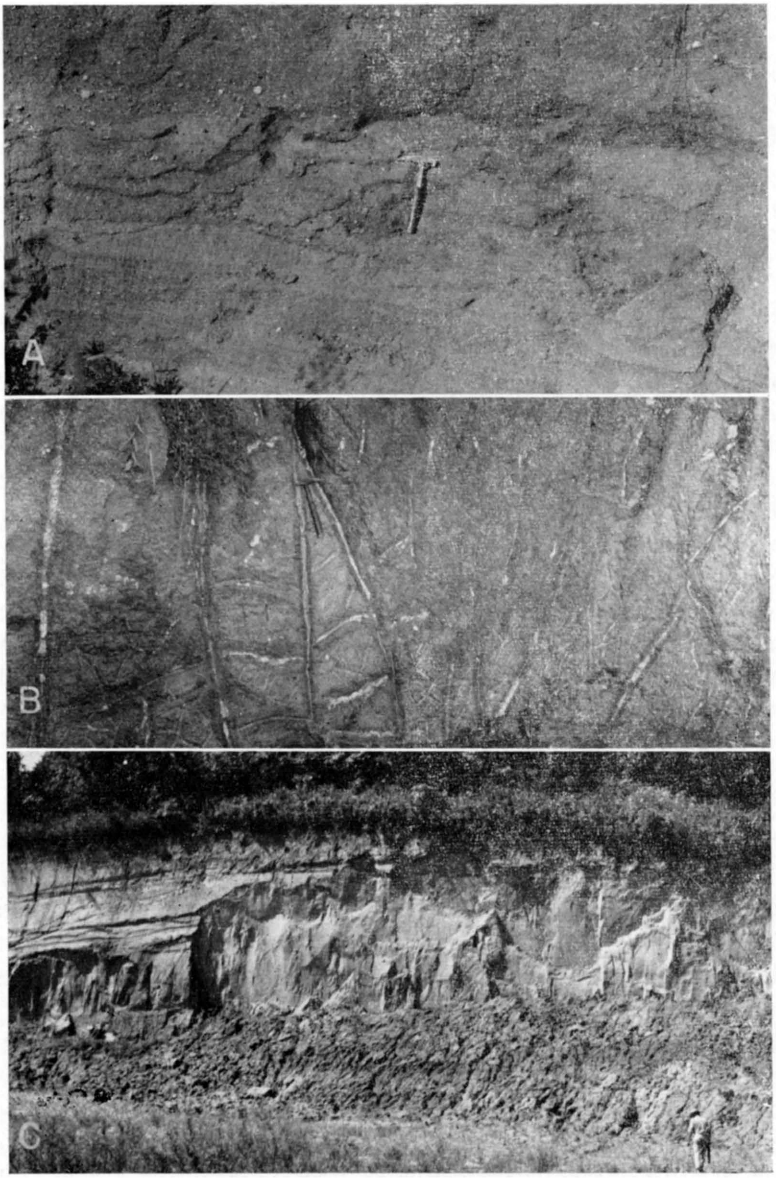

Plate 7. **Pleistocene deposits in northeastern Kansas. A,** Sand and gravel interstratified with Kansas till; SW¼ NW¼ sec. 27, T. 6 S., R. 14 E., Jackson County. (A. R. Leonard, 1949.) **B,** Joints in Kansas till showing oxidized rinds and calcite fillings along joint plane; SW¼ sec. 12, T. 2 S., R. 10 E., Marshall County. (A. R. Leonard, 1949.) **C,** Bignell and Peoria loess of the Sanborn formation, NE¼ SE¼ sec. 7, T. 2 S., R. 20 E., Doniphan County (Iowa Point section). Bignell loess is 35 feet thick, fossiliferous, and rests on deep Brady soil developed in top of Peoria loess near base of exposure. (1948.)

porting evidence for such an origin consists of its restriction to upland positions where the till plain is not deeply dissected, its unusually high clay content, and the absence of a fully developed soil profile on the till below the clay. Other suggested origins include the alteration of a layer of Loveland loess or solfluction deposits of Illinoian age. That it is not a soil gley layer, or gumbotil, which it superfically resembles, is demonstrated by its relation to the underlying till and the absence of resistant pebbles, common in the till.

It is probable that the "Nortonville clay" of northeastern Kansas is comparable to the material which occurs in a similar stratigraphic position in northern Missouri and was called "gumbotil" by Krusekopf (1948, pp. 413-414). He has described these Missouri clay deposits and it has been demonstrated (YiHseung, Marshall, and Krusekopf, 1950) that they cannot be accounted for by soil-forming processes, but, by referring to them as "gumbotil" he has further confused the meaning of that term. As gumbotil is used by some workers in a genetic sense to apply to humic-gley soils or Planosols (for example the Afton soil at the Iowa Point section) and by others in an objective lithologic sense applying to sediments of diverse origins, the term is not generally used in Kansas literature.

Age and correlation.—Kansas till has been generally accepted as type for the Kansan Age, the second glacial episode of the Pleistocene. The equivalence of deposits classed as Kansas till in Kansas with similarly named deposits in Nebraska and Iowa has been demonstrated by (1) tracing and (2) stratigraphic sequence. This stratigraphic unit was first traced southward from the Union County, Iowa, localities by Bain (1897) and has been traced extensively in Iowa (Kay and Apfel, 1929), Nebraska (Lugn, 1935; Condra and Reed, 1950), and by test drilling in northeastern Kansas (Frye and Walters, 1950). The second line of evidence is that those workers in Nebraska and Iowa have demonstrated, by delineating the southern limits of younger glacial deposits, that only the Nebraskan and Kansan glaciers could have extended as far south as Kansas. Therefore the conclusive evidence in Doniphan County, Kansas (the Iowa Point section, Frye and A. B. Leonard, 1949) of two tills separated by a significant weathering interval requires the correlation of the upper of these two tills with the Kansas till at localities to the north. Although molluscan faunas have not been obtained from Kansas till in the area north and east of Kansas, large faunas have been obtained from water-deposited sediments, locally associated with volcanic ash, framed between tills, and molluscan fossils have been obtained from the basal part of the Kansas till in Kansas.

The precise placement of various deposits of Kansas till within the span of the Kansan Age is difficult. Till, as a direct deposit from glacial ice, obviously cannot be laid down at a given spot before the ice front has reached it; also, as the ice front retreats, if it remains active, it will continue the deposition of till. Therefore the deposits of the Atchison formation (pro-Kansan) in Marshall County and along the central Kaw Valley may be wholly younger than type Atchison and the same age as the Kansas till that overlies type Atchison. Also, the earliest outwash deposits from the retreating Kansan glacier near its maximum extent are older than till made at the retreating ice front as it withdrew from Kansas.

MEADE FORMATION

Definition and subdivisions.—The Meade formation was described in 1941 by Frye and Hibbard (p. 411) and the type locality specified as the Pleistocene strata overlying the Ogallala formation in sec. 21, T. 33 S., R. 28 W., Meade County, Kansas (section published by Frye, 1942, p. 98). This locality has been restudied and a measured section is given below. The name "Meade gravels" was proposed by Cragin in 1896 (p. 52) for fossiliferous gravels in central Meade County. Although the unit was inadequately defined, a type locality was not clearly specified and a measured section was not given, it is judged that Cragin's Meade gravels correspond to the Grand Island member of the Meade formation of present classification of the Kansas Geological Survey because Cragin stated that his "Meade gravels" were overlain by the Pearlette volcanic ash, with which they were frequently gradational, and that the gravels were equivalent to the Tule division of Cummings (in Texas). Only the Grand Island member satisfies these requirements. In 1949 Hibbard (1949b, p. 70) proposed that the beds at the type locality of the Meade formation be renamed the "Crooked Creek formation" and that the name "Meade formation" (Hibbard, 1949b, p. 66) be applied to deposits in the NW¼ sec. 13, T. 30 S., R. 23 W., Clark County (about 35 miles east-northeast from Meade), and to beds exposed along Spring Creek Valley west of Meade, classed here as Blanco formation.

In 1941 (Frye and Hibbard, p. 411) deposits younger than those exposed at the type section were included within the Meade formation, an expedient which was defended (Frye, 1942) as an aid to mapping on conventional map scales. Frye, Swineford, and Leonard (1948, p. 521) restricted the span of the Meade

Meade formation, type locality, in the SE¼ NE¼ NE¼ sec. 21, T. 33 S., R. 28 W., Meade County, Kansas. Measured in canyons south of State Highway 98 and east of Crooked Creek, August 9, 1951.

	Thickness, feet
QUATERNARY—Pleistocene	
Meade formation (Kansan Stage)	
Sappa member	
13. Sand with some silt, pale yellowish-brown (10YR6/2) to moderate yellow. Abundant large hard caliche nodules. Exposed to top of east valley wall of Crooked Creek at upland level	5.0
12. Sand, fine, and silt, massive, pale yellowish - brown (10YR6/2) to moderate yellowish-brown (10YR5/4). Caliche throughout, more abundant at top, nodules range up to 1 foot in diameter	7.0
11. Silt and fine sand, pale olive (10Y6/2), caliche concentration at top and a few small caliche nodules throughout	6.0
10. Silt and fine sand, pale yellowish-brown (10YR6/2) with scattered caliche nodules. Stratigraphic position of the Borchers vertebrate fauna	2.0
9. Silt and clay, pale olive (10Y6/2) to yellowish-gray (10Y7/2); a few caliche nodules near top	5.5
8. Volcanic ash, **Pearlette bed**, weathered, yellowish-gray ((5Y7/2) with yellowish mottling. In adjacent canyons the ash is fresh and displays the petrographic characters typical of the Pearlette bed. In commercial ash mines both north and south of this locality the Cudahy vertebrate fauna and a large molluscan fauna have been obtained from the beds immediately below the ash; at some localities fossil snail shells occur within the ash	6.0
7. Sand with some silt, massive and free of caliche, pale olive (10Y6/2) slightly mottled with yellow	3.5
6. Silt, sand, and clay, grayish-olive (10Y4/2), mottled with yellowish; caliche nodules disseminated throughout and coalesced into a cemented zone at top	5.0
5. Silt, sandy, and clay, dusky-yellow (5Y6/4) with disseminated caliche	1.5
4. Silt, with some sand and clay, light olive-gray (5Y3/2); disseminated caliche nodules	2.5
3. Silt with some sand, clay, and gravel, moderate reddish-brown (5YR4/4), poorly sorted. Contains pebbles up to 1.5 inches in diameter; nodular caliche gives a mottled appearance on weathered surface	8.0

Grand Island member	
2. Sand and gravel, with some fine sand and silt; gravel arkosic, tan, grades into well-sorted sand and gravel at the base; large pebbles exceed 2 inches in diameter; small scattered caliche nodules in the upper part. Erosional unconformity at base	10.4
Total thickness of Meade formation	62.4
TERTIARY—Pliocene	
Ogallala formation	
1. Silt and sand, pinkish-tan, unevenly cemented with calcium carbonate and containing large caliche nodules; contains a few *Biorbia fossilia* seeds. Lower part is cross-bedded sand, gravel, and cobbles exposed to the level of Crooked Creek. Test hole penetrated Permian redbeds 17 feet below base of exposure on east side of Crooked Creek.	
Total thickness of Ogallala formation	84.0

formation to that represented by the beds at the type section. This restricted definition of the Meade has been accepted by the Kansas Geological Survey and is standard usage in all official reports (Moore and others, 1951, pp. 14-16). The name is used throughout Kansas and includes retreatal Kansan outwash in the glaciated area. Deposits equivalent to the Meade formation have been correlated from western Texas across western Oklahoma, Kansas, Nebraska, and into southeastern South Dakota and western Iowa (Frye, Swineford, and Leonard, 1948).

In Kansas and generally throughout the Great Plains and central Missouri Valley region, deposits correlated with the Meade formation are coarse-textured in the lower part and grade upward into finer textured clastics. Lenticular deposits of volcanic ash occur within the formation at many localities. Although the strata comprising the Meade formation are conformable throughout, these contrasting lithologies merit recognition as named subdivisions. In Nebraska, equivalent deposits are classed as Grand Island and Sappa formations and these names have been adopted in Kansas to designate members within the Meade formation.

The Grand Island formation in Nebraska was described by Lugn in 1935, and named for a type section in the Platte River bluffs east of Hamilton bridge and in the Platte River Valley southeast of Grand Island, Hall County, Nebraska (Lugn, 1935, pp. 106, 107). Lugn (1935, p. 103) stated concerning the Grand Island: "It is the inwash-outwash equivalent of the Kansan till and the early Kansan inter-till sands and gravels of eastern Nebraska.

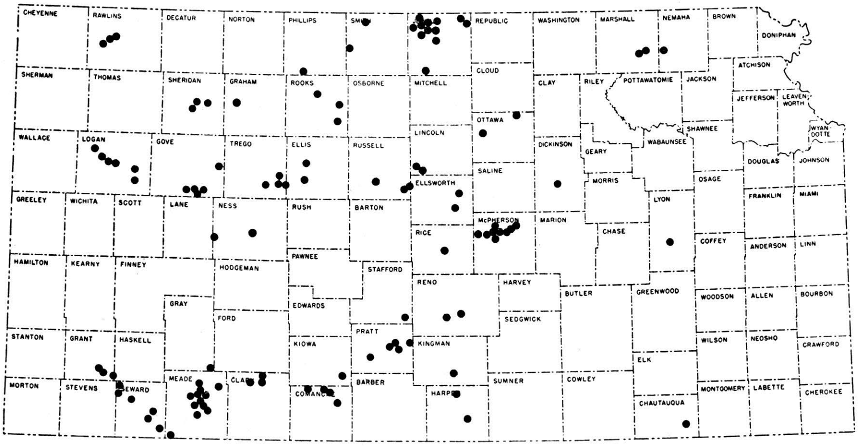

FIG. 3—Map showing distribution in Kansas of the principal deposits of Pearlette volcanic ash. All known deposits of volcanic ash in Kansas are listed by Carey and others (1952).

It ranges in thickness from 30 to perhaps 150 feet, but averages about 75 feet."

The Sappa formation in Nebraska was named by Condra and Reed (1950, p. 22) from exposures in the abandoned volcanic ash mine of the Cudahy Packing Company near Orleans in Sappa Township, Harlan County, Nebraska. The name was proposed as a direct replacement for the name Upland formation of Lugn (1935, p. 119), which prior to 1948 was in general use to designate these deposits. The type locality of Lugn's Upland formation is along West Branch Thompson Creek about 2½ miles west of the town of Upland in Franklin County, Nebraska. Lugn (1935, p. 119) considered the Upland to be Yarmouthian in age but Condra and Reed (1950, p. 12) correlate the Sappa formation as late Kansan. The Sappa member was described in Kansas by Frye, Swineford, and Leonard (1948).

The Pearlette volcanic ash bed (Pl. 8) occurs as lentils within the Sappa member. The name Pearlette was proposed by Cragin in 1896 from outcrops in the vicinity of the long abandoned Pearlette post office, Meade County, Kansas. The Pearlette bed (Fig. 3) is present discontinuously in Sappa member, Tule formation, and equivalent beds in Texas, Colorado, Oklahoma, Kansas, Nebraska, Missouri, Iowa, and South Dakota. The ash

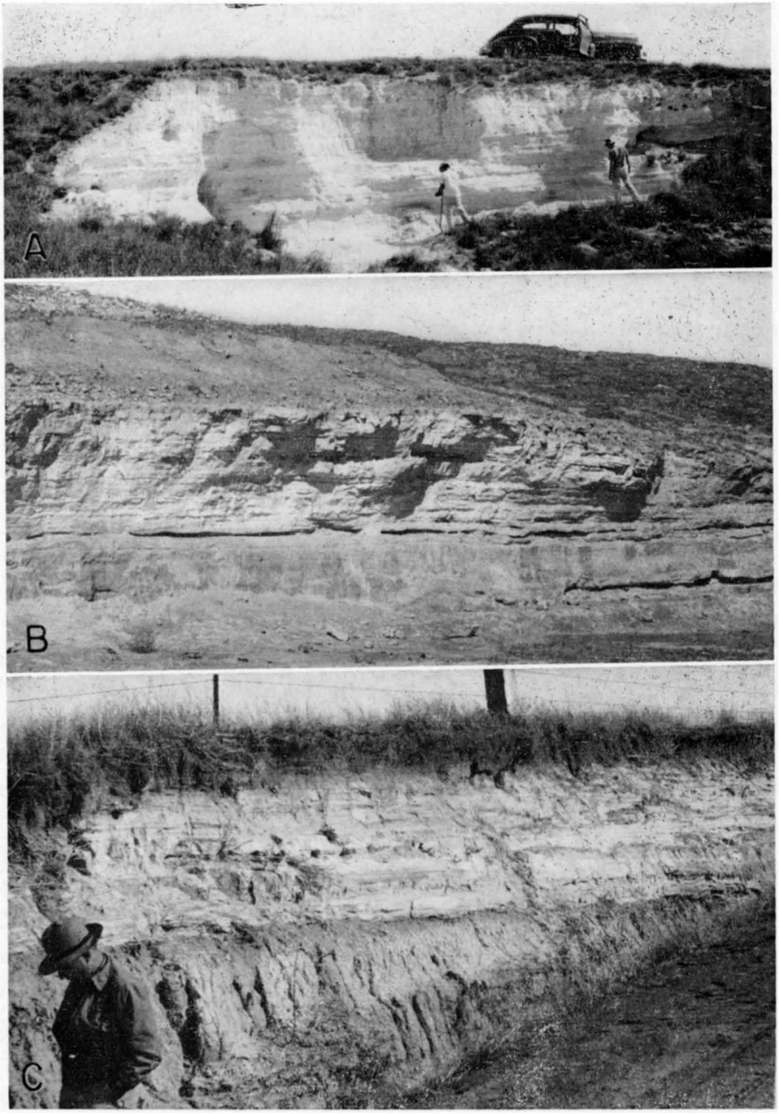

PLATE 8. **Pearlette volcanic ash. A,** Pit in Pearlette ash in the NE¼ SW¼ sec. 21, T. 13 S., R. 26 W., Gove County. Beds immediately below the ash yielded large molluscan fauna. (Norman Plummer, 1948.) **B,** Pit in Pearlette ash in the NW¼ sec. 34, T. 8 S., R. 23 W., Sheridan County. Maximum thickness of ash is 16 feet. (1951.) **C,** Pearlette ash in road cut in the NW¼ SW¼ sec. 27, T. 13 S., R. 10 W., Lincoln County, 7 feet of ash exposed. Large molluscan fauna (Wilson Valley faunule) and fossil vertebrates were collected from beds at the base. (1951.)

is judged to have been derived from a source in north-central New Mexico (Swineford, 1949). Its petrographic character has been studied (Swineford and Frye, 1946; Carey and others, 1952) and it has been correlated throughout most of the area of its occurrence (Frye, Swineford, and Leonard, 1948). The distinctive petrographic characters of the Pearlette volcanic ash have been described as follows (Frye, Swineford, and Leonard, 1948, p. 513):

> 1. The color includes certain light shades of orange-yellow, which are not characteristic of fresh ash described from the Pliocene (Calvert mine).
> 2. The refractive index is consistently 1.499-1.501.
> 3. The shape of the shards is characteristically sharply curved, with thickened glass at the bubble junctures, which are commonly curved and branching at wide angles. Fibrous shards are present in all samples.
> 4. Many shards have groups or clusters of elongate vesicles which are seldom found in ash of Pliocene age.
> 5. The percentage of iron oxide is less than 2 as shown by eight of nine chemical analyses, with a range from 1.43 to 2.07 per cent....
> 6. The specific gravity ranges from 2.21 to 2.32....

Character and distribution.—In Kansas the Meade formation occurs extensively as abandoned valley fillings in the southwestern and central areas, as chert gravel terraces in the east-central area, and as outwash terrace deposits along the Kansas, Blue, Little Blue, and other river valleys in the northeastern glaciated area. In north-central and northwestern Kansas the Meade formation occurs as discontinuous terrace remnants along several valleys but is quantitatively of minor importance (Pl. 1).

In the east-central area the Meade formation has been studied in detail only along the Neosho-Cottonwood Valley. In this important valley, Meade formation constitutes much of the fill under the Emporia terrace (Moore, Jewett, and O'Connor, 1951) which occurs almost continuously from Chase County southward to the Oklahoma state line. Along this valley the Emporia terrace surface has a height of 25 to 40 feet above the adjacent flood plain, but 40 feet is probably the more typical height. The formation here consists of chert gravels with some sand and beds of silt in the lower part (Pl. 9B) overlain by silts and sandy silts. At several places, for example the cuts along U.S. 50S west of Emporia, a well-developed soil overlain by a few feet of Peoria loess occurs in the upper part of the terrace silts. A distinctive lithologic element is the presence of Pearlette volcanic ash (Frye, Swineford, and Leonard, 1948) in the terrace deposits within the city limits of Emporia. In the east-central part of the State the Meade formation, except for a small percentage of limestone pebbles in the lower part and a lower percentage of red clay matrix in the upper part, is lithologically indistinguishable from the older chert gravel terrace deposits. It is recognized and traced by its physiographic position and dated by the contained Pearlette volcanic ash bed.

In other valleys of eastern Kansas chert gravel terraces in a comparable topographic position may be late Kansan in age and equivalent to the Emporia terrace. In Elk River Valley terrace remnants 20 to 30 feet above flood plain have been observed at Langdon and Howard in Elk County. Other possible equivalents were examined at Cen. E. line sec. 15, T. 20 S., R. 17 E. and in the SW¼ sec. 1, T. 22 S., R. 11 E., Greenwood County, where the gravels are relatively near their source and angular pebbles predominate.

In northeastern Kansas the Grand Island gravels present a striking contrast in lithology with the chert gravels of the Emporia terrace. In the northeastern area the Grand Island gravels are outwash valley train deposits derived from the retreating Kansan glacier. They consist of cobbles (up to 18 inches in diameter) of limestone, igneous and dark metamorphic rocks, and pink quartzite (Pl. 6A, 6C). In the central Kansas River Valley where the Meade formation underlies the surface of the extensive dissected remnants of the Menoken terrace (Davis and Carlson, 1952) the relation of the Grand Island gravels to Kansas till is clearly demonstrated by the interfingering of till with the lower part of the gravels (for example, SW¼ sec. 9, T. 11 S., R. 15 E., Shawnee County). This terrace, where it has been studied eastward from Topeka, stands approximately 80 feet above Kansas River flood plain and has a bedrock floor approximately 20 feet above the flood plain. A terrace equivalent to the Menoken has not been recognized in the Missouri River Valley of northeastern Kansas.

Grand Island outwash gravels are extensive and well exposed along the valleys of the Big and Little Blue Rivers and Mill Creek in Marshall and Washington Counties. The earliest outwash deposition in this region is judged to have occurred when the Kansan glacier stood across the Big Blue River Valley. This is indicated by the occurrence of coarse gravels containing quartzite and other glacial rock types on the uplands west of the valley (SW¼ SE¼ sec. 25, T. 3 S., R. 5 E.; NW¼ NW¼ sec. 16, T. 4 S., R. 4 E., Washington County) and along Mill Creek Valley (pits southeast of the City of Washington). The topographic position of these deposits is markedly higher than the prominent outwash terrace along the valleys of Little and Big Blue Rivers which represent a later phase of Kansas outwash after the glacier had retreated from its maximum extent. The Grand Island outwash gravels along these present valleys are relatively well sorted, contain boulders (Pl. 6C) in the lower part but grade upward through well-sorted sand and gravel to a silty sand zone at the top, and attain a thickness of more than 50 feet. These gravels are well exposed in pits at the following localities: SW¼ SE¼ sec. 16, T. 3 S., R. 7 E.; SE cor. sec. 16, T. 4 S., R. 7 E.; NE¼ NW¼ sec. 30, T. 4 S., R. 7 E., Marshall County; NE cor. sec. 18, T. 3 S., R. 5 E., Washington County.

West of Washington County in northern Kansas, Kansan outwash (Meade formation) fills an abandoned valley that enters the Republican River Valley in northern Republic County, and some deposits of Meade formation in adjacent Jewell County may be outwash that was carried across the site of the present Republican Valley. The filling of the abandoned valley in northern Republic County was formerly called the Belleville formation (Wing, 1930; Fishel, 1948). Although it is probable that this outwash spillway from the Kansan ice front extended down the Republican River Valley, the deposits have not been traced through this area.

Within the area thickly mantled with Kansas till, few exposures of outwash gravels have been observed. Outwash deposits have been studied along the valley of Vermillion River, particularly west of Frankfort (Marshall County) where Pearlette volcanic ash occurs in the upper (fine sand and silt) part of the deposit, and in road cuts and a small pit in the NW¼ sec. 31, T. 2 S., R. 13 E., Nemaha County.

Westward into central Kansas along the Kansas-Smoky Hill Valley, evidence concerning the Grand Island gravels is fragmentary. Southwest of Junction City sand and gravel with a lithology consistent with outwash rests on relatively high bedrock at a position only slightly below the upland level. As these

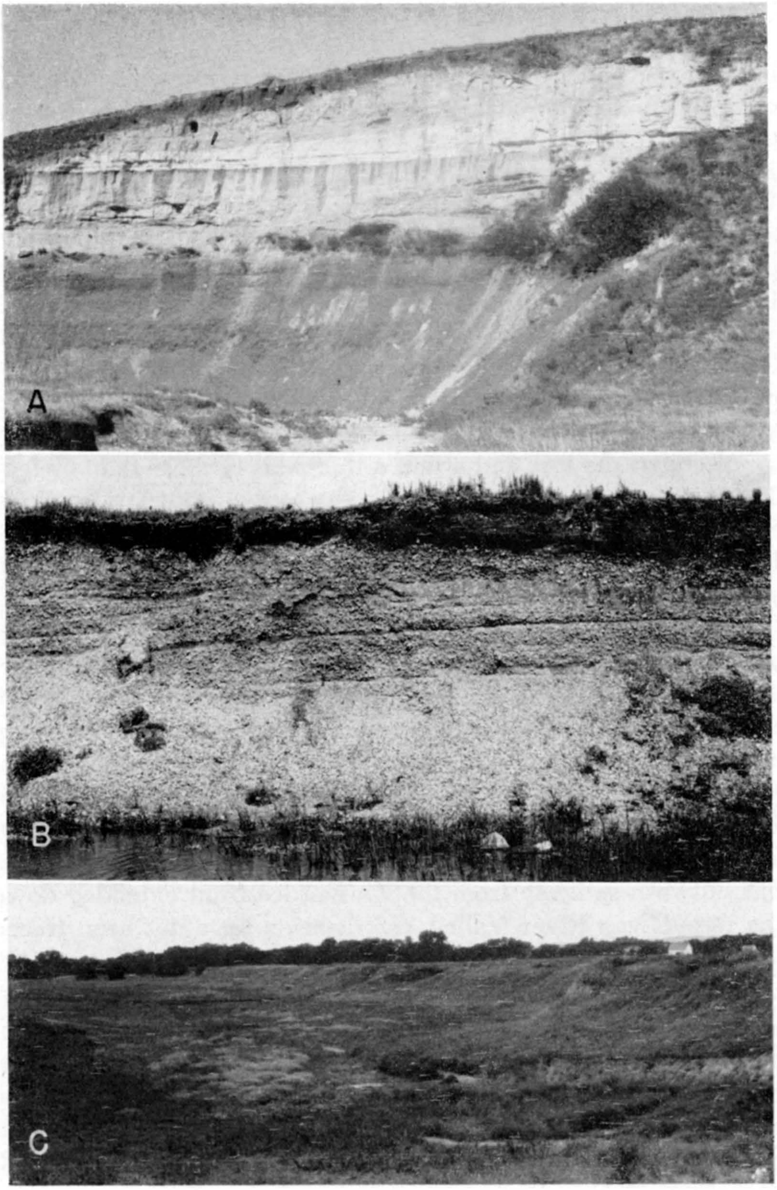

PLATE 9. Terraces and terrace deposits. A, Meade formation, Grand Island member, overlain by Sappa member including Pearlette volcanic ash, with thin veneer of Crete gravels forming surface of Pfeifer terrace of Smoky Hill River Valley. Meade formation rests on Carlile shale (Cretaceous). NE¼ SE¼ sec. 28, T. 14 S., R. 21 W., Trego County. (1950.) **B,** Chert gravel assigned to Grand Island member, Meade formation, in pit in the Emporia terrace of Cottonwood River Valley. Terrace surface is approximately 35 feet above the level

sands and gravels on the north side of the valley are at a markedly higher position than the top of a terrace remnant, which is Illinoian in age, on the south side of the valley, they are judged to be Kansan outwash deposited by a westward-flowing drainageway at the time of maximum extent of the Kansan glacier. At the time of maximum glacial advance all possible courses to the east were blocked by ice, and as deposits along all valleys south of the present Kansas River divide and east of the Flint Hills crest contain deposits which conclusively deny the presence of outwash, glacial drainage, at least for a time, must have gone southwest and south through then existing valleys in central Kansas.

The approximate position of the floors of late Kansan valleys in the area south of Abilene, Dickinson County, is indicated by a small terrace remnant along Turkey Creek Valley (SW¼ sec. 35, T. 14 S., R. 2 E.). Here Pearlette volcanic ash and a large snail fauna in the upper part of gravels and sand rest on bedrock significantly above the adjacent low terrace. As this drainage is from the south, the gravels consist predominantly of Permian and Cretaceous rocks and do not reflect an outwash source, even though the depositing stream joined an outwash-carrying valley. Sands and gravels that occur in a comparable terrace position, masked partly by sand dunes, on the north side of Smoky Hill Valley in this area may be Kansan outwash (Grand Island member).

In contrast to the fragmentary record southwestward into the Salina area, the region to the south and west in central Kansas contains extensive deposits of Meade formation. These deposits occur principally as the fillings of former major valleys abandoned in post-Kansan time, and as dissected high-level valley fillings now under the surface of a prominent terrace along Smoky Hill Valley westward from Marquette. One of the largest of these filled abandoned valleys, called McPherson valley, extends southward under the present Smoky Hill-Arkansas divide through western McPherson County, Harvey and Reno Counties, into Sedgwick County. The character of this valley

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of adjacent flood plain. Cen. sec. 10, T. 19 S., R. 9 E., Chase County. (1950.) C, Scarp of Kirwin terrace on north side of Solomon River Valley; SE¼ sec. 6, T. 6 S., R. 12 W., Osborne County. The Kirwin terrace is comparable to other alluvial terraces (Almena, Newman) of northern Kansas, and the sediments comprising its upper part are latest Wisconsinan to Recent in age. (1950.)

and its contained deposits is known from the records of more than 100 test holes (Lohman and Frye, 1940; Williams and Lohman, 1949) and from the exposures of deposits constituting the fill at their dissected north end in west-central McPherson County. This valley carried southward some outwash from the northeast at the time of the Kansan glacial maximum as well as the drainage of the Smoky Hill basin from the west for a much longer time. The Meade formation in this valley (formerly classed within the broadly inclusive McPherson formation) consists of gravel and sand, attaining a maximum thickness of 100 feet, which grades upward into silt and sand containing Pearlette volcanic ash (Carey and others, 1952) in several exposures.

Deposits of the Meade formation extend southward through McPherson valley, under the Hutchinson dune tract, into the valley of Arkansas River (Pl. 2) where they join (Pl. 1) comparable deposits of Meade formation that constitute the fill of buried valleys extending toward the west and northwest (Fent, 1950, 1950a; O. S. Fent, in preparation*). As the McPherson valley carried the major drainage of the area southward, it was cut below the level of the adjacent Nebraskan Blanco deposits and the Pliocene Ogallala formation (called Delmore formation by Williams and Lohman, 1949) in northern McPherson County. Southward along Arkansas Valley from the junction of McPherson valley with the system of valleys containing Fent's (1950) Chase channel, the topographic position of the Meade formation progressively rises to a high terrace position just north of Ninnescah River Valley west of Arkansas River. Here (sec. 27, T. 30 S., R. 1 E., Sumner County) the Kansan terrace is only slightly below the upland to the northwest which is veneered with Blanco formation.

South of Ninnescah River Valley the Meade formation caps the uplands east of Arkansas Valley. These deposits are largely assignable to the Grand Island member as they consist of gravel and sand (SW¼ NW¼ sec. 36, T. 31 S., R. 1 E.; W½ sec. 1, T. 32 S., R. 1 E.; SE¼ sec. 21, T. 33 S., R. 1 E.; NE¼ NE¼ sec. 36, T. 34 S., R. 2 E., Sumner County) and where exposed in a small abandoned pit in the SW¼ NW¼ sec. 25, T. 34 S., R. 2 E., Sumner County, a heavy soil profile with a reddish B horizon is developed in these slightly arkosic gravels.

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*Indicates study of geology and ground-water resources of Reno County in progress.

On the east side of Arkansas Valley gravels occur in the Cen. W½ sec. 21, T. 34 S., R. 5 E., Cowley County, at approximately the same topographic position with respect to the Arkansas Valley but markedly below the Flint Hills upland several miles farther east. At this locality the lithology of the gravels is typical of those of the Flint Hills. These gravels, containing rocks characteristic of the Permian bedrock in the area north-northeast from where they occur, rest on the eroded surface of the Fort Riley limestone. In spite of their strong lithologic contrast with the gravels west of the Arkansas Valley they are classed as Meade formation because of the similarity of topographic position and because the gravels on the west side of the valley contain a small but persistent percentage of Permian chert pebbles requiring a source east of the present position of Arkansas River Valley. These facts, and the regional relationships, lead to the judgment that the principal southward drainageway across this area in late Kansan time was located west of the present Arkansas River Valley and that it had important tributaries from the northeast which drained the west flank of the Flint Hills uplands area.

In the region of central Kansas along the Arkansas River Valley and in the area to the south included within the great bend of the Arkansas, the Meade formation has its most extensive development in the State. In this area it has been studied by the use of several hundred test holes and logs in Rice (Fent, 1950), Barton and Stafford (Latta, 1950), Reno (O. S. Fent, in preparation), Pratt (D. W. Berry, in preparation*), and Pawnee and Edwards (McLaughlin, 1949) Counties, and its relation to early Pleistocene filled valleys has been discussed by Fent (1950a). Although the Meade formation is generally not well exposed in this area, several good exposures of Pearlette volcanic ash and associated molluscan faunas are afforded by small pits in southwestern Reno County (SE cor. NE¼ sec. 1, T. 25 S., R. 7 W.; SW¼ SE¼ sec. 6, T. 25 S., R. 7 W.). Pearlette volcanic ash has been studied at several localities in Pratt and Kingman Counties (Carey and others, 1952) and has been penetrated in several test holes drilled in Rice County (Fent, 1950). In this area the Meade formation is composed largely of sand and gravel (Grand Island member); it occurs as the lower or intermediate part of the filling of val-

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*Indicates study of geology and ground-water resources of Pratt County in progress.

leys cut in the bedrock (Pls. 1, 2) and in much of the area is overlain by the Illinoian Crete gravels and Wisconsinan dune sand and alluvium.

In the northern part of the Great Bend region the Grand Island gravel member reflects a source in adjacent central Kansas to the northwest. The Grand Island is more arkosic than the older Blanco formation gravels, indicating that during late Kansan time the Ogallala formation was being eroded throughout a more extensive region. In the southern part of this area (Pratt County) the Grand Island has a larger percentage of granitic pebbles than in the north, its lithology approaching that of the late Pleistocene alluvium of the Arkansas River.

In the northern two tiers of Kansas counties west of the influence of outwash from continental glaciation, the Meade formation is known from scattered small deposits. These few localities establish that most of the major valleys of this area formerly contained late Kansan alluvial terraces that have subsequently been largely removed by erosion. In Prairie Dog Creek Valley a remnant of Grand Island gravels, containing a diagnostic molluscan fauna, occurs within the anomalous loop of that stream northwest of Woodruff, Phillips County, and is well exposed in a cut of the C. B. and Q. Railroad (erroneously identified by Frye and A. R. Leonard, 1949, as Crete). Fossiliferous Sappa silts overlying Grand Island gravels are also exposed in a dissected terrace remnant south of Long Island, Phillips County, and at both of these localities the deposits are distinctly higher in the topography than the adjacent Crete sand and gravel member of the Sanborn formation. Fossiliferous Meade formation occurs at several localities along the North Fork Solomon River in south-central Norton County, and Grand Island gravels resting on Cretaceous Niobrara chalk are well exposed in a cut along Highway U.S. 283 in the NW¼ SW¼ sec. 19, T. 5 S., R. 22 W. Here, also, this dissected remnant of late Kansan terrace stands topographically higher than adjacent deposits of Illinoian age, but its position indicates that the valley floor had been cut to a level slightly below the base of the adjacent Ogallala formation before deposition of the Meade formation. Perhaps the relation of Kansan, Illinoian, and Wisconsinan terraces along the Solomon River system is most clearly discernible in the area west of Portis, Osborne County (A. R. Leonard, 1952). Here the fossiliferous

Sappa and Grand Island members of the Meade formation are well exposed in a pit in the NW cor. sec. 11, T. 6 S., R. 13 W., in a large remnant of the high level (Kansan) terrace and extensive intermediate (Illinoian) and Kirwin (Wisconsinan) terraces occur in the same segment of the valley. The same general relation of terraces is demonstrated westward along South Fork Solomon Valley by a terrace remnant in the S½ sec. 12, T. 8 S., R. 27 W., Sheridan County, where two small pits expose Grand Island gravels (on Ogallala formation) overlain by Sappa silts containing Pearlette volcanic ash, and an abandoned pit in Pearlette volcanic ash in the NW¼ sec. 34, T. 8 S., R. 28 W., Sheridan County.

In north-central and northwestern Kansas along the Solomon River system and the streams tributary from the south to Republican River, the Pleistocene deposits, although fragmentary, clearly demonstrate a physiographic terrace sequence—the older deposits occur on higher terraces and the younger deposits on progressively lower terraces. This relation is in strong contrast to the situation in part of central Kansas where, although incised deeply below the Pliocene Ogallala, progressively younger Pleistocene deposits overlie older units in the filled bedrock valleys in a normal stratigraphic sequence. The Smoky Hill River system, which stands between these areas geographically, is also intermediate in physiographic relations. In this system there is record of (1) moderate incision below the Pliocene surface followed by late Nebraskan alluviation; (2) deep incision, almost to the level of the present flood plain, followed by late Kansan alluviation; (3) Illinoian alluviation across the top of late Kansan deposits with virtually no downcutting; (4) deep incision in early Wisconsinan time to the bedrock floor of the present valley followed by alluviation, and then minor cut and fill during Recent time (Fig. 4). The complex Kansan-Illinoian terrace has been traced almost continuously from western Logan County to eastern Ellsworth County (Frye, Leonard, and Hibbard, 1943; A. R. Leonard and D. W. Berry, in preparation*), and into the dissected deposits at the north end of the abandoned McPherson valley in northwestern McPherson County (Pl. 1).

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*Indicates study of the geology and ground-water resources of the central Smoky Hill River Valley in Ellis County and southeastern Trego County, Kansas, in progress.

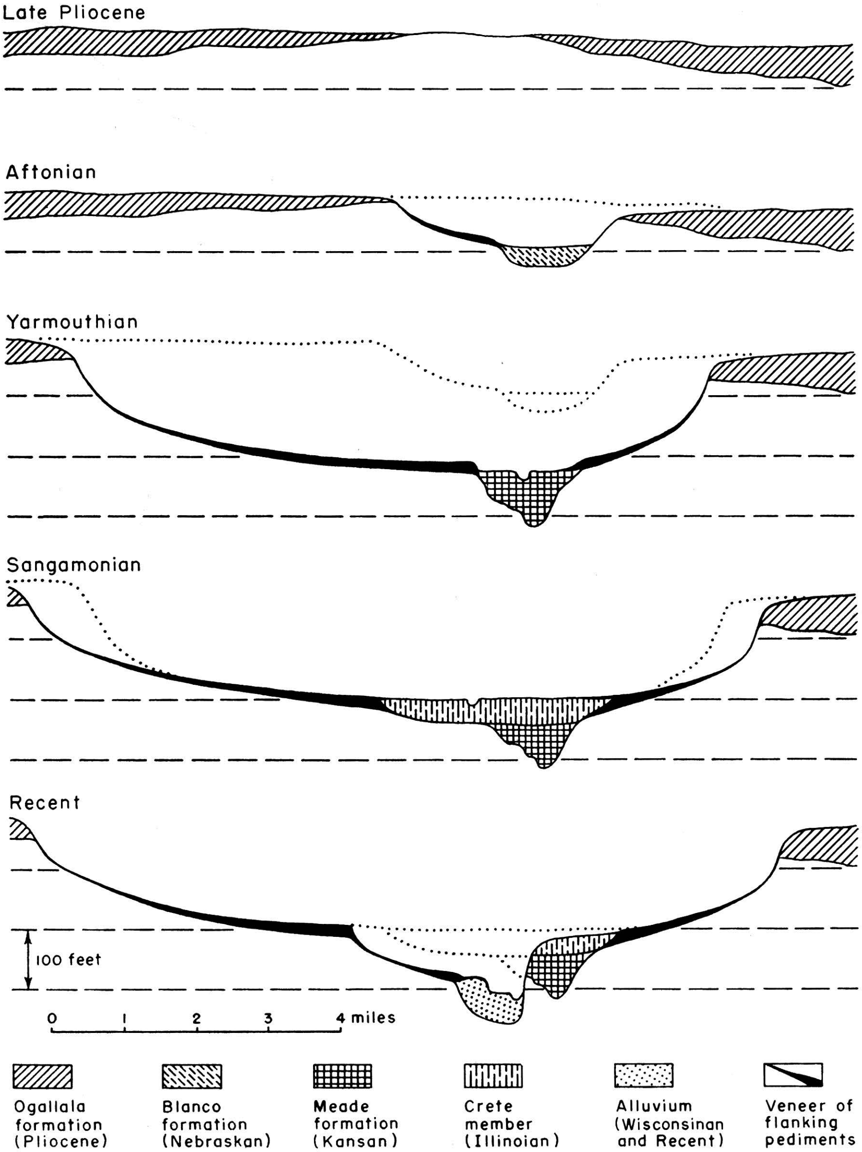


FIG. 4.—Idealized cross sections showing the development of the Smoky Hill River Valley during Pleistocene time. Data are from western Kansas and the sections are particularly generalized from south-central Gove County. Wisconsinan and Recent dissection by minor tributaries is ignored.

The gradient of the surface of the Kansan-Illinoian terrace of the Smoky Hill converges with and diverges from the gradient of the late Wisconsinan terrace and the flood plain in response to bedrock control. The Ft. Hays and Greenhorn limestones are relatively resistant units and as valley cutting has proceeded the points of valley crossing of these units have migrated upstream and therefore interruptions in the stream profile have migrated upstream.

In the western part of the State the Kansan Smoky Hill Valley was relatively narrow and the Meade formation is confined to a sharply constricted bedrock trough. In contrast, the overlying Crete (Illinoian) gravels are more extensive laterally and the terrace surface marked by their top grades into the surface of the flanking pediments cut on the Cretaceous bedrock. The stratigraphic sequence under this terrace surface is shown by the following measured section from Gove County.

Section of Meade formation and Crete member, Sanborn formation, exposed in side of tributary valley, south of Smoky Hill River in the NW¼ NE¼ sec. 26, T. 15 S., R. 29 W., Gove County.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation—Crete member (Illinoian Stage)	
7. Sand and gravel, granitic, well-sorted, contains pebbles up to 1½ inches in diameter. Unconformable on Meade formation and adjacent Niobrara chalk	6.6
Meade formation (Kansan Stage)	
Sappa member	
6. Silt, massive, strongly calcareous, light-gray, contains disseminated sand grains and pebbles. Superfically resembles weathered chalk	10.7
5. Silt, even-bedded, with some sand. Lenses of **Pearlette volcanic ash** ranging in thickness up to 1.5 feet. Lenses of fine even-bedded sand	8.0
Grand Island member	
4. Sand and gravel, fine to medium	2.6
3. Silt with some sand, compact, light-gray and tan, weathered surface superficially resembles chalk	1.5
2. Sand and gravel, granitic and local Cretaceous and Ogallala pebbles. Pebbles range up to 3 inches in maximum diameter. Irregular unconformable surface at base	5.2
Total thickness of Pleistocene deposits	**34.6**
CRETACEOUS—Gulfian	
Niobrara formation—Smoky Hill chalk member	
1. Shale, chalky, thin-bedded, blue-gray and tan.	

A few miles eastward along this terrace in Gove County a gravel pit exposes the thick channel gravel phase of the Grand Island overlain by discontinuous eroded remnants of fossiliferous Sappa member and thick coarse channel gravels of the Crete member of the Sanborn formation (Cen. N. line sec. 29, T. 15 S., R. 28 W., Gove County). In this area, where the unconformity at the base of the Crete is cut entirely through the Sappa member, the Crete gravels are indistinguishable lithologically from the Grand Island gravels.

Farther east along Smoky Hill Valley excellent exposures of the Meade and Crete underlying this terrace surface occur in eastern Trego County. Here the Meade formation rests on Cretaceous Carlile shale, contains Pearlette volcanic ash (Pl. 9A), and is overlain by thick deposits of coarse gravels of the Crete member. In this area detailed test drilling (A. R. Leonard and D. W. Berry, in preparation) has shown the character of the constricted deep Kansan channel filled with Meade formation and overlain by the broader fill of Crete gravels.

Eastward into Russell County the Kansan-Illinoian terrace becomes progressively wider, attaining a maximum width of nearly 5 miles, and the flanking pediments become less distinct. In this segment of the valley several good exposures show the Meade and Crete near the mouths of entering tributary valleys where the deposits under the terrace surface are thinner than in the central part of the valley and the lithology of these units reflects a local source (SW¼ sec. 35, T. 14 S., R. 11 W.). A measured section from this area is given below.

Kansan and Illinoian deposits under terrace of Smoky Hill Valley, SW¼ sec. 35, T. 14 S., R. 11 W., Russell County.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation—Crete member (Illinoian Stage)	
6. Upper part of interval covered, may contain colluvium and some Peoria loess. Lower part is cross-bedded irregularly sorted sand, gravel, and silt and contains caliche nodules near surface. Gravel contains pebbles of Cretaceous chalk	20.0
Meade formation (Kansan Stage)	
Sappa member	
5. Sand, fine, and silt; massive in upper part, thin-bedded in lower part with lenses of sand, tan and buff. Contains fragments of fossil vertebrates and snails	10.6
4. **Pearlette volcanic ash**; thickens to the west	0.2

3. Silt and fine sand, gray to greenish-gray, with thin beds of sandy clay, some pebbles in lower part. Terrestrial snails occur in lower 5.5 feet, aquatic snails in upper 1 foot below volcanic ash (Tobin faunule)	6.5
Grand Island member	
2. Gravel and sand, cross-bedded, interbedded with thin beds of silt. Gravel predominantly of Cretaceous chalk and sandstone with some granitic pebbles. Cobbles of chalk and sandstone as much as 0.7 foot in maximum diameter	3.9
Total thickness of Pleistocene deposits measured	41.2
CRETACEOUS—Gulfian	
Dakota formation	
1. Shale, siltstone, clay, and sandstone, red, brown, tan, and gray; to level of flood plain of Smoky Hill River	40.0

During Kansan time a major tributary from the northwest joined the early Smoky Hill Valley in western Ellsworth County. The lower course of this tributary is recorded by abandoned "Wilson valley," and its contained deposits, which extend across the present divide between the Saline and Smoky Hill Rivers (Frye, Leonard, and Hibbard, 1943; Frye, 1945b). The surface of the floor of Wilson valley is accordant and continuous with the surface of the Kansan-Illinoian terrace of the Smoky Hill Valley, but to the north the dissected valley floor stands more than 150 feet above the channel of Saline River. The deposits under the floor of this abandoned valley consist largely of Meade formation containing Pearlette volcanic ash (Pl. 8C) and associated molluscan fauna. The lack of Crete gravels—in contrast to the Smoky Hill Valley—indicates that Wilson valley was abandoned after Kansan time and prior to Illinoian time. Thin Loveland silt containing Sangamon soil overlain by thin Peoria loess locally mantles the Meade formation. The maximum thickness of Pleistocene deposits under the floor of Wilson valley, indicated by outcrops and a line of test holes along the Ellsworth-Lincoln County line (Berry, 1952) is about 75 feet.

The foregoing data show that the Kansan deposits of the Smoky Hill Valley, abandoned Wilson valley, abandoned McPherson valley, and south-central Kansas including the Great Bend area and Rice County, all fit an integrated stream pattern and are all genetically related. The contrasting topographic positions of the Meade formation in various parts of this region are due to post-Kansan drainage changes.

In southwestern Kansas the Meade formation is not present or is poorly exposed except along the valley of Crooked Creek in central Meade County, the Cimarron Valley, and Bluff Valley in northwestern Clark County. In these areas the formation and its contained Pearlette volcanic ash are well exposed and have been studied intensively (Frye and Hibbard, 1941; Frye, 1942; Hibbard, 1944; McLaughlin, 1946; Byrne and McLaughlin, 1948; Frye, Swineford, and Leonard, 1948; A. B. Leonard, 1950; Carey and others, 1952). The type locality of the formation is in this area. It consists of exposures in the east valley wall of Crooked Creek south of the City of Meade; more than 30 localities of Pearlette volcanic ash are known in the southwestern area (Carey and others, 1952); abundant molluscan faunas have been described (A. B. Leonard, 1950); and the bulk of the fossil vertebrates known from the Kansan deposits of Kansas have been collected in this area (Hibbard, 1944, 1949a, 1949b).

The lithology of the Meade formation of central Meade County contrasts with the lithology of the formation in the central Kansas region in that the Sappa member constitutes a much larger part of the total volume of the unit, and along the trend of the Crooked Creek fault, suggests deposition in slack water. The Grand Island member, although containing similar rock types, is generally finer. However, some exposures along Cimarron River Valley (particularly near Arkalon in Seward County) display thick coarse gravels in the Grand Island member.

Age and correlation.—Correlation of beds equivalent to the Sappa member of the Meade formation has been established with certainty through a region extending from west-central Texas across western Oklahoma, Kansas, and Nebraska and into southeastern South Dakota and western Iowa. This has been possible largely due to the association in these deposits of a petrographically distinctive volcanic ash bed with a large and definitive molluscan fauna, although the more common techniques of tracing alluvial terraces and lithologic units and stratigraphic sequence were also used extensively.

For many years deposits of volcanic ash have been known to occur at several stratigraphic positions in the Miocene, Pliocene, and Pleistocene deposits of the central Great Plains region. Petrographic studies of ash from these several stratigraphic positions revealed that each fall possessed distinctive physical properties and therefore it became possible to identify the Pearlette bed from uncorrelated deposits (Swineford and Frye, 1946; Frye, Swineford, and Leonard, 1948). When a unique lithology such as this became combined with a molluscan faunal assemblage of more than 60 species containing first appearances, last appearances, and restricted species, a means was provided for making long-range correlations that could be extended with safety across major drainage divides and between deposits from different sources.

Not only has the Meade formation (Sappa member) been correlated with certainty across a region embracing parts of seven states, but also its stratigraphic framing is almost equally well established. In Kansas, Sappa member with Pearlette volcanic ash has been studied in Marshall and Nemaha Counties where it occurs unconformably on Kansas till, and at many localities in central and western Kansas it occurs unconformably on Blanco formation. At several localities in the Missouri Valley area of Nebraska, Iowa, and South Dakota, deposits correlated with the Sappa member by Pearlette volcanic ash or molluscan fauna are judged to occur stratigraphically above Kansas till (Frye, Swineford, and Leonard, 1948). These data establish the Meade formation as post-Kansas till deposition. At several score localities in Kansas and also at a few localities northward from Kansas along the Missouri Valley, Sappa member is overlain unconformably by Loveland loess (Illinoian) containing in its top the Sangamon soil. Also, near Santee and other localities in northeastern Nebraska the Sappa is overlain by Iowa till (Frye, Swineford, and Leonard, 1948). These data clearly frame the Meade formation between the times of maximum advance of the Kansan glacier and that of the Illinoian glacier but do not place it more precisely within this interval.

Placement of the Meade formation within this framed interval is judged to be possible from several other lines of evidence. (1) A small but diagnostic molluscan fauna has been collected from the base of the Kansas till at the Iowa Point section, Doniphan County, Kansas, and all species obtained are characteristic of the Sappa fauna. (2) An evaluation of the relationship of alluvial cut and fill to times of glacial advance (Frye, 1951) has been presented elsewhere in this report and indicates that this deposit is genetically related to the retreat of the Kansan glacier. (3) In the marginal area of the Kansan glacier, particularly the central Kaw Valley, Atchison formation, Kansas till, and Grand Island member form a conformable sequence, and in fact Grand Island gravels and Kansas till interfinger at a few places. (4) Yarmouth soil, with a degree of development comparable to Sangamon soil in the same area, and developed on Sappa silts is overlain by Loveland loess (Illinoian) at a few localities. These data demonstrate that the Grand Island member is retreatal outwash of the Kansan glacier, and in areas remote from glaciation equivalent in age to such outwash; and that the Sappa member (conformable and gradational with the Grand Island) is a continuation and later phase of this episode of alluviation, perhaps culminating at or slightly after the dissipation of the Kansan glacier. Therefore, the Grand Island is classed as late Kansan and the Sappa as latest Kansan and perhaps earliest Yarmouthian.

YARMOUTHIAN STAGE

Evidence of Yarmouthian time in Kansas is preserved in the Yarmouth soil, and perhaps locally in the uppermost part of the Sappa member of the Meade formation, which may be earliest Yarmouthian in age. Evidence of Yarmouth soil development extends generally over northern, central, and western Kansas, but only at a few places has a Yarmouth soil been observed where an uneroded profile is developed in Kansan sediments, overlain by known Illinoian sediments. A complete Yarmouth profile has been studied by Alvin R. Leonard and by us in the SW¼ SE¼ sec. 13, T. 2 S., R. 10 W., Jewell County. Here the Sappa beds below the profile are fossiliferous and it is overlain by Loveland loess containing a well-developed Sangamon soil in the top which is in turn overlain by Peoria loess. At this locality the profile suggests somewhat poorly drained conditions on the Yarmouth soil surface. The partly eroded lower part of a Yarmouth profile overlain by Loveland loess occurs at the Iowa Point section in Doniphan County and at several other localities in Atchison, Doniphan, and Brown Counties.

A Yarmouth soil profile of strikingly different morphology is exposed in an abandoned gravel pit 1½ miles southeast of Washington in Washington County. Here the profile is developed in relatively coarse Grand Island outwash gravels which are overlain by colluvium of presumed Illinoian age. The A horizon of the profile has been removed by erosion but 3 to 5 feet of leached zone is exposed below the colluvium in the pit face. The base of the leached zone is sharp and marks the upper limit of Permian limestone pebbles, abundant in the unleached gravel below. The deep graveliferous B horizon is reddish brown in color with a relatively high clay content in the interstices of the gravel.

A profile developed on Kansan sediments but lacking an Illinoian cover has been observed at many localities in central and southwestern Kansas. Such a profile was studied in auger holes in eastern Reno County by James Thorp, W. I. Watkins, and us, and in this area under flat surfaces this Yarmouth-Sangamon (perhaps also Brady) soil is quite deep with a heavy B horizon and caliche nodules more than 3 inches in diameter. West of Meade, Meade County, highway cuts expose a Yarmouth-Sangamon soil developed in Sappa silts and overlain by Peoria loess. Here this soil (A horizon removed by erosion) is dark red and the caliche has been welded into vertical nodular stringers below an almost continuous zone of nodular caliche. The total caliche zone commonly exceeds 3 feet in thickness.

In east-central Kansas a soil on the Emporia terrace below a thin veneer of Peoria loess may be a Yarmouth-Sangamon profile. Also in this area some bedrock residual soils may have started their development in Yarmouthian time.

A soil buried beneath thin Peoria loess occurs extensively in the central part of the glaciated area of northeastern Kansas; it is well exposed in fresh cuts along Highway U.S. 36 west of Hiawatha, Brown County. Wedges of colluvium, as much as 4 or 5 feet in thickness on the lower part of gentle slopes and rarely exceeding a foot or 2 in the crests of spurs, rests on oxidized Kansas till (both leached and unleached) with a distinct concentration of cobbles and pebbles at the "contact" or slip-plane. A deep well-drained reddish-brown profile occurs extensively in the top of this colluvial veneer and below Peoria loess. Although this profile may be a Yarmouth-Sangamon soil, it is judged more likely that the Yarmouth soil—formed on an essentially uneroded till plain surface—was destroyed by erosion, that the colluvial veneer developed in Illinoian time, and that the buried soil is the Sangamon, because the present well-drained topography of the region had been formed before this buried profile developed.

In the relatively little-dissected High Plains area of west-central and northwestern Kansas a buried soil consistently occurs on the eroded Ogallala below a cover of Peoria loess. Although the culmination of the development of this buried soil was during Sangamonian time, some exposures show evidence of multiple cycles of soil development (Pl. 10) that probably include the Yarmouth soil.

The evidence, as it has been observed in Kansas, indicates that when the Yarmouth soil is compared with the Afton and Sangamon soils from situations of similar parent material, drainage, and climate, the three soils display an approximately equivalent stage of development, although all three soils show a strong contrast from east to west and from north to south across the State.

SANBORN FORMATION

The Sanborn formation, unlike all other stratigraphic units of formational rank in the Kansas Pleistocene, includes deposits of two stages (Illinoian and Wisconsinan) and the several substages of the Wisconsinan. Furthermore, it includes two unconformities, defined by the Sangamon and Brady buried soils, and represents three distinct cycles of deposition. In the official classification of the Kansas Geological Survey the Sanborn formation includes, in ascending order, the following members: (1) Crete sand and gravel member; (2) Loveland silt member, commonly containing within its top the Sangamon buried soil; (3) unnamed early Wisconsinan alluvial deposits; (4) Peoria silt member, commonly containing within its top the Brady buried soil; (5) unnamed late Wisconsinan alluvial deposits; and (6) Bignell silt member. Although three cyclic units, each of which is genetically comparable to the Meade or Blanco formation, are represented by the Crete-Loveland-Sangamon, by the early Wisconsinan alluvium-Peoria-Brady, and by the late Wisconsinan alluvium-Bignell-topsoil, it is judged to be advisable to retain the broadly inclusive Sanborn as the unit of formation rank as an expedient to mapping. The eolian or loess phase of the three members is widely distributed in upland areas in situations that make it impracticable to separate them for field mapping on

Plate 10. Complex of buried soils developed in Ogallala formation and overlain by Peoria loess. Three generations of caliche, the lowest (oldest) of which may be as old as Aftonian, are overlain by Peoria loess capping the High Plains surface. Exposure in road side gully, SE¼ NE¼ sec. 33, T. 10 S., R. 28 W., Sheridan County. (1950.)

conventional map scales. The several members of the formation will be discussed by geologic stages as have the older units of the Kansas Pleistocene.

The name Sanborn formation was first proposed by Elias in 1931 (p. 163), as follows:

> 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 substatute [*sic*] for the old terms "Tertiary marl" or "Plains marl" introduced for this formation by Robert Hay. The new name is derived from Sanborn, Neb., which is the nearest town to a locality of the formation in the northwestern corner of Cheyenne county, Kansas, where loess attains a thickness of 180 feet. Loess is exposed here in steep bluffs of numerous canyons on the south side of Arikaree river. Loess is underlain here by a few feet of Ogallala and by the Pierre shale.

Concerning the upper, or loess, part of the formation Elias (1931, p. 179) restricted the name Sanborn to the loess of the divide area as follows:

> It seems to the writer that only the loess that covers the divides can be considered to be of Pleistocene age, the loess of the valley slopes and bottoms being largely if not wholly redeposited from the divides, the redeposition having taken place probably for the most part in late Pleistocene and Recent times. At any rate redeposition of the topographically higher loess to the lower areas is still going on, the wind and surficial waters being the chief agents of transportation.

Although Elias did not give a measured section for the type, or specifically designate a type section, he later agreed (Frye and Fent, 1947, p. 41) that the exposures in canyons extending from the NW¼ sec. 20, T. 1 S., R. 41 W. into the adjacent SW¼ SE¼ sec. 17, T. 1 S., R. 41 W., Cheyenne County (Pl. 11E) were in his type area and constituted a suitable type section. A measured section from these canyons is given below. At the type locality the Sanborn consists of water-laid Crete and Loveland capped with Sangamon (Brown) soil containing remains of *Citellus richardsoni,* overlain by Peoria loess which contains a sparse molluscan fauna. Brady soil and the overlying Bignell loess are well exposed in road cuts in the central part of Cheyenne County (SE¼ SE¼ sec. 28, T. 3 S., R. 39 W.).

Subsequent to Elias' naming of the Sanborn formation it was used as a broadly inclusive unit, embracing virtually all the Pleistocene deposits in northwestern and north-central Kansas

Type locality of Sanborn formation, section measured in canyon on the south side of Arikaree River in the SW¼ SE¼ sec. 17, T. 1 S., R. 41 W., Cheyenne County.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
Peoria member (Wisconsinan Stage, Iowan and Tazewellian Substages)	
6. Silt, massive, calcareous, light-tan; contains very fine sand in lower part, sparsely fossiliferous in middle, upper part largely covered	90.0
Crete-Loveland member (Illinoian Stage)	
5. Silt and fine sand; **Sangamon soil** in upper part, light-brown, small amount of clay in B horizon, weakly developed vertical structure, weakly calcareous; contains fossil remains of *Citellus richardsoni*	3.0
4. Silt and very fine sand, massive, calcareous, tan to buff	3.0
3. Silt, fine sand, very fine sand, and a few thin beds of clay, interbedded; thin to moderately thick-bedded, tan, buff, and gray, mostly calcareous. In adjacent canyons, both east and west, the top of the Ogallala formation is in a position near or above the top of this interval.	24.0
2. Silt, sand, and gravel, in erosional channel cut through the Ogallala formation and into underlying Pierre shale. Gravels and sand are poorly sorted, irregularly bedded to massive, and contain many pebbles derived from Ogallala and Cretaceous rocks	10.0
Total thickness of Sanborn formation measured	130.0
CRETACEOUS—Gulfian	
Pierre shale	
1. Shale, weathered, bentonitic, coffee-colored, to bottom of canyon and along canyon to level of Arikaree River	

(Leonard and Frye, 1943; Hibbard, Frye, and Leonard, 1944; Frye, 1945, 1945a; Byrne, Coombs, and Bearman, 1947, 1949; Byrne, Beck and Houston, 1948, 1949; Byrne, Houston, and Mudge, 1948, 1950; Byrne, Beck, and Bearman, 1949; Byrne and others, 1950, 1950a; Byrne, Coombs, and Matthews, 1951; Byrne, Johnson, and Bergman, 1951). However, by 1947 (Frye and Fent) it was proposed that the formation be restricted to the span of rocks described here. In recent years this restriction has been followed generally (Frye, Swineford, and Leonard, 1948; Frye and A. R. Leonard, 1949; Frye and others, 1949; Fent, 1950; Moore and others, 1951; Frye and A. B. Leonard, 1951; Swineford and Frye, 1951).

Various locally named units in Kansas that consist in part or entirely of deposits known to be of Illinoian or younger age, and which are properly classed at least in part as Sanborn formation, include the "Bluff formation" (Hawn, 1866), "Plains marl" or "Tertiary marl" (Hay, 1885, 1893; Haworth, 1897, 1897a; Williston, 1899), "Salt Creek gravel beds" (Logan, 1897), "Sheridan beds" (Scott, 1897), "McPherson *Equus* beds" (Haworth and Beede, 1897; Beede, 1898), "Kingsdown marl" or formation (Cragin, 1896; Smith, 1940; Frye and Hibbard, 1941; Hibbard, 1949b), "Belleville formation" (Wing, 1930), "Gerlane formation" (Knight, 1934; Frye, 1945a), "*Equus niobrarensis* beds," "Jones Ranch beds," and "Odee formation" (Smith, 1940), and "Vanhem formation" (Hibbard, 1949b).

ILLINOIAN STAGE

During the Illinoian Age continental glaciers were more remote from Kansas than during any of the other glacial ages. During the Nebraskan and Kansan Ages continental glaciers invaded northeastern Kansas, and during the Wisconsinan, continental glaciers of each of the four glacial sub-ages either crossed the Missouri Valley north of Kansas or invaded major tributary valleys of the Missouri. In contrast, the closest approach to Kansas of clearly identified Illinoian continental glacial deposits is extreme eastern Iowa and western Illinois. Quantitatively, deposits of the Illinoian Stage in Kansas are far less important than the preceding Kansan, and, although more widespread, are volumetrically comparable to the Nebraskan. In Kansas this stage consists predominantly of stream-laid gravel, sand, and silt with a minor quantity of eolian silt or loess.

Alluvial Illinoian deposits have their maximum development along the valleys of central and north-central Kansas and are relatively minor elsewhere. Loess of the Illinoian Age also has its maximum development in this same general area. The Illinoian Stage in Kansas is represented by the Crete and Loveland members of the Sanborn formation.

CRETE MEMBER, SANBORN FORMATION

The name Crete formation was proposed for Nebraska usage in 1947 by Condra, Reed, and Gordon (p. 24) from a type locality in road cuts west of Crete, Saline County, Nebraska, in the NE¼ sec. 32, T. 8 N., R. 4 E. They state concerning the formation:

> The Crete formation is a channel fill deposit which rests unconformably upon the Upland [Sappa] formation or older Pleistocene deposits and is believed to be Illinoian in age. It is variable in composition depending upon the local material available for reworking in Crete time. Thus we find that the Crete consists of sand and gravel reworked from Kansan till or late Kansan sands and gravels in the narrower Crete channels in Eastern Nebraska and Western Iowa; that it consists of sands and some gravels which resemble the Grand Island formation in the broad through valleys of east central Nebraska; and that it consists of sands and gravels rich in pink feldspars of western source in Central and Western Nebraska modified by contributions of pebbles and boulders of reworked Ogallala or older formations where it occurs not too distant from bedrock outcrops.

In Kansas the Crete member of the Sanborn formation has been described briefly for the State by Frye and A. B. Leonard, (1951, p. 293), and in more detail for specific areas by Frye and A. R. Leonard (1949), Berry (1952), A. R. Leonard and D. W. Berry (in preparation), and Davis and Carlson (1952). Its geographic distribution is shown on the map in Plate 1, and its regional stratigraphic relations in the generalized cross sections in Plate 2. In alluvial deposits the separation of Crete and Loveland members is arbitrary, the sand and gravel deposits being classed as Crete and the predominantly silty upper part of the alluvial sequence classed as Loveland. In some areas where silt and sand are interbedded a distinction between the two members is not attempted and the deposits are classed as Crete-Loveland. The eolian silt (loess) of the upland areas that is stratigraphically equivalent to these deposits is, of course, classed as Loveland member.

In the glaciated area of northeastern Kansas the Crete member is relatively unimportant, occurring in isolated small outcrops. Along the Kaw Valley Crete deposits underlie the surface of disconnected small remnants of the Buck Creek terrace (Davis and Carlson, 1952). This terrace, named for a small area at the mouth of Buck Creek Valley on the north side of Kaw Valley, northwest of Lawrence, stands in an intermediate position between the prominent Menoken terrace of Kansan age and the nearly continuous low Newman terrace of the Wisconsinan and Recent Ages. Test drilling (Davis and Carlson, 1952) shows that the bedrock floor of the valley was cut to within approximately 20 feet of the bedrock floor below the Newman terrace before the deposition of the Buck Creek terrace fill and therefore a major episode of valley incision occurred after the deposition of the late Kansan Meade formation in the valley and prior to the deposition of the late Illinoian Crete member. Where preserved in the Kansas River Valley the Crete consists predominantly of sand with some silt and contains some gravel in the lower part. In the Smoky Hill River Valley, southwest of Junction City, one small remnant of Crete has been studied in a terrace that is comparable in situation to the Buck Creek terrace eastward in the Kaw Valley. At this locality a molluscan fauna was obtained from the Crete-Loveland deposits.

The Crete member has not been identified in the Missouri River Valley in Kansas.

In the area south of Kansas River Valley and east from the crest of the Flint Hills the Crete member is judged to be represented by the highest elements of the low terrace complex, distinctly below the level of the Emporia and equivalent terraces. Positive identification of Crete in this area has thus far not been possible.

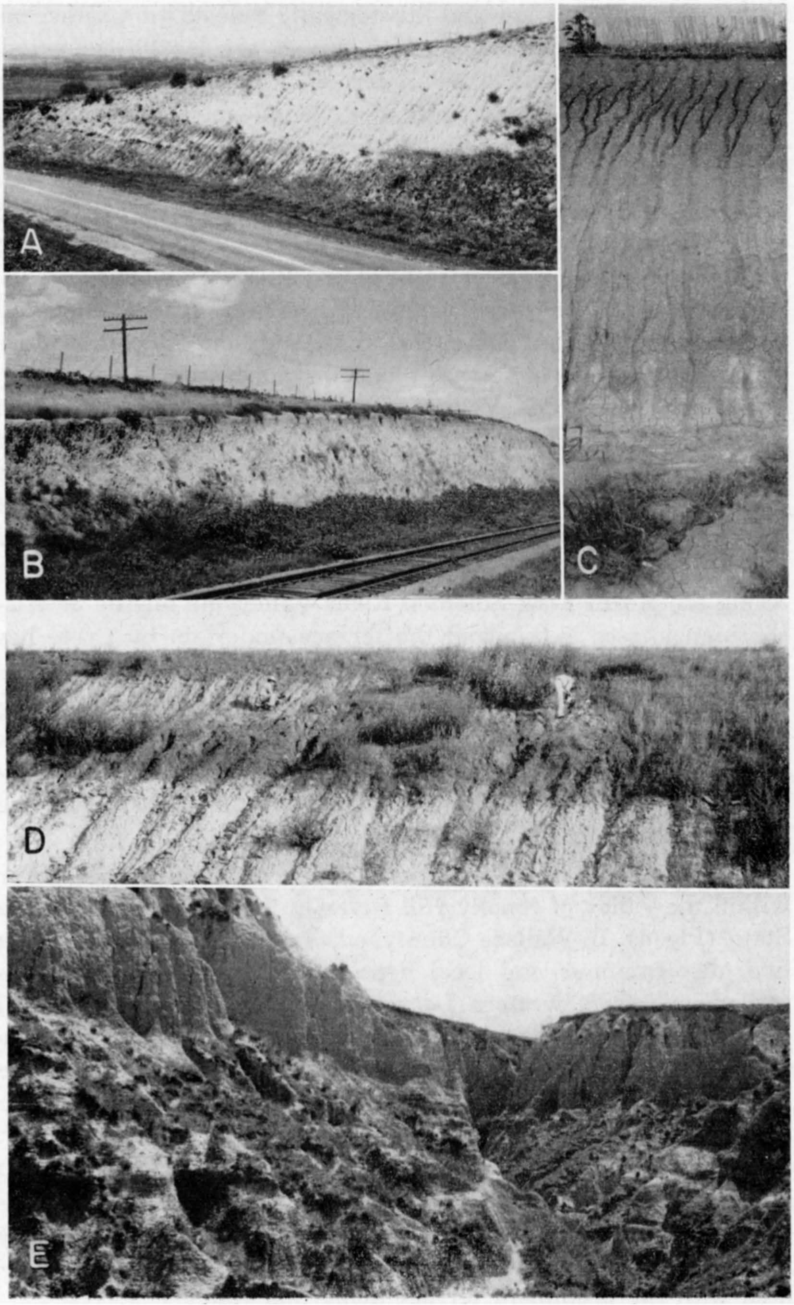
The Crete member is well developed in north-central Kansas where it occurs as local gully fills and as persistent terraces along the major valleys. In this area the Crete closely reflects the lithology of the drainage basin containing the deposit. At some places local deposits of Crete consist largely of caliche pebbles with some pebbles of Cretaceous chalk (SW¼ SE¼ sec. 6, T. 2 S., R. 4 W., Jewell County where Crete rests on Sappa silt and contains a diagnostic snail fauna), or of pebbles of Ogallala "mortar beds" (SW¼ SW¼ sec. 29, T. 1 S., R. 21 W., Norton County). The reflection of local source, even in major valleys of the region, is illustrated by disconnected remnants of a low terrace underlain by Crete gravels along Saline Valley. In central Russell County (secs. 34, 35, and 36, T. 12 S., R. 14 W.) the Crete consists largely of pebbles of Greenhorn limestone (Cretaceous) that caps the valley walls and crops out along the tributaries, whereas eastward in central and eastern Lincoln County (Berry, 1952) the Crete contains a large percentage of pebbles derived from the Dakota formation which constitutes most of the area of the valley sides. In northeastern Lincoln County and adjacent Ottawa County the Crete terrace along

Salt Creek Valley is low and lithologically reflects the Cretaceous bedrock of the valley walls. The gravels are locally cemented, and at one locality (NE¼ NW¼ sec. 29, T. 10 S., R. 5 W., Ottawa County) are cut deeply into the Sappa member (including Pearlette volcanic ash) of the Meade formation.

The Crete member is well developed and present almost continuously along the valleys of Prairie Dog Creek across Norton and Phillips Counties (Frye and A. R. Leonard, 1949) and the North Fork Solomon River eastward from Norton County (A. R. Leonard, 1952). In these valleys it has been studied in detail both by surface methods and test drilling, and in both valleys occurs as a persistent terrace along the north side of the valley. In Prairie Dog Creek Valley the accumulation of Wisconsinan loesses on the terrace surface and the valley side slope has masked the physiographic expression of the terrace to such an extent that it is difficult to limit cartographically without benefit of subsurface data; the Crete sands are well exposed at a few localities (NW¼ NW¼ sec. 8, T. 3 S., R. 23 W., Norton County). Along the North Fork Solomon River Valley the mantle of Wisconsinan loesses is thin and the terrace underlain by Crete has a recognizable physiographic form.

In the northwestern part of Kansas major through-flowing valleys do not exist and the Crete terraces in the headwaters portions of valleys in that area are discontinuous or indistinguishable. Thin deposits of Crete from local sources, however, are not uncommon (Pl. 11A, 11E).

In Kansas the best exposures of Crete sand and gravel occur within the valley of Smoky Hill River in the western half of the State (Fig. 4). In Wallace County, adjacent to the Colorado State line, discontinuous and local deposits of Crete have been observed, and from western Logan County eastward into central Kansas the Crete gravels form a persistent upper part of the Kansan-Illinoian (Pfeifer) terrace along the valley. The Crete is well exposed in this area (particularly where it overlies Meade formation on the north side of Smoky Hill River in sec. 29, T. 14 S., R. 21 W., Trego County) and has been described in Trego and Ellis Counties by A. R. Leonard and D. W. Berry (in preparation). Some of the better exposures were mentioned in the preceding discussion of the Meade formation (Kansan) associated with the prominent terrace along this valley.


A
B
C
D
E

In western McPherson County subsurface data (O. S. Fent, personal communication) show Crete gravels to overlie unconformably the Sappa member of the Meade formation which constitutes the major part of the fill in this abandoned valley. As these gravels fit approximately the projected gradient of the Crete terrace deposits extending 200 miles west along Smoky Hill Valley it is judged that the drainage from this valley continued southward through the McPherson valley until after Illinoian time.

Crete gravels have their greatest quantitative development in the region south of the great bend of the Arkansas River, but in much of this region outcrops are poor and they are known primarily from subsurface data (D. W. Berry, in preparation; O. S. Fent, in preparation, personal communication). Crete gravels resting on Sappa silts are exposed in west-central Kingman County and central Pratt County (for example, SW cor. sec. 23, T. 27 S., R. 11 W., where Crete gravels overlie sandy Sappa containing Pearlette volcanic ash). The extent of Crete gravels in this region is shown on the map (Pl. 1) and the cross sections (Pl. 2).

In southwestern Kansas the Crete member has been recognized with certainty at very few places and it seems evident that it is quantitatively not important in that area. It should be remembered, however, that the separation of the Crete and Loveland members, where they are both water-laid, is arbitrary and is based on the texture of the sediment. Therefore, some deposits that are classed as Loveland or Crete-Loveland in this report might be considered by other workers to be more properly classed as Crete.

PLATE 11. **Peoria loess and Sangamon soil. A,** Fossiliferous Peoria loess, 35 feet thick, on Sangamon soil in Crete-Loveland, on Ogallala. Brady soil and Bignell loess at top of cut; sec. 2, T. 3 S., R. 33 W., Rawlins County. (1948). **B,** Fossiliferous Peoria loess in cut of Chicago, Rock Island, and Pacific Railroad, SW¼ NW¼ sec. 8, T. 8 S., R. 35 W., Thomas County. Peoria is 30 feet thick. (1943.) **C,** Peoria loess with well-developed Chernozem soil in top, on eroded Sangamon soil in fossiliferous Crete-Loveland. Cretaceous Dakota formation (not shown in photo) at base. NW¼ SW¼ sec. 35, T. 17 S., R. 13 W., Barton County. (1949.) **D,** Peoria loess on Sangamon soil in thin Loveland loess on Cretaceous Greenhorn limestone. The Sangamon profile is deep, poorly drained, nearly black in upper part. NW¼ NW¼ sec. 9, T. 3 S., R. 1 W., Republic County. (A. R. Leonard, 1948). **E,** Peoria loess (90 feet thick and sparsely fossiliferous) on Sangamon soil yielding *Citellus richardsoni* in Crete-Loveland, on Cretaceous Pierre shale. Type locality of Sanborn formation, SW¼ SE¼ sec. 17, T. 1 S., R. 42 W., Cheyenne County. (1948.)

LOVELAND MEMBER, SANBORN FORMATION

The name Loveland was first proposed by Shimek (1909; 1910) from exposures in the east bluff of Missouri River Valley at the town of Loveland, Iowa (the type locality is listed by Kay and Graham, 1943, p. 64, as sec. 3, Rockford Township, T. 77 N., R. 44W., Pottawattamie County). Shimek described the formation as compact reddish or yellowish silt and clay, occurring stratigraphically above Kansas till and below the buff (Peoria) loess. Kay and Graham (1943, pp. 63-64) reviewed the history of the term and its expansion to include sand and gravel deposits below the reddish silt and clay. They considered the silt and clay to be eolian in origin and referred to it as loess. Lugn (1935) has described in detail the Loveland formation in Nebraska which he considered to consist of two phases, a "valley phase" of water-deposited gravel and sand and a "loess phase" of eolian silt (Lugn 1935, p. 128). He stated that the Loveland occupies a stratigraphic position unconformable upon the Upland (Sappa) formation and is terminated upward by a soil below the Peorian loess. In 1947 Condra, Reed, and Gordon (pp. 25-28) reviewed the Loveland formation in Nebraska and by the designation of the Crete as a separate formation removed the alluvial gravels from the Loveland.

The Loveland member in Kansas was discussed by Frye and A. B. Leonard (1951, pp. 294-298) who state (p. 295): "The term 'Loveland silt member' is applied in Kansas both to the water-laid silts in valley situations and to the loess of the uplands. The two facies of the silt unit have been determined to be stratigraphically continuous along some valley-side slopes, occupy the same stratigraphic position, are the same age, and can be mapped together conveniently." It is appropriate to add that at some localities it is difficult to determine in the field if Loveland silts are of fluviatile or eolian origin. Shimek's original type locality is generally accepted and has been restudied by us. At the type section the upper 22 to 24 feet of the Loveland is within the profile of the Sangamon soil, is leached of primary calcium carbonate, and has the reddish cast Shimek described. The basal few feet of the type Loveland, however, is calcareous, contains a zone of caliche nodules just below the leached material, is similar lithologically and in color to the younger loess at the same locality, and contains a meager but distinctive molluscan fauna (Frye and A. B. Leonard, 1951, p. 294).

In Kansas, Loveland loess has been recognized along Missouri and Kansas River Valleys and in the north-central, central, and southwestern areas. The Loveland silt member has been studied along Kansas River Valley and many of the valleys of the north-central, northwestern, and central regions where it consists of water-laid sediments. Alluvial Loveland silt occurs as the upper part of the deposits of the Buck Creek terrace of Kansas River Valley (Davis and Carlson, 1952). In the glaciated area of northeastern Kansas Loveland loess is well-exposed in Doniphan (Iowa Point section) and Brown (SE¼ SE¼ sec. 23, T. 2 S., R. 20 E.) Counties and has been studied in auger holes and cuts in Atchison (SE¼ sec. 32, T. 6 S., R. 21 E.), Leavenworth, and Wyandotte (SE¼ sec. 2, T. 11 S., R. 24 E.) Counties. The Loveland loess of this area is thin, rarely exceeding 20 feet in thickness, and its distribution is adjacent to the major valleys.

In northern Kansas the Loveland silt is a thin but distinctive and persistent unit westward from Republican River Valley for 200 miles (Hibbard, Frye, and Leonard, 1944; Frye and Fent, 1947; Frye and others, 1949; Frye and A. R. Leonard, 1949). In this area the secondarily imposed characters of the Sangamon soil almost completely mask the primary character of the Loveland member as at many localities where it was studied its entire thickness was found to be included within the Sangamon profile. In this north-central area the Loveland member occurs not only as an upland loess (Jewell, Smith, and Phillips Counties) but also as stream-laid silt (SW¼ NW¼ sec. 26, T. 2 S., R. 23 W., Norton County) and as colluvium on valley side slopes.

In northwestern Kansas thin Loveland loess occurs at only a few places although water-laid and colluvial deposits classed as Crete or Crete-Loveland are relatively widespread and the Sangamon soil continues to serve as a persistent and recognizable stratigraphic datum.

In the Smoky Hill Valley region of western Kansas, in spite of the extensive development of the Crete gravels, the Loveland member is quantitatively of small importance. On some valley side slopes silty colluvium (NW¼ sec. 3, T. 16 S., R. 29 W., Lane

County) of Illinoian age contains a well-developed Sangamon soil in its top and is overlain by fossiliferous Peoria loess.

In central Kansas the Loveland loess is well developed in some localities, particularly in Rice and McPherson Counties (Frye and Fent, 1947; Fent, 1950). An exceptional exposure occurs in a road cut in the NW¼ SW¼ sec. 7, T. 18 S., R. 7 W., Rice County, where very thin Bignell overlies Brady soil in Peoria loess which rests on a humic-gley Sangamon soil in Loveland (fossiliferous in lower part) which rests on an eroded soil developed on the underlying clayey shale of the Cretaceous Dakota formation. Westward from Rice County Loveland loess occurs discontinuously on the Cretaceous upland overlain by Peoria and at some localities is fossiliferous (Pl. 11C).

In the southwestern corner of the State Loveland loess has not been recognized although sands have been observed in its stratigraphic position. Eastward in southwestern Kansas, relatively thick Loveland loess is exposed in Clark (NW¼ sec. 3, T. 30 S., R. 24 W.) and Ford (sec. 22, T. 29 S., R. 23 W.) Counties where it is overlain by thin fossiliferous Peoria loess.

Loveland loess has not been recognized in the chert gravel province east of the Flint Hills, although Sangamon soil, as a residual profile on shale, has been observed below thin Peoria loess.

The age of the Crete and Loveland members is established as Illinoian by stratigraphic framing on a regional and definitive basis. At several score localities the Crete and Loveland members can be demonstrated to be appreciably younger than the Sappa member of the Meade formation (late Kansan). As the time interval separating the Loveland from the Sappa was sufficient to permit, at some localities, the development of a mature Yarmouth soil profile (Jewell County) and at other localities the deepening of valleys through bedrock by more than 100 feet (A. R. Leonard, 1952), an age older than Illinoian is precluded. Furthermore, as the Loveland member contains, in its top, at several hundred localities studied, a mature Sangamon soil profile overlain by abundantly fossiliferous (early Wisconsinan) Peoria loess, an age younger than Illinoian is precluded. The Crete-Loveland contains a distinctive molluscan fauna that permits correlation with the type locality of the Loveland. In the glacial sequence of the central Missouri Valley region the Loveland has been framed stratigraphically between Kansas till and Sappa equivalents below and Iowa till above (Frye, Swineford, and Leonard, 1948). However, the absence of Illinois till in the Missouri Valley region prevents a direct correlation here of the Crete-Loveland with glacial deposits of this stage.

SANGAMONIAN STAGE

Record of Sangamonian time in Kansas is provided almost exclusively by the widespread, well-developed, and exceptionally well-preserved buried Sangamon soil. This soil has been studied in exposures, auger holes, and rotary test holes at several hundred localities distributed from the Missouri River Valley bluffs in northeastern Kansas to the Colorado state line and in central, west-central, and southwestern Kansas. It provides one of the best records of a former period of soil formation known in the geologic column. In Kansas this soil has been called a "soil in the Sanborn formation" (Hibbard, Frye, and Leonard, 1944), the "Loveland soil" (Frye and Fent, 1947), and the Sangamon soil (Frye and A. B. Leonard, 1951). As the term Sangamon was applied a half century ago to a soil in this stratigraphic position, the Kansas Geological Survey, following the usage of Thorp, Johnson, and Reed (1951), has adopted (Moore and others, 1951) Sangamon as the state-wide name for this buried soil.

As the original description of the Sangamon was based on an occurrence in the Mississippi River basin, the soil occurring in the upper part of the Loveland loess at the Loveland type section in Iowa has been used as a section of reference for work in Kansas. At Loveland, Iowa, the soil is well developed with a profile approximately 25 feet in depth. The zone of clay accumulation is 2 to 3 feet thick, shows well-developed structure, and is light red-brown in color; the upper 22 to 24 feet of the soil is leached of calcium carbonate, and a zone of caliche accumulation occurs at the base of the leached zone. The character of the profile indicates development under conditions of moderate to fair drainage. The Sangamon (or Loveland) soil has been described from many localities in Nebraska (Lugn, 1935; Schultz and Stout, 1945; Condra and Reed, 1950; Thorp, Johnson, and Reed, 1951). In much of the earlier literature on Nebraska the Sangamon soil has been referred to as a soil in the *Citellus* zone.

The *Citellus* zone (Condra and Reed, 1950, p. 31) should be considered a faunal zone, characterized by the fossil remains of the ground squirrel for which it is named, and not a stratigraphic unit.

Unlike the older buried soils the Sangamon has been observed at a sufficiently large number of localities and throughout a region great enough in extent to make it possible to evaluate its morphological differences from place to place. Its physical character varies primarily in response to (1) conditions of drainage, (2) parent material, and (3) climatic factors correlated with geographic location. By comparing profiles controlled by similar conditions of drainage and parent material the strong effect of geographic location becomes obvious.

Concerning the character and environment of the Sangamon soil Thorp, Johnson, and Reed (1951, p. 12) state as follows:

> On the Great Plains, it appears from the dark-colored A horizons and thick, reddish-brown clayey B horizons that the dominant vegetation probably was grass, and that the dominant well-drained soils were Reddish Prairie soils and reddish Chernozems with maximal textural contrasts between A and B horizons. However, eastward from eastern Nebraska and western Iowa, some of the buried Sangamon soils are podzolic and probably were developed under forest.

Sangamon soil has its maximum development in the area adjacent to the Missouri River Valley. This development is well displayed at the Loveland type section and other exposures in western Iowa, at the Iowa Point section and near-by exposures in Doniphan and Brown (SW¼ sec. 12, T. 1 S., R. 18 E.) Counties, Kansas, and at localities adjacent to the Missouri River as far south as Kansas City (SW¼ sec. 2, T. 11 S., R. 24 E.).

Westward from the Missouri River in the glaciated area the Loveland loess becomes thin and discontinuous and Sangamon soil is developed on colluvial wedges on dissected Kansas till and is overlain by Peoria loess. The Sangamon soil where developed on thin colluvium is generally a well-drained profile with a tough B horizon that is a strong red-brown in color. Its configuration roughly conforms to the present topography. Where it is well exposed in cuts along U.S. Highway 36 west of Hiawatha in Brown County the soil is truncated low along the valley sides by subsequent erosion and the hilltops are capped asymmetrically by Peoria loess.

At the western margin of the glaciated area along Blue River Valley Sangamon soil occurs in thin Loveland loess (SE¼ SW¼ sec. 13, T. 1 S., R. 7 E., Marshall County) or as a residual soil on Permian shales (NW¼ sec. 31, T. 2 S., R. 7 E. and NW¼ NE¼ sec. 36, T. 5 S., R. 8 E., Marshall County) overlain by thin Peoria loess. Westward in Washington County and eastern Republic County Sangamon soil is developed in thin Loveland loess and as a residual profile on Cretaceous Dakota formation and Greenhorn limestone (Pl. 11D). It is well exposed adjacent to Republican River Valley (SW¼ sec. 9, T. 3 S., R. 4 W., Republic County; NE¼ NE¼ sec. 19, T. 8 S., R. 3 E., Clay County; SW¼ sec. 34, T. 5 S., R. 2 W., Cloud County). In this area fossil remains of the rodent *Citellus richardsoni,* typical of this buried soil in Nebraska, have been collected at several localities.

West of Republican River Valley the Sangamon soil has been examined in auger holes where it is a poorly drained profile under thin Peoria loess that mantles much of the extensive plain on Cretaceous Carlile shale (NE¼ NE¼ sec. 15, T. 3 S., R. 5 W.), and on the uplands above the Fort Hays limestone scarp where this soil is generally a well-drained profile (NE¼ SW¼ sec. 25, T. 3 S., R. 8 W.; SW¼ SW¼ sec. 10, T. 3 S., R. 8 W.). The Sangamon soil is most extensively exposed in the area of western Jewell County, Smith (SE¼ NE¼ sec. 33, T. 3 S., R. 11 W.; NW¼ SW¼ sec. 29, T. 2 S., R. 14 W.) and Phillips (NW¼ sec. 23, T. 2 S., R. 18 W.; SW¼ SW¼ sec. 24, T. 4 S., R. 19 W.) Counties, and eastern Norton County. Here the buried soil is exposed at hundreds of places along valley sides, in plowed fields, and in road cuts; where exposed it is generally a moderately well-drained profile and from east to west becomes somewhat thinner and lighter colored. At some places where the soil is developed in sand the top of the caliche zone is a sharp but crenulate line (road cut, NW¼ sec. 29, T. 4 S., R. 19 W., Phillips County). In central Norton County (SW¼ NW¼ sec. 11, T. 3 S., R. 23 W.) the B horizon is pale reddish brown and the depth of leaching commonly does not exceed 36 inches. As the Loveland loess is discontinuous in northwestern Kansas the Sangamon soil is commonly developed on water-laid or colluvial materials (Pl. 11A), but is exposed at many places (NE¼ NE¼ secs. 3 and 12, T. 3 S., R. 27 W., Decatur County; NE¼ sec. 29, T. 3 S., R. 36 W., Rawlins County). Westward to the Colorado state line in northern Kansas the Sangamon soil continues to decrease in depth of leaching and becomes lighter in color. At several localities in north-central and northwestern Kansas fossil remains of *Citellus richardsoni* have been collected from this soil (Hibbard, Frye, and Leonard, 1944).

Southward from the northern tier of counties the Sangamon soil is less commonly exposed and at many localities it is developed in sandy materials (SW¼ SE¼ sec. 5, T. 12 S., R. 24 W., Trego County). At other places where the soil is developed in thin colluvial materials on Ogallala, several generations of soil formation are observable in the profile (Pl. 10).

In the High Plains south of Smoky Hill River Valley and north of Arkansas River Valley the Sangamon soil is rarely exposed. The high flat surface of this region is mantled almost continuously with thin Peoria loess. The Sangamon soil, or perhaps a complex of Sangamon and earlier Pleistocene soils, has been penetrated at many places by auger borings through the Peoria loess. The Sangamon soil in this area is developed on Ogallala (SW cor. NW¼ sec. 19, T. 21 S., R. 40 W., Hamilton County; SW cor. sec. 35, T. 20 S., R. 35 W., Wichita County) and on thin and locally sandy Loveland member (SE¼ NE¼ sec. 1, T. 25 S., R. 29 W., Gray County; NW¼ SW¼ sec. 31, T. 23 S., R. 28 W., Kearny County).

South of Arkansas River in southwestern Kansas exposures of Sangamon soil are rare. However, more commonly exposed below thin Peoria loess are truncated soils, with strong caliche zones, representing development through both Yarmouthian and Sangamonian time (NW¼ sec. 7, T. 32 S., R. 28 W., Meade County). Eastward in southern Kansas truncated Sangamon soil is exposed on Loveland loess below thin fossiliferous Peoria loess (SE¼ NW¼ sec. 4, T. 30 S., R. 24 W., Clark County; NW¼ sec. 22, T. 29 S., R. 23 W., Ford County).

Examination of the Sangamon soil from localities where the profile was moderately well drained and developed on moderately calcareous silt parent material along the 400 mile traverse westward from Missouri River Valley to the Colorado state line in northern Kansas and 200 miles southward to the Oklahoma state line shows that this buried soil displays about the same degree of geographic change as the surface soils of the region. It should be kept in mind, however, that the Sangamon soil where buried under Wisconsinan deposits is more deeply and strongly developed than the surface soils on Wisconsinan deposits of the same locality. In the Missouri River Valley area the Sangamon soil is leached of $CaCO_3$ to depths of 20 to 24 feet and the depth of leaching decreases to less than 18 inches in northwestern Kansas. Like the modern soils the Sangamon changes from a forest border and Prairie soil in the northeastern corner of the State, through a Chernozem belt, to a soil of a semi-arid type in the northwest. Throughout this east-west traverse the Sangamon soil has some caliche accumulation, even in the northeastern area, but the maximum development occurs in the west-central area. Also, throughout the traverse, in well-drained situations, the B horizon has a reddish cast, becoming palest in the northwestern counties of the State. The strongest changes southward in western Kansas are a marked increase in the caliche zone, increase in depth of leaching and clay accumulation, and strong increase in intensity of the red color of the B horizon. The character of the Sangamon soil shows that the distribution of climatic and floral zones in Kansas during Sangamonian time was similar to that of the present, although the present boundary lines may have been displaced toward the east.

WISCONSINAN STAGE

The Wisconsinan is the youngest of first-rank glacial stages, and deposits of this age constitute the surface materials over more than half of the area of Kansas (Pl. 1). The classification of the deposits of the Wisconsinan Stage is more complex than that of the other glacial stages of the Pleistocene because (1) there were several episodes of glacial advance and retreat, and (2) these deposits, being younger, are better preserved and more extensively exposed at the surface. Five substages of the Wisconsinan are recognized in Kansas: Iowan, Tazewellian, Bradyan, Caryan, and Mankatoan. Of these substages, four are characterized by glacial advance and retreat and are based on type localities in the Mississippi Valley region. The remaining substage (Bradyan) was an interglacial interval similar in character, if not duration, to the preceding interglacial stages. The Bradyan is characterized by the Brady soil named from a type locality in southwestern Nebraska.

The named stratigraphic units of the Wisconsinan Stage, the Peoria silt member and the Bignell silt member, are included within the Sanborn formation. However, extensive alluvial deposits of early Wisconsinan and late Wisconsinan ages and accumulations of eolian dune sands are extensive in the State but have not been assigned formal names. Alluvial deposits of this stage occur primarily along the existing valleys and have expression as low terraces; therefore they have generally been mapped as terraces or physiographic units and the deposits described in association with the mappable terrace form. These alluvial materials fit into the same cyclic pattern as the alluvial deposits of the earlier Pleistocene stages but it is judged to be advisable for the sake of clarity and convenience to continue the practice of relating them to the terrace form which must be utilized for mapping purposes. The dune sands also represent several different ages within the Wisconsinan and Recent and similarly are mapped on the basis of physiographic expression. In some areas they have been active during historic time. For these reasons a formal stratigraphic name has not been applied to dune sands in Kansas.

The evidence in Kansas shows that the deposits assignable to the Iowan and Tazewellian Substages constitute an essentially continuous series of sediments as do those of the Caryan and Mankatoan Substages. The Bradyan interglacial Substage serves to divide the Wisconsinan into two distinct segments and in the following discussions the deposits will be considered as early Wisconsinan (pre-Bradyan) and late Wisconsinan (post-Bradyan) in age.

The Wisconsinan also differs from the other glacial stages in Kansas in regard to the effect of continental glaciation. In Nebraskan and Kansan time glaciers extended into northeastern Kansas, and in Illinoian time the central Missouri River Basin was free of continental glaciers. In contrast, in Wisconsinan time continental glaciers, although failing to reach Kansas by some hundreds of miles, repeatedly invaded the Missouri Valley region to the north of Kansas and exerted an important direct effect on fluviatile and eolian sedimentation in the State. Iowan glacial ice covered much of northern Iowa (Kay and Graham, 1943; Smith and Riecken, 1947) and extended across Missouri River into northeastern Nebraska (Condra and Reed, 1950);

Tazewellian and Caryan glaciation have been described in southeastern South Dakota (Flint, 1947; H. E. Simpson, 1947), and the Mankatoan glacier extended far south into central Iowa. Valley glaciation was extensive in the central Rocky Mountain region during Wisconsinan time and therefore outwash was moving into or across Kansas from the west as well as the north.

EARLY WISCONSINAN ALLUVIAL DEPOSITS

Generally over Kansas an episode of valley deepening preceded the deposition of early Wisconsinan alluvial deposits. In some parts of central Kansas the amount of valley deepening was small (Fent, 1950a) and these deposits rest on earlier Pleistocene alluvium, but along all the valleys across the northern part of the State valley floors were deepend below the bedrock floors of the earlier Pleistocene valleys. This was also true in the Smoky Hill River Valley in western Kansas (Fig. 4) and in south-central Kansas the valley floors were deepened by several hundred feet (Pl. 2). In the valleys of streams now tributary to Kansas River a comparable episode of deep valley trenching did not occur in late Wisconsinan time and the pre-Bradyan alluvial deposits are now buried beneath post-Bradyan alluvial deposits. In strong contrast, along the valleys of some streams tributary to Cimarron and Salt Fork Rivers (tributary to Arkansas River in Oklahoma) the early Wisconsinan alluvial deposits form a distinct terrace, the late Wisconsinan alluvial deposits underlie a second distinct terrace at a lower level and are cut deeper into bedrock, and the Recent alluvium occurs at a still lower level. Thus, the Wisconsinan erosional history of south-central Kansas was quite different from that of the northern half of the State.

In the Kansas River basin of northern Kansas early Wisconsinan alluvial deposits are rarely exposed. Remnants of a terrace of Illinoian age are present in many of these valleys and the younger deposits occupy an erosional valley cut through these sediments, but where the upper part of the post-Illinoian alluvium is exposed it has been determined to be late Wisconsinan or Recent in age. Therefore, if early Wisconsinan alluvium is present in this region, it is judged to be the lower part of the fill below the low terrace surface. The lower part of this fill is below flood plain level and is known in some areas only from test drilling (Davis and Carlson, 1952, for Newman terrace in Kansas River Valley; Frye and A. R. Leonard, 1949, for Almena terrace of Prairie Dog Creek Valley, Kirwin terrace of North Solomon River Valley, and unnamed terrace of Sappa Creek Valley; A. R. Leonard, 1952, for Kirwin terrace of North Solomon River Valley; A. R. Leonard and D. W. Berry, in preparation, for Schoenchen terrace of Smoky Hill River Valley). As the lower part of this low terrace fill is consistently below flood plain level, it has yielded no fossils and the determination of its age rests entirely on its position, erosionally below Illinoian deposits and stratigraphically below late Wisconsinan deposits. The inferred early Wisconsinan alluvium consists entirely of sand and gravel and lithologically reflects the local rocks of the particular drainage basin.

Although this relationship is true throughout most of the Kansas River basin, in extreme northwestern Kansas in the headwaters area a few exposures of early Wisconsinan alluvium (SW¼ sec. 35, T. 11 S., R. 40 W., Wallace County) have been examined. In this area these alluvial deposits, the base of which contains boulders with a maximum diameter of 1 foot, are conformably below fossiliferous Peoria loess and have been exposed by post-Bradyan erosion. These facts suggest that in the headwater area the gradients of the early and late Wisconsinan streams have crossed.

In extreme south-central Kansas (Clark, Comanche, Barber, Harper, and Sumner Counties) two distinct Wisconsinan terraces have been observed along many of the valleys, particularly in the headwater portions. Along the northern tributaries to Cimarron River these two terraces are distinct and have yielded diagnostic early and late Wisconsinan faunas (SW¼ NW¼ sec. 20, T. 33 S., R. 23 W., Clark County). Each terrace fill generally contains a weakly developed soil within it. The early terrace deposit is commonly red in color, reflecting a source in the local rocks, whereas the younger terrace fill is gray to gray-tan in color. As the terraces along some of these valleys are traced toward Cimarron River they converge, intersect, and before the Cimarron River is reached the early Wisconsinan terrace disappears under the late Wisconsinan deposits. At some places (for example along Kiger Creek, NE¼ sec. 26, T. 33 S., R. 24 W., Clark County) the early Wisconsinan alluvium slopes back from the creek and converges imperceptibly with the pediment veneer on the Permian bedrock, but near the creek channel these deposits are overlain by a thin wedge of late Wisconsinan alluvium.

In Clark and adjacent counties an unusual type of Wisconsinan alluvium occurs as the filling of "sinks" or solution-subsidence areas (Frye and Schoff, 1942; Frye, 1950). As these features were isolated during their formation, their dating rests on their contained fossils and the intersection of lines of dissection. The evidence indicates that those exposed along Crooked Creek and Cimarron Valleys in southern Meade County were filled during Wisconsinan time, and a large molluscan fauna collected from the "Jones sink" in the headwaters of Sand Creek (secs. 33 and 34, T. 32 S., R. 27 W. and secs. 3, 4, and 9, T. 33 S., R. 27 W., Meade County) is early Wisconsinan in age. The coarse gravel grading upward into fine-textured fill of a sink is exceptionally well exposed in cuts along U.S. Highway 160 in the NW¼ NE¼ sec. 10, T. 33 S., R. 24 W., Clark County . Here the relation to adjacent lower (younger) filled "sinks" indicates that the deposits must be as old as early Wisconsinan, or perhaps slightly older. Much of central and southern Clark County is marked by solution-subsidence areas which were filled in late Pleistocene time.

The same sequence of low terraces that occurs along the Cimarron tributaries was also observed along tributaries to Salt Fork River. In southern Harper County long pediment surfaces are accordant with a terrace along East Branch Plum Creek. In the Cen. E½ sec. 35, T. 34 S., R. 8 W., cut banks expose about 10 feet of conglomerate, sand, and silt with a reddish color resting on Permian bedrock. These deposits contain a weak soil profile 2 feet below the top, their surface has only a slight topographic discordance with the thin pediment veneer on adjacent bedrock, and they contain in their lower part a distinctive early Wisconsinan molluscan fauna. A very narrow inner terrace has a surface 6 to 8 feet lower, is gray to gray-tan in color, and contains a distinctive late Wisconsinan molluscan fauna.

Although best exposed in the tier of counties adjacent to the Oklahoma state line, fossiliferous early Wisconsinan alluvium has been studied at other localities in central Kansas. It occurs as minor gully fills at the base of Peoria loess (NE¼ NE¼ sec. 2, T. 27 S., R. 22 W., Ford County) and as isolated terrace remnants along some valleys (Cen. N. line sec. 3, T. 28 S., R. 9 W., Kingman County).

PEORIA MEMBER, SANBORN FORMATION

The term Peorian was proposed by Leverett (1898a, p. 248) for a presumed interglacial interval between deposition of the Iowan loess and Shelbyville till in Illinois. The name was derived from exposures in the vicinity of Peoria, Illinois. Alden and Leighton (1917) showed that the Iowan loess was post-Iowan, or "Peorian" in age, and usage gradually changed the name of the loess from Iowan to Peorian. Peorian has been used throughout Iowa to apply to loess that occurs stratigraphically between the Iowa and Mankato till sheets (Kay and Graham, 1943) and, beyond the limits of these tills, unconformably on the Sangamon soil in Loveland loess. In Nebraska the term Peorian has been used for loess above Sangamon soil (Lugn, 1935) and below the Brady soil (Schultz and Stout, 1945; Condra and Reed, 1950). In Illinois, loess deposits within the border of the Tazewell till are interstratified with tills and are called Farmdale, Iowan, and Tazewell (Leighton and Willman, 1950), but beyond the limit of Tazewell till the Iowan and younger loesses are generally not differentiated and are collectively referred to as Peorian loess (Smith, 1942).

As now recognized in Kansas, the Peoria silt member of the Sanborn formation includes loess (Pl. 11) and locally water-laid silt that is stratigraphically continuous with it. Stratigraphic and faunal (A. B. Leonard, 1951) data show the Peoria of Kansas to be equivalent to the Peorian formation of Nebraska, to Peorian loess of much of western Iowa, and to loesses classed as Farmdale, Iowan, and Tazewell in central Illinois. The term Peoria is deemed appropriate for this unit in Kansas because of its equivalency to loess beyond the margin of the Tazewell till in the vicinity of Peoria, Illinois, in spite of the slightly different usage of the term Peorian in Illinois. In this report where the unit is designated Peoria loess the deposit consists of eolian silt on upland and intermediate levels, whereas the name Peoria silt member includes not only the loess but also water-laid deposits of silt on lower topographic positions.

The stratigraphy, petrography, origin, and molluscan faunas of the Peoria loess in Kansas have recently been described in some detail (Frye and A. B. Leonard, 1951; Swineford and Frye, 1951; A. B. Leonard, 1951) and relatively few specific localities will be described here.

The Peoria silt member is uniform, homogeneous, generally fossiliferous, calcareous, and massive silt. In texture it ranges from coarse silt and very fine sand adjacent to the bluffs of Republican and Arikaree River Valleys in northwestern Kansas, Republican River Valley in the north-central area, and Missouri River Valley in Doniphan County, to medium to fine silt and clay in Marshall and adjacent counties and the thin upland patches in east-central Kansas. Adjacent to Arkansas River in the southwest the Peoria contains some medium to fine sand. Although generally massive, some lamination occurs in the Peoria of both extreme northeastern and northwestern Kansas. The member is commonly buff in color with a reddish or tan cast in the northeastern area and a pale yellow cast in the northwestern part of the State. In thickness the Peoria ranges from maxima of 90 feet in Cheyenne County (Sanborn type section), more than 100 feet in Doniphan County (Frye and Walters, 1950), and 40 feet in the Republican River Valley bluffs of Republic County through the extensive areas of 20 to 40 feet thickness in northwestern and west-central Kansas to the thin discontinuous upland veneer less than 2 feet in thickness in the central part of the glaciated area and in east-central Kansas. The pattern of distribution of eolian silt shown in Plate 1 is essentially the distribution pattern of Peoria loess as loess in Kansas, volumetrically, is predominantly Peoria.

As the Peoria is at or near the surface in approximately one-third of the area of Kansas many excellent exposures exist and it is readily accessible to the hand auger and test drill. It has been studied at many hundred localities in northern and western Kansas and at scattered localities in the central and western areas. The stratigraphy of the Peoria is relatively simple and strikingly uniform over the State. Where sufficiently thick it displays a partly leached zone at the base that may be described as an "inverted A horizon" above the A horizon of the Sangamon soil. It is judged that, after the development of the Sangamon profile, loess accumulation on the uplands started so slowly that the silt was incorporated into the top of the profile as a super-attenuated upper part of the A horizon, but as the rate of deposition increased it eventually exceeded the rate of leaching and this leached material grades upward into calcareous loess containing fossil mollusks. At a few localities in southwestern Nebraska distinct but very weak soil zones occur in the upper part of this basal zone and suggest minor pauses in loess accumulation. This lowermost leached zone is the upper part of the *Citellus* zone of Nebraska literature and was called the basal faunal zone by A. B. Leonard (1951). Above the basal zone the Peoria contains three distinct faunal zones (A. B. Leonard, 1951) but over most of the State there is no lithologic break. In Doniphan County (Iowa Point section) a thin leached zone separates the upper and lower faunal zones and may correspond to the weak soil in the early Wisconsinan alluvial deposits of south-central Kansas. The stratigraphic relation of the Peoria loess is shown by the measured sections from Iowa Point, the type Sanborn locality, and the three given below.

Section of Sanborn formation measured by O. S. Fent in the NW cor. SW¼ sec. 7, T. 18 S., R. 7 W., Rice County.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
Bignell silt member (Wisconsinan Stage, Caryan-Mankatoan Substages)	
4. Silt, entirely in profile of top soil	1.5
Peoria silt member (Wisconsinan Stage, Iowan-Tazewellian Substages)	
3. Silt, light-tan, leached throughout but contains a few caliche nodules and stringers; contains **Brady soil** at top.	6.4
Loveland silt member (Illinoian Stage)	
2. Silt, calcareous in bottom 1.5 feet; upper part in profile of **Sangamon soil**, a deep humic-gley with black A horizon containing secondary lime from leaching of Peoria above. Basal 1 foot contains molluscan fauna	6.5
Total thickness of Pleistocene deposits	14.4
CRETACEOUS—Gulfian	
Dakota formation	
1. Clay shale, gray and tan, weathered, contains caliche nodules.	

Sanborn formation measured in highway cuts in the NW¼ sec. 11, T. 3 S., R. 23 W., Norton County.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
Peoria silt member (Wisconsinan Stage, Iowan-Tazewellian Substages)	
3. Silt, massive, gray to yellowish-tan, mealy; contains snails	25.0
Crete-Loveland member (Illinoian Stage)	
2. Silt, sand, and some gravel. **Sangamon soil** in upper part, a well-drained profile with brown A horizon and reddish-brown B horizon containing vertebrate fossils. The soil thins toward the north and at the bluff of Prairie Dog Creek Valley only 1.5 feet (predominantly A horizon) overlies Ogallala formation. Maximum thickness at south part of exposure	7.9
TERTIARY—Pliocene	
Ogallala formation—Ash Hollow member	
1. Sand, silt, and gravel, cemented loosely throughout with calcium carbonate	31.0
Total thickness measured	63.9

Sanborn formation exposed in road cut and creek bank in the NW¼ NW¼ and SW¼ NW¼ sec. 26, T. 2 S., R. 23 W., Norton County.

	Thickness, feet
QUATERNARY—Pleistocene	
Sanborn formation	
Bignell silt member (Wisconsinan Stage, Caryan-Mankatoan Substages)	
3. Silt, massive, gray, sparsely fossiliferous, contains well-drained soil profile in top	4.0
Peoria member (Wisconsinan Stage, Iowan-Tazewellian Substages)	
2. Silt, yellow-tan, massive, calcareous, fossiliferous, mealy, contains **Brady soil** in top, 18 inches leached, dark A horizon and brown B horizon with clay accumulation	20.0
Loveland silt member (Illinoian Stage)	
1. Silt and clay with sand in lower part, entirely within the profile of the **Sangamon soil**; red-brown in upper part, clay in B horizon, strong caliche accumulation 5 feet below top.	7.5
Total thickness measured	33.5

The Peoria loess is determined, from the facts that it becomes finer texturally and diminishes in thickness in directions away from major outwash-carrying valleys, from its occurrence on upland surfaces, its contained molluscan faunas, its degree of sorting, and its relation to buried soils to be an eolian deposit (Swineford and Frye, 1951). It has expression in the topography over large areas in the State. Along the Missouri and Republican River Valleys the accumulation of loess has increased the topographic relief as it has in parts of the High Plains area of northwestern Kansas. The High Plains surface of central and western Kansas has been rendered even more featureless by the loess blanket. This eolian silt has virtually erased earlier shallow drainageways, and larger valleys possess loess "drifts" along the northwestern valley walls (NE¼ sec. 12, T. 19 S., R. 37 W., Wichita County). Along some northwestern valleys (exemplified by Prairie Dog Creek Valley in Norton County) loess drift from the north-northwest has virtually obliterated the surface expression of the "heel" of the Illinoian age terrace and forms a continuous loess mantle from the uplands across this terrace.

BRADYAN SUBSTAGE

The Bradyan Sub-Age is an interglacial interval of relatively short duration characterized by stable soil-forming conditions. Occurring between the Tazewellian and Caryan Sub-Ages it serves to divide the Wisconsinan into two unequal parts. This sub-age (substage) takes its name from the Brady buried soil (Pl. 12) described by Schultz and Stout (1945, p. 241) from exposures in the south wall of the Platte River Valley in sec. 3, T. 12 N., R. 29 W., Lincoln County, Nebraska. The name has been used generally throughout northern and western Kansas.

With reference to Brady buried soil where developed on Peoria loess in north-central and western Kansas and southern Nebraska, Thorp, Johnson, and Reed (1951, p. 9) make the following statement:

> Some of it is a Chernozem-like silt loam without textural variation in the profile; and some of it has a mottled subsoil suggesting that it may be a preserved Wiesenboden or Humic-Gley soil. The Bignell loess, that overlies the Brady soil in places, has in it a succession of dark bands or weak soils that represent short periods of pause or slow-down in loess deposition. 'Double soils' with one dark A horizon superimposed over another, and in places with

claypans in the buried soils as described by Williams (1945), are very common in the regions where Chernozem, Chestnut, and Brown soils are developed in Peoria and younger loess. The 'double soils' are most distinct near the probable sources of the loess, and the two A horizons blend on the plains a few miles from these theoretical sources. Thus the 'Brady soil' in many places is a part of the modern soil.

Unlike the Sangamon soil, which is observable almost continuously east-west across northern Kansas and north-south across western Kansas, the Brady buried soil has regional extent only in the northwestern quadrant of the State. In the Missouri River Valley bluffs of Doniphan County Brady soil is exposed below Bignell loess at a few localities (Iowa Point section) and has a maximum depth of 14 feet. However, west of Missouri River Valley the Brady has not been recognized with certainty in eastern Kansas.

In northwestern and west-central Kansas Brady buried soil has been recognized at most localities where the Bignell loess has been observed resting on Peoria loess. It is best exposed in the area from Phillips County (Pl. 12A, 12B) westward through Norton County (SE¼ SW¼ sec. 11, SW¼ sec. 14, and NE cor. sec. 23, T. 2 S., R. 23 W.; SE¼ NE¼ sec. 22, T. 4 S., R. 23 W.; NE cor. sec. 10 and NW cor. sec. 18, T. 5 S., R. 22 W.), Decatur County (SW¼ sec. 23, T. 4 S., R. 27 W.; SW¼ sec. 36, T. 5 S., R. 29 W.), Rawlins County (Pl. 11A), and into Cheyenne County (SE¼ SE¼ sec. 28, T. 3 S., R. 39 W.), and southward through Graham County (NE¼ NE¼ sec. 14 and NW¼ NW¼ sec. 36, T. 6 S., R. 23 W.), Thomas County (NE¼ sec. 7, T. 8 S., R. 35 W.), Logan County (NE¼ sec. 32, T. 12 S., R. 37 W.), Greeley County (NW¼ sec. 9, T. 16 S., R. 40 W.), and into Scott County (SE¼ sec. 6, T. 17 S., R. 32 W.). Throughout this region the Brady is developed in Peoria loess, the profile is moderately to poorly drained, and the depth of leaching ranges from about 1 to 3 feet. The A horizon is generally dark and caliche nodules one-half to 1 inch in diameter occur in the base of the B horizon. The B horizon is generally dark gray to gray brown and in some localities has clay accumulation and good structure whereas at other localities little textural contrast occurs between the A and B horizons. The profile of the Brady is generally deeper than the modern profile developed on the overlying Bignell loess, but this contrast may not be significant because at many of the Brady

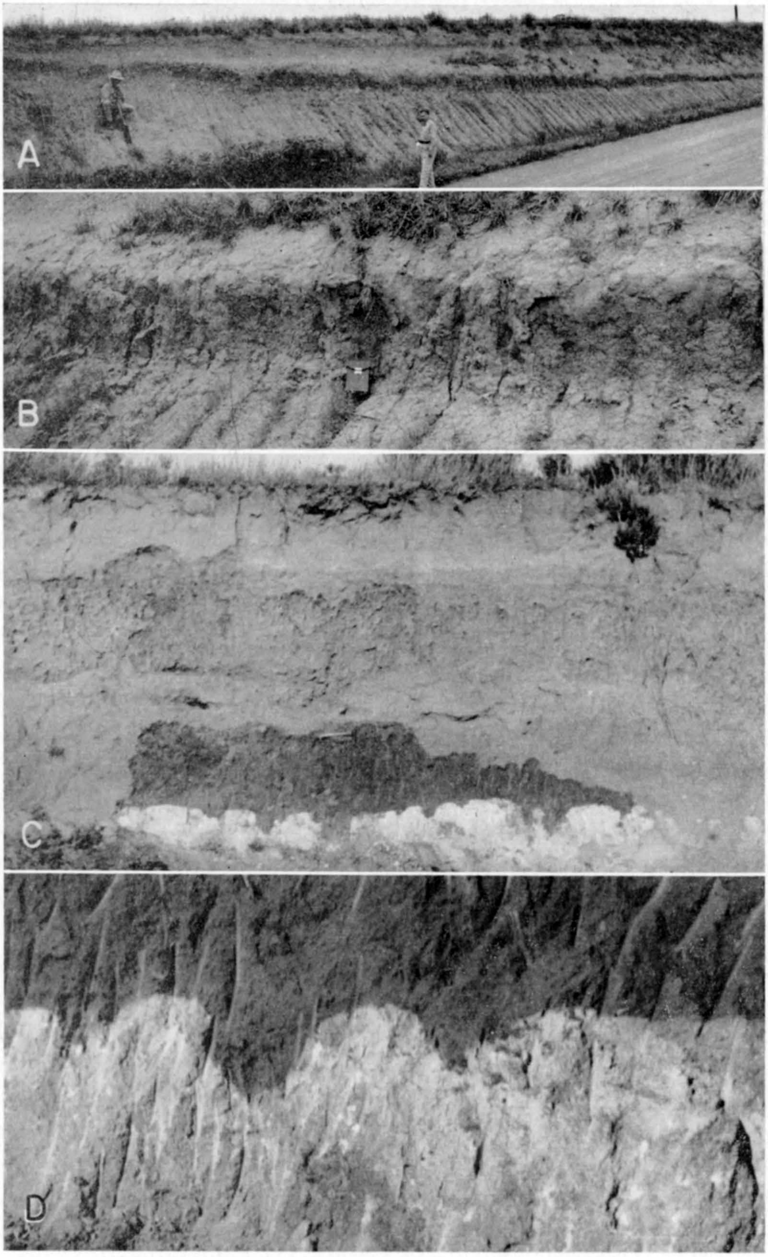


Plate 12. **The Brady soil in western Kansas. A** and **B,** Brady soil in Peoria loess overlain by Bignell loess, north of Speed, Phillips County. (A. R. Leonard, 1947.) **C** and **D,** Brady soil developed in early Wisconsinan alluvium containing molluscan fauna, overlain by thin alluvium containing late Wiscon-

exposures this buried soil is judged to have developed under conditions of poorer drainage than did the modern soil at the same locality.

As exposures of early Wisconsinan alluvium are virtually nonexistant in northwestern Kansas, the Brady buried soil is known only from the loess section on uplands and intermediate levels in this region. In south-central Kansas, however, the Brady has been studied at a few localities (Pl. 12B, 12C) where it is developed in alluvial deposits. Here it is more strongly developed than in the north, the B horizon has a pale reddish cast, and the caliche zone is thick with a sharp though crenulate boundary at the top.

Although Bignell loess has not been recognized in southwestern Kansas, a soil developed in Peoria loess and overlain by dune sand (SE¼ sec. 25, T. 29 S., R. 43 W., Stanton County) is judged to be approximately equivalent to the Brady. This soil is similar in morphology to the Brady soil of northern Kansas but is deeper and more strongly developed. As the age of the overlying dune sand has not been established the interval during which the profile developed is not known.

The evidence from the character of the Brady soil suggests that the climate under which it developed was much the same as that of the present. The degree of development, when contrasted with the Sangamon and older soils on the one hand and with the modern soil on the other, suggests that the Bradyan interval was comparable in duration to Recent time but was only a fraction (perhaps one-third to one-fourth) the length of the Sangamonian and earlier major interglacial ages.

LATE WISCONSINAN ALLUVIAL DEPOSITS

Alluvium of late Wisconsinan age occurs in virtually all the valleys of Kansas; it constitutes much of the surface area shown by the Wisconsinan and Recent patterns on Plate 1. Throughout the Kansas River basin (roughly the northern half of Kansas) post-Bradyan Wisconsinan alluvium, consisting of coarse to fine sand, silt, and small amounts of clay and gravel, underlies the

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sinan soil which is overlain by 2 feet of Recent alluvial sand to the top of the cut. The top of the caliche zone of the Brady soil is sharply defined in this alluvium of silty sand. (1951).

surfaces of extensive low terraces. These low terraces occur 5 to 45 feet above the flood plains and commonly their height is 20 to 30 feet. Although in some valleys they are above maximum flood level in most places extreme flood crests cover their surfaces. This was dramatically illustrated by the maximum flood of record in the Kansas River Valley during July 1951 when all but the high points of the former natural levees on this terrace surface were covered by water for the first time since 1844. These rare episodes of flooding have added an increment, of unknown but probably small thickness, of Recent material to the surface of the terrace and have served to erase from the terrace surface the characteristic flood plain features, such as meander scrolls and abandoned channel segments. In the major valleys low and very gently sloping natural levees are nevertheless still distinguishable.

Along some of the valleys of northern Kansas this terrace, or terrace complex, has been studied, named, and mapped. In the Kansas River Valley it is called the Newman terrace (Davis and Carlson, 1952), in the North Fork Solomon River Valley, the Kirwin terrace (Frye and A. R. Leonard, 1949, A. R. Leonard, 1952), in Prairie Dog Creek Valley, the Almena terrace (Frye and A. R. Leonard, 1949), and in the Smoky Hill River Valley the Schoenchen terrace (A. R. Leonard and D. W. Berry, in preparation). Similar terraces have been studied, but not formally named, in South Fork Solomon River Valley, Republican River Valley, Sappa Creek Valley, Hackberry Creek Valley, and several minor tributaries to Kansas River. The existence of this system of low terraces throughout all but the westernmost part of the Kansas River basin in Kansas indicates a uniform history of late Wisconsinan alluviation throughout this region followed by dissection and development of the modern flood plains during Recent time.

A rather persistent feature of the low terraces is the presence within them of a weakly developed, but black and distinctive soil band. This soil commonly occurs above the level of the active flood plain and from 5 to 15 feet below the surface of the terrace. It has been observed in this terrace along many of the valleys in northern Kansas (NE¼ sec. 34, T. 3 S., R. 17 W., Phillips County; SE¼ SE¼ sec. 15, T. 3 S., R. 24 W., Norton County; SE¼ NE¼ sec. 1, T. 13 S., R. 29 W., Gove County) where it is a moderately to poorly drained immature profile; in some exposures it is associated with both higher and lower humic bands which suggest very short periods of surface stability.

The late Wisconsinan to early Recent age of these low terraces is indicated by their contained fossil mollusks at many localities, by the fact that the Peoria loess and Brady soil (which do not extend over the terrace surfaces) are at some places truncated by the valley sides, by their extremely youthful physiographic expression, and by the observed flooding of their surfaces by maximum floods. That their period of major alluviation was terminated in latest Wisconsinan or early Recent time is demonstrated by their relation to the modern active flood plains which are cut appreciably below the low terrace surface. The age of the persistent weak soil in the upper part of the terrace deposits is not known—it may be as young as early Recent.

Along some of the northern valleys tributary to Arkansas River in the central part of the State late Wisconsinan alluvium constitutes the only recognizable terrace. An excellent exposure of these deposits is afforded by an artificial channel cut in the SE¼ SE¼ sec. 9, T. 21 S., R. 5 W., McPherson County. In this section the modern top soil is strongly developed (leached 18 inches with reddish B horizon and prominent caliche zone) in sandy material. A Wiesenboden profile developed in silt and sandy silt (A and B horizons very dark, caliche zone at base of 12 to 18 inches of leached material) occurs 3½ feet below the terrace surface. Below this buried soil, which may correspond in age to the persistent buried low terrace soil of the Kansas River basin, a post-Bradyan molluscan fauna was collected. At a depth of 9 to 10 feet below the terrace surface is a second buried soil (leached 2 feet, dark A horizon, and a reddish cast to the B horizon) developed in calcareous reddish silt that overlies sand down to the channel level.

A comparable terrace, both in form and deposits, occurs along Sawlog Creek Valley (Cen. E. line sec. 27, T. 23 S., R. 22 W., Hodgeman County) where a post-Bradyan molluscan fauna was collected below a buried soil and along Pawnee River Valley (SE cor. sec. 20, T. 21 S., R. 21 W., Hodgeman County).

South of Arkansas River Valley, in extreme south-central Kansas, late Wisconsinan alluvium occurs in many of the valleys under a distinct terrace surface at a level lower than the adjacent early Wisconsinan terrace. The bedrock floor below the two terraces also shows distinct offset in level. This relation is well shown by exposures in the cut bank of Medicine Lodge River in the NE¼ SW¼ sec. 20, T. 33 S., R. 11 W., Barber County. Near these exposures on the surface of the second terrace (possibly the type of Knight's Gerlane formation) is the town of Gerlane. The channel bank exposure shows the terrace deposit to consist of sand and silt grading downward into sand and gravel which rests on Permian shale and siltstone at a level 3 to 4 feet above normal water level in Medicine Lodge River. The late Wisconsinan terrace truncates the "Gerlane" terrace and its bedrock floor is an unknown depth below channel level. This terrace consists predominantly of sandy silt and clayey silt; it contains a buried soil (dark A horizon and weakly developed B horizon) about 4 feet below the terrace surface; a post-Bradyan molluscan fauna was collected from below the base of the buried soil profile. This terrace with its contained buried soil is in turn truncated by the flood plain sediments, the surface of which stands at approximately the same level as the bedrock floor of the second or "Gerlane" terrace.

The relation of these young terraces is also shown by fossiliferous exposures along East Branch Plum Creek in the Cen. E½ sec. 35, T. 34 S., R. 8 W., Harper County. Along this small valley the terrace deposits are thinner and the young terrace (containing a post-Bradyan molluscan fauna) is quite narrow but the physiographic relations are similar to the locality described along Medicine Lodge River.

In the area of east-central and southeastern Kansas it is judged that late Wisconsinan alluvial deposits are generally indistinguishable from Recent alluvium and constitute a part of the flood plain complex in most of the major valleys. Minor flood plain terraces have been observed in many of these valleys but precise dating has as yet not been attempted.

BIGNELL MEMBER, SANBORN FORMATION

The Bignell loess was named by Schultz and Stout (1945, p. 241) from exposures along the south bluff of the Platte River Valley, near the town of North Platte, in sec. 3, T. 12 N., R. 29 W., Lincoln County, Nebraska. Thin discontinuous deposits of Bignell are distributed widely over the northwestern quadrant of Kansas (at all localities cited for Brady soil in previous section). In that area the member is generally less than 10 feet thick, resembles the underlying Peoria loess in lithology, and contains a distinctive, though sparse, molluscan fauna. Its stratigraphic position is shown in the measured sections of the Peoria member.

In northeastern Kansas Bignell loess occurs discontinuously along the Missouri River Valley bluffs in Doniphan County, where it has the maximum thickness (35 feet) observed in the State (Iowa Point section). In Doniphan County this loess has a relatively dense concentration of snail shells.

In central Kansas the Bignell loess occurs only at a few places (measured section in Rice County) and is quite thin and nonfossiliferous. It has not been recognized in southeastern or southern Kansas.

Wherever observed the Bignell loess is so similar to the Peoria that it can be distinguished from it only by the presence of the Brady soil stratigraphically below it or by its contained molluscan fauna. Quantitatively it is insignificant in comparison to the Peoria member.

The Bignell, like the Peoria and Loveland members of the Sanborn formation, is intended to include, in addition to the loess, alluvial silts that are stratigraphically continuous with it. Therefore, it might be appropriate to class within the Bignell member some of the silty upper part of the late Wisconsinan alluvial deposits. This has not been the practice in Kansas because stratigraphic continuity between the two environments of deposition has not been established for the Bignell as it has for the older silt members, the exact age of the deposits has not been determined, and the alluvial materials are always mapped on the basis of their physiographic form without formal stratigraphic name.

The age of the Bignell is determined to be Caryan-Mankatoan because it rests on Brady soil (developed during Bradyan time in Tazewellian deposits); it contains a fauna distinctly younger than the Tazewellian fauna of the upper zone Peoria and perhaps somewhat older than the living fauna of the region; physiographic relations indicate that it was deposited prior to the development of the Recent flood plain sediments; and the surface soil developed in its top is roughly comparable in degree of development to the

Brady buried soil. Although these data establish it as late Wisconsinan they do not permit definite correlation of the Bignell with Caryan or Mankotan, nor for that matter do they clearly exclude it from earliest Recent time. It is our judgment that its deposition started in Caryan time and extended through Mankatoan time.

RECENT STAGE

The Recent Stage is comprised of those deposits made since the extinction of the Mankatoan glacier as an active force, or during "the last 10,000 years." The Recent Age is exceedingly short when compared with the other ages of the Pleistocene; also it is difficult to delimit. Its fauna includes the present living fauna of the region and possesses far fewer elements of contrast with late Wisconsinan faunas than are present even within the Wisconsinan. Evidence from the morphology of soil profiles indicates that the Recent Age is no longer than the Bradyan interglacial Sub-Age and merits an age (stage) classification only because of its recency and the fact that we live within it.

Recent deposits in Kansas consist of alluvium under the surfaces of some flood plains and in the upper part of some low terrace deposits, the surficial part of the eolian sand included in many of the sand dune tracts, and possibly also a small quantity of eolian silt or loess. Although these deposits are quantitatively of small significance, the fact that wherever they occur they are the surface materials makes them geographically important (Pls. 1, 2). Thin colluvial veneers on many slopes and much of the modern soil developed during Recent time.

SAND DUNE TRACTS

Eolian sand, consisting of well-sorted, moderately to well-rounded, generally noncalcareous arkosic sand and displaying a recognizable dune topography, occurs at the surface of approximately 3,500 square miles in Kansas (Pl. 1). During the present century dunes have been migrating actively over a relatively small fraction of this area. In some localities (Pl. 13) the sand is in striking dune form with individual dunes attaining a maximum height of as much as 70 feet (Smith, 1940, p. 153) whereas in other areas the dunes constitute gentle swells in the topography and contain a soil profile of sufficient maturity to permit cultivation in most years.

The sand dune tracts are discussed as part of the Recent Stage because in most areas the last episode of dune formation, or eolian sand migration, occurred during Recent time; however, the major dune tracts were initiated, and may even have had their major development, during Wisconsinan time. A formal stratigraphic name has not been applied to these surficial eolian sands in Kansas.

The largest dune tract in Kansas, and one of the larger tracts in the United States, has been referred to as the Great Bend tract or the Kinsley dune tract (Pl. 1). This expanse of dunes occupies much of the area enclosed within the great bend of Arkansas River in Barton, Stafford, Pawnee, Edwards, Kiowa, Pratt, Rice, and Reno Counties. Northeast of the Arkansas River flood plain a dune tract that is a geographic extension of the Great Bend tract is located in Rice, Reno, and Harvey Counties and is called the Hutchinson dune tract. Westward along the south side of Arkansas River there is a continuous belt of dunes extending from the Great Bend area to the Colorado state line. This belt of dunes expands into a sizable area called the Garden City dune tract in southern Kearny and Finney Counties and central Gray County. This entire integrated dune complex, covering an estimated 3,000 square miles, is genetically related to Arkansas River and its Illinoian and younger deposits. In topographic expression the dunes range from rugged and active to relatively low gentle swells with a stable soil at the surface. The rugged active dunes are commonly located near Arkansas River, and the areas more remote from the river present, on the average, a more subdued topography. The presence of moderately mature surface soil profiles 12 to 18 inches deep on some of the subdued dunes does not necessarily indicate great antiquity as the original sands were noncalcareous, highly permeable, well drained, and covered with a prairie flora, all factors conducive to rapid development of dark-colored soils.

Within the Great Bend dune tract and its extensions, several cycles or episodes of dune formation have occurred within late Pleistocene time. Buried soils are present below the younger sands and are well exposed in the Hutchinson area (cut of Chicago, Rock Island, and Pacific Railroad in secs. 15 and 22, T. 22

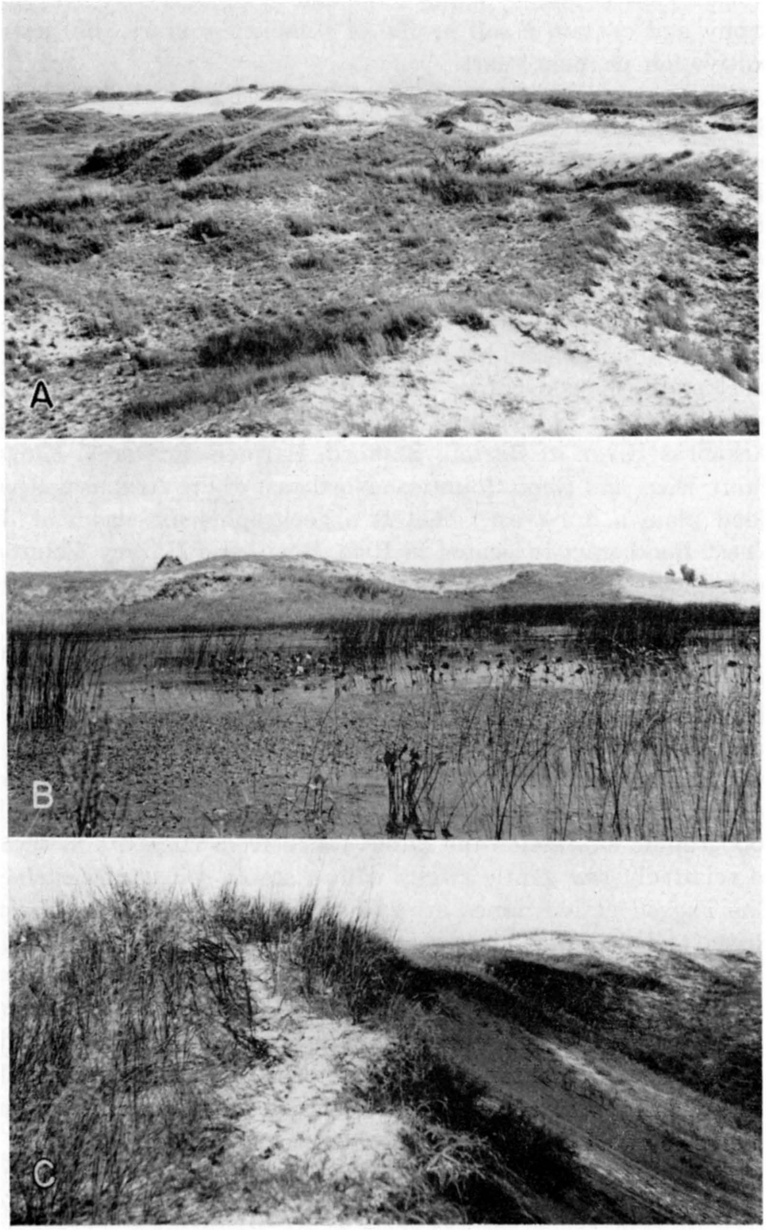

Plate 13. Late Pleistocene sand dunes. A, Active dune area on post-Bradyan Wisconsinan surface north of Cimarron River in the "Englewood basin," SW¼ SW¼ sec. 8, T. 35 S., R. 24 W., Clark County. (Ada Swineford, 1951.) **B,** Small pond and bordering dunes west of "Salt basin" in the Great

S., R. 5 W., Reno County). The earliest dune sands in this area are known to be no older than early Wisconsinan as Crete sand and gravel and Loveland silt occur extensively below the sand (Pl. 1). As the dunes rest on a floor of fossiliferous Peoria silt at some places (near Bear Creek bridge in the NW¼ sec. 12, T. 28 S., R. 41 W., Stanton County) it is judged that much of the dune formation occurred in late Wisconsinan and Recent time.

South of the Arkansas River area, several disconnected dune areas occur on the High Plains surface. Some of these (southeastern Pratt County) have not furnished evidence of multiple periods of development, whereas others (the Fowler area) display evidence of several cycles. In the Fowler area the dunes occur along the margin of a late Wisconsinan or Recent temporary lake (Frye, 1942) and rest on a floor of fossiliferous Sappa silt. Two well-developed buried soils separating units of dune sand are exposed in the cut of the Rock Island Railroad in sec. 35, T. 30 S., R. 26 W., Meade County. The youngest dune sand here is Recent in age but the older cycles may be Wisconsinan in age.

An extensive area of low subdued dunes occurs on the High Plains surface both north and south of Cimarron River in Morton, Stevens, Seward, and Meade Counties. At a lower level, several tracts of dunes, in some places resting on a floor of late Wisconsinan alluvium, occur near Cimarron River in southern Clark County (Pl. 1).

Smith (1940, pp. 153-168) has discussed the sand dunes of southwestern Kansas and described a cycle of development as follows (p. 160):

> The dune cycle embraces two distinct phases, characterized by different processes: first an *eolian,* or active stage, and, second, an *eluvial,* or passive phase. During the eolian phase, the dune is built up. Stabilization by vegetation introduces the eluvial phase, throughout which the dune is protected from wind attack, and undergoes gradual wasteage through weathering and creep. This second phase of the cycle, however, is subject to interruption through rejuvenation, whereby wind action is resumed and a new cycle inaugurated.

Bend sand dune tract; NE¼ sec. 29, T. 21 S., R. 11 W., Stafford County. (Ada Swineford, 1951.) C, Active dune area on south side of Arkansas River Valley west of Syracuse, Hamilton County. (Ada Swineford, 1951.)

VALLEY ALLUVIUM

Virtually all major valleys and many minor valleys in Kansas contain active flood plains composed of Recent alluvium. Many of these flood plains should be considered "complexes" as they possess minor terraces, or pseudoterraces formed by point-bar accretions, meander scrolls, incipient natural levees, or eolian scour and deposition. The surficial material of some low terraces that stand distinctly above the adjacent flood plain is Recent in age and the material of the active flood plain is Recent—perhaps in large part late Recent—in age. In many of the major valleys (Kaw, Republican, Prairie Dog, etc.) the Recent alluvial deposits are a minor insertion into the upper part of the late Wisconsinan alluvium and are underlain by the slightly older deposits. However, in some other valleys, particularly in south-central Kansas, Recent alluvium was deposited in an erosional trough that had been cut into bedrock through the late Wisconsinan fill. In some valleys in east-central Kansas (Cottonwood-Neosho system) Recent alluvium has not been differentiated from the Wisconsinan deposits. Alluvium of silt, sand, and gravel deposited during the Recent Age is quantitatively minor, is now in the process of deposition or modification by erosion and redeposition, has been assigned no formal stratigraphic name, and will not be discussed in detail.

STRATIGRAPHIC PALEONTOLOGY

GENERAL CONSIDERATIONS

The guiding principles of stratigraphic paleontology have been well known for many years, but since they are not always borne in mind, even by those whose work is dependent upon them, a review of the most important considerations seems appropriate. (1) Fossils are useful in stratigraphic studies only when they occur in identifiable and characteristic faunal assemblages of limited vertical range; they thus become in essence a real part of the distinctive lithology of the rocks that contain them. (2) Distinctive assemblages of fossils must occur at many localities over a wide area if they are to be useful to the stratigrapher; otherwise the sites of occurrence, although perhaps interesting, become mere curiosities to the student of stratigraphy and without value for correlation of strata of rocks. (3) The principle of superposition applies to assemblages of fossils as well as to the rocks themselves, even though the vertical sequence of distinctive faunal assemblages may not be readily correlatable with stratigraphic schemes based on other criteria. And (4) it must be kept in mind that the validity of interpretations of past ecological conditions, based on the presence of organic remains in the rocks, is invariably dependent upon a knowledge of living representatives of the same or similar groups of organisms.

In the light of these principles, the groups of fossil organisms of stratigraphic significance in the Pleistocene rocks of Kansas become stringently limited. A few fossil seeds of grasses have been found at one or two exposures (SE¼ sec. 20, T. 13 S., R. 11 W., Lincoln County) and pieces of well-preserved wood have been recovered from Kansas till (NW¼ sec. 10, T. 6 S., R. 20 E., Atchison County) but these sporadic occurrences obviously have no practical importance in stratigraphic studies. The zygospore cases of some kind of alga resembling *Chara* are known to occur at several exposures in sediments of Nebraskan (SW¼ sec. 22, T. 33 S., R. 29 W., Meade County) or late Kansan (NW¼ sec. 36, T. 14 S., R. 11 W., Russell County; NW¼ sec. 28, T. 13 S., R. 10 W., Lincoln County) age. These fossils have no stratigraphic consequence at the present because they are too poorly understood taxonomically, their areal distribution is too greatly restricted, and their vertical range is not known. Studies of fossil pollens have been carried on at a single locality in Kansas (NE¼ sec. 16, T. 6 S., R. 17 E., Atchison County) where pollen of spruce and pine (R. L. McGregor, Department of Botany, University of Kansas, personal communication) have been isolated from sediments in a marsh deposit of late Wisconsinan age. Exploitation of fossil pollen in Pleistocene sediments in the State might prove to be profitable in stratigraphic studies. The fact is, however, that paleobotany has not yet contributed significantly to a knowledge of Pleistocene stratigraphy in Kansas.

The shells of ostracods are known to occur at a few places in sediments of Nebraskan (SW¼ sec. 22, T. 33 S., R. 29 W., Meade County) and late Kansan (SW¼ sec. 13, T. 30 S., R. 23 W., Clark County; SW¼ sec. 35, T. 15 S., R. 2 E., Dickinson County; SE¼ sec. 22, T. 14 S., R. 12 E., Wabaunsee County; and other localities) age but no systematically organized and intensive search for these minute fossils has ever been undertaken in the State. Exploitation of fossil ostracods for stratigraphic purposes in Pleistocene deposits in Kansas must await the acquisition of a knowledge of the living ostracod fauna of the region, which is at present almost entirely lacking. Studies of living and fossil ostracods, such as those currently in progress in Illinois (Kesling, 1951) might well prove to be profitable, especially where lacustrine sediments occur. Pending the development of a better knowledge of these organisms, fossil ostracods are virtually useless in studies of Pleistocene stratigraphy in Kansas.

In large measure, vertebrate fossils are also of limited utility for state-wide studies of stratigraphic correlation in the Pleistocene sediments under consideration. The early studies of Hay (1917; 1917a, 1924) and others were often conducted without critical attention to the stratigraphic occurrence of fossils, or identifications of the animals were based on inadequate or poorly preserved materials. Recent intensive studies of fossil vertebrates in sediments of Nebraskan and Kansan age (Hibbard, 1937; 1937a; 1937b; 1938; 1939; 1940; 1940a; 1941; 1941a; 1941b; 1941c; 1942; 1943; 1943a; 1944; 1948; 1949a; 1949b; 1950; 1951; 1951a; 1952a) in southwestern Kansas and at a few exposures in Kansan sediments in the central part of the State (Frye, Leonard, and Hibbard, 1943; Hibbard, 1952) have resulted in a highly detailed knowledge of Pleistocene vertebrates at a small number of exposures of limited areal distribution and restricted vertical range. While the value of these studies is fully recognized, the restricted areal and vertical distribution of the described assemblages of vertebrate fossils removes them from practical consideration in stratigraphic studies over the State. The vertebrate paleontology of Illinoian and Wisconsinan deposits in Kansas is essentially unknown, and since the reported occurrence of vertebrate fossils in sediments of these ages is sporadically and erratically distributed, remains of vertebrate animals contained in these portions of the Pleistocene rocks in Kansas have little practical utility in studies of stratigraphic correlation. That fossil vertebrates have been a valuable aid in studies directed toward elucidating the major subdivisions of Pleistocene rocks in the midcontinent region and intercontinental correlations of major subdivisions cannot be denied, but for reasons already stated, the field stratigrapher

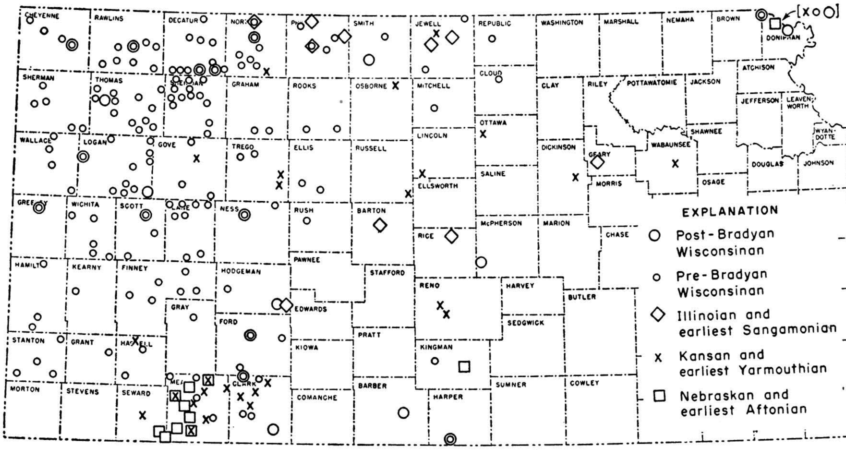

FIG. 5.—Map of Kansas showing geographic distribution of Pleistocene molluscan faunas listed in this report.

cannot feasibly utilize them in detailed correlation studies within Kansas.

In view of the present state of knowledge of the several kinds of organic remains preserved in Pleistocene deposits in Kansas, the shells of Mollusca are certainly the most widely useful fossils for purposes of stratigraphic correlation. The shells of mollusks occur in distinctive and recognizable assemblages of species, the assemblages are reasonably well distributed over much of the State (Fig. 5), there is a known vertical sequence of distinctive faunal assemblages characterizing each major cycle of Pleistocene deposition (Fig. 11), and in the case of Wisconsinan deposits, molluscan faunal aggregations even permit subdivisions of massive silts into zones corresponding to recognized lithologic units in the glaciated portion of the Mississippi Valley. Furthermore, since the ecological requirements of most mollusks are known, at least in their broad aspects, paleoecological interpretations of a conservative nature may be made with a reasonable expectation of accuracy. No claim for inerrancy in the use of these fossils can be made; distinctive assemblages are often lacking at critical exposures, the shells are highly susceptible to weathering and to destruction by abrasion in coarse fluviatile clastics, and identification of the kinds of mollusks, based on the shells alone, is often fraught with difficulty and a certain degree of inaccuracy. These admitted limitations are largely nullified by the ease with which shells are preserved in many sediments, notably silts, the widespread occurrence of shells where vertebrate fossils are rare or absent, the relatively high population density of most kinds of mollusks where they occur at all, and their sedentary habits as animals, from which it usually may be inferred that the shells were deposited in Pleistocene sediments not far from the places where the animals lived.

Molluscan Faunal Assemblages in Nebraskan Deposits

A total of 34 kinds of fossil mollusks are known to be associated with deposits of Nebraskan age in Kansas; their occurrence and distribution at 11 localities are shown in Figure 6, and illustrations of a representative faunal assemblage are shown on Plate 14. At each of these localities, except one, shells of mollusks occur in fine silts and clays, or in sandy silts of lacustrine or fluviatile origin. Shells in sandy lentils in the uppermost 4 feet of the David City gravel (SE¼ sec. 6, T. 2 S., R. 20 E., Doniphan County) were first discovered and collected by Raymond C. Moore; additional collections of shells from David City gravels and from lentils of sand or sandy silt in Nebraska till at the Iowa Point section were subsequently made by Frye, his students, and Leonard from time to time as excavation by the State Highway Department at this site exposed successive lentils of fossiliferous sand or silt.

Known occurrences of fossiliferous sediments of Nebraskan age in Kansas are limited in number, but the incidence of distinctive molluscan faunules in such deposits in Seward and Meade Counties in the southwest; in Kingman County in the south-central, and in Doniphan County in the northeastern part of the State gives these characteristic molluscan assemblages a statewide, if sparse, distribution. The occurrence in each of these areas of groups of molluscan species that are known to be restricted to sediments of Nebraskan age does, however, make these faunal assemblages of significant value in studies of stratigraphic correlation.

The assignment of a Nebraskan age to the fossil mollusks discussed here is based on several considerations, among the most important of which is the direct relation of this distinctive faunal assemblage to glacial till of unquestioned Nebraskan age, and the positive establishment of its stratigraphic position with respect to Pearlette volcanic ash and its associated characteristic Kansan fauna. Twelve species among the 34 are not known to occur in older or in younger sediments, and of these restricted species, five of them (*Amnicola crybetes, Lymnaea diminuta, L. perexilis, Menetus kansasensis,* and *Promenetus blancoensis*) occur in David City gravel and Nebraska till in Doniphan County where the stratigraphic relations are known clearly. At the Kingman County locality (Fig. 6) these same five species occur with several others (*Lymnaea macella, L. turritella,* and *Vertigo hibbardi*) which are of limited vertical range (A. B. Leonard, 1952a). Furthermore, the Kingman County exposure lies topographically below adjacent widespread deposits known to be of late Kansan age, and the degree of weathering and amount of caliche accumulation in the sediments associated with the molluscan faunule is further indication of Nebraskan age. In southwestern Kansas, the five restricted species known from David City gravel and Nebraska till are associated with seven others (*Gastrocopta paracristata, G. rexroadensis, Gyraulus enaulus, Lymnaea macella, L. turritella, Polygyra mooreana,* and *Vertigo hibbardi*) also known to be restricted in vertical range. Here the relation of the fossiliferous sediments to Afton soil is not always entirely clear, but the faunal assemblages are stratigraphically below, and readily separable on a faunal basis from the molluscan assemblages associated with the Pearlette volcanic ash and related silts, previously shown to be of late Kansan age (Frye, Swineford, and Leonard, 1948). Three species of mollusks (*Carychium perexiguum, Deroceras aenigma,* and *Strobilops sparsicosta*) occur in assemblages associated with deposits of Kansan age as well as in the assemblages under discussion, but in Kansan sediments these three species are associated with a distinctively different aggregation of molluscan species.

Further evidence of the Nebraskan age of the molluscan families considered here is the absence in them of a number of genera (*Aplexa, Discus, Euconulus, Hendersonia, Oxyloma, Planorbula, Pomatiopsis, Stenotrema, and Valvata*) which are of common occurrence in sediments of Kansan age. In addition, a number of genera that occur in both horizons are represented by different species at the two levels. The following incomplete list serves to emphasize this observation.

Nebraskan species	Kansan species
Amnicola crybetes	*Amnicola limosa parva*
Gastrocopta paracristata	*Gastrocopta cristata*
Gastrocopta rexroadensis	*Gastrocopta proarmifera*
Gyraulus enaulus	*Gyraulus pattersoni*
Lymnaea perexilis	*Lymnaea reflexa*
Lymnaea diminuta	*Lymnaea parva*
Menetus kansasensis	*Menetus pearlettei*
Polygyra mooreana	*Polygyra texasiana*
Promenetus blancoensis	*Promenetus umbilicatellus*
Vertigo hibbardi	*Vertigo ovata*

It is usual in Pleistocene sediments, except eolian silts, to find shells of terrestrial species of mollusks mingled with the shells of species known to live in or near water, and the safe assumption is that shells of terrestrial species are washed into ponds and streams from surrounding slopes. Drift lines of modern lakes and ponds often contain, along with miscellaneous organic and other detritus cast up by wave action, the shells of both aquatic and terrestrial species of mollusks. The aggregate molluscan fauna from Nebraskan sediments in the State reflects this tendency for the shells of mollusks from various habitats to be deposited together. Slightly more than half (19) of the total number of species represented are those of terrestrial habit; 15 species are typically aquatic in habit. Among the several exposures of Nebraskan sediments from which molluscan faunules have been obtained, all contained some mixture of terrestrial and aquatic species, except the Iowa Point exposures in Doniphan County, where, thus far, none but aquatic species have been collected.

Among the aquatic species, *Amnicola crybetes* represents the branchiate or gill-bearing snails, which are limited in habitat to permanent and relatively silt-free waters, since they are dependent upon water for respiration. Such snails cannot survive more than brief periods of drying. Species of *Menetus, Promenetus, Gyraulus,* and *Ferrissia,* while not branchiate snails, are susceptible to drying, and die after extended exposure to dessication. Some of the living species of *Physa, Lymnaea,* and *Helisoma,* on the other hand, are able to survive extended periods without the presence of open water, although they require a relatively high humidity for long survival. Even *Sphaerium,* a lamellibranch mollusk, is able to survive the lack of open water for considerable periods of time by taking advantage of the rela-

		Faunal localities										
	Molluscan species	SE ¼ sec. 6, T. 2 S., R. 20 E., Doniphan	SW ¼ sec. 12, T. 29 S., R. 8 W., Kingman	*SW ¼ sec. 31, T. 30 S., R. 26 W., Meade	*SW ¼ sec. 34, T. 30 S., R. 28 W., Meade	*SW ¼ sec. 33, T. 30 S., R. 29 W., Meade	*NW ¼ sec. 6, T. 31 S., R. 30 W., Meade	NW ¼ sec. 19, T. 32 S., R. 28 W., Meade	SW ¼ sec. 22, T. 33 S., R. 29 W., Meade	*NE ¼ sec. 33, T. 34 S., R. 29 W., Meade	SW ¼ sec. 35, T. 34 S., R. 30 W., Meade	SW ¼ sec. 36, T. 34 S., R. 31 W., Seward
Nebraskan or older to Recent	*Cionella lubrica* (Muller)							●	●			
	Ferrissia parallela (Haldeman)					●		●	●		●	
	Ferrissia rivularis (Say)		●					●	●		●	
	Gastrocopta holzingeri (Sterki)							●	●			●
	Gastrocopta tappaniana (C. B. Adams)		●		●		●	●	●	●	●	●
	Hawaiia minuscula (Binney)			●	●	●		●	●	●	●	●
	Helicodiscus singleyanus (Pilsbry)		●				●	●	●		●	
	Helisoma antrosa (Conrad)	●		●				●	●		●	●
	Lymnaea humilis modicella (Say)		●					●	●	●		●
	Physa anatina Lea	●	●			●		●	●		●	●
	Pisidium sp.		●					●	●		●	
	Pupoides albilabris (C. B. Adams)							●	●	●	●	
	Retinella electrina (Gould)		●						●		●	
	Sphaerium sp.	●	●			●		●	●			
	Strobilops cf. *labyrinthica*							●	●			●
	Succinea grosvenori Lea							●	●			●
	Vallonia gracilicosta Reinhardt				●			●	●			
	Vertigo milium Gould				●			●	●		●	●
	Zonitoides arboreus (Say)		●						●			
Nebraskan to Yarmouthian	*Carychium perexiguum* Baker		●				●	●		●	●	
	Deroceras aenigma Leonard			●				●	●		●	●
	Strobilops sparsicosta Baker							●	●		●	●
Restricted to Nebraskan	*Amnicola crybetes* Leonard	●	●	●	●	●	●	●	●	●	●	●
	Gastrocopta paracristata Franzen & Leonard			●	●	●	●	●	●		●	●
	Gastrocopta rexroadensis Franzen & Leonard							●	●		●	●
	Gyraulus enaulus Leonard		●	●	●			●		●		
	Lymnaea diminuta Leonard	●	●		●		●		●		●	●
	Lymnaea macella Leonard		●			●			●			●
	Lymnaea parexilis Leonard	●	●					●	●		●	●
	Lymnaea turritella Leonard		●			●	●	●	●		●	●
	Menetus kansasensis Baker	●	●		●				●		●	●
	Polygyra mooreana (Binney)								●		●	
	Promenetus blancoensis Leonard	●	●				●		●		●	●
	Vertigo hibbardi Baker		●				●		●	●	●	●

FIG. 6.—Occurrence of fossil mollusks in Nebraskan deposits at 11 localities in Kansas. Asterisk indicates collection from test hole samples. for "*Lymnaea parexilis*" read *Lymnaea perexilis*.

tively high humidity found in cracks in the bottoms of drying ponds and streams, or in the burrows of worms and crayfish.

At the Iowa Point section, the molluscan faunule although not rich in species, is sufficient to indicate a terrain characterized by the presence of permanent ponds and streams. Even though the genera *Physa, Helisoma,* and *Sphaerium* are represented there, from the presence of the branchiate snail, *Amnicola crybetes,* and such aquatic pulmonates as *Menetus kansasensis and Promenetus blancoensis* which presumably were dependent upon permanent bodies of water, the conclusion may safely be drawn that such permanent ponds and streams were prevalent in the area at the time of the approach of the Nebraskan glacier. No safe inference can be drawn relative to prevailing mean temperatures in the area, although the climate may have been somewhat cooler than at present for some time previous to the actual approach of the moving Nebraskan ice. Many species of *Amnicola, Menetus,* and *Promenetus* now live at higher latitudes than Kansas, but there are many exceptions to this generalization; a species of *Menetus* survives in ponds in the artesian basin in Meade County, and many species of *Amnicola* are to be found in the humid but warm southeastern part of the United States. *Amnicola* seems not to be represented in the living molluscan fauna

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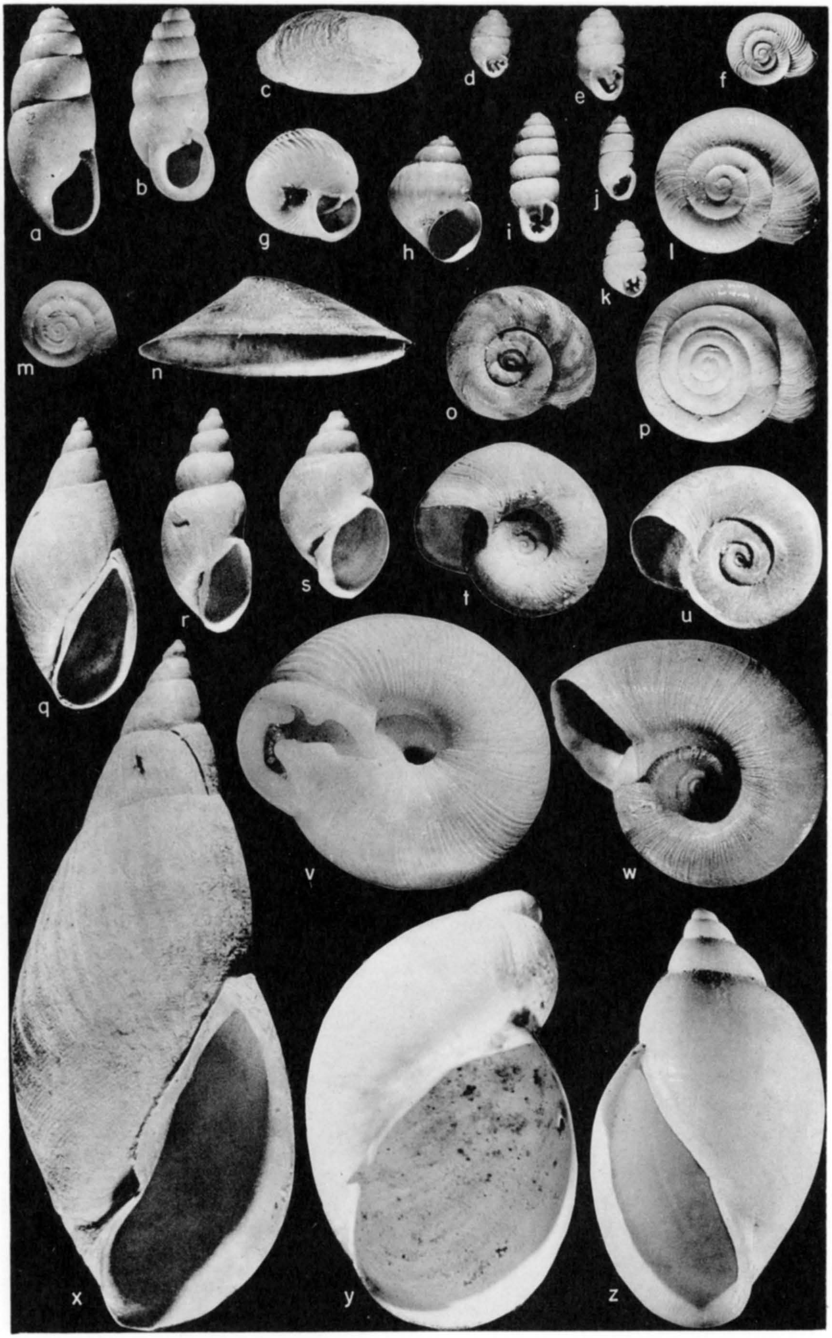
EXPLANATION OF PLATE 14

A representative assemblage of mollusks from Nebraskan deposits in Kansas. All figures enlarged approximately 5 times natural size.

FIGURE
a—*Cionella lubrica* (Müller)
b—*Pupoides albilabris* (C. B. Adams)
c—*Deroceras aenigma* Leonard
d—*Vertigo hibbardi* Baker
e—*Gastrocopta rexroadensis* Franzen and Leonard
f—*Vallonia gracilicosta* Reinhardt
g—*Strobilops sparsicosta* Baker
h—*Amnicola crybetes* Leonard
i—*Gastrocopta paracristata* Franzen and Leonard
j—*Carychium perexiguum* Baker
k—*Gastrocopta tappaniana* (C. B. Adams)
l—*Retinella electrina* (Gould)

FIGURE
m—*Hawaiia minuscula* (Binney)
n—*Ferrisia parallela* (Haldeman)
o—*Promenetus blancoensis* Leonard
p—*Zonitoides arboreus* (Say)
q—*Lymnaea macella* Leonard
r—*Lymnaea turritella* Leonard
s—*Lymnaea diminuta* Leonard
t—*Gyraulus kansasensis* Baker
u—*Gyraulus enaulus* Leonard
v—*Polygyra mooreana* (Binney)
w—*Helisoma antrosa* (Conrad)
x—*Lymnaea perexilis* Leonard
y—*Succinea grosvenori* Lea
z—*Physa anatina* Lea

Shells illustrated in figures d, e, h, i, o, q, r, s, t, u, v, and x are restricted to Nebraskan deposits in Kansas. All are extinct except fig. v (*Polygyra mooreana*) which seem identical with a species still living in southern Texas. Shells represented by figures c, g, and j are common in Nebraskan deposits, but they appear also in faunal assemblages in Kansan sediments. Other species illustrated are typical of Nebraskan faunal assemblages, but they range into Wisconsinan or Recent time (Fig. 11).



Frye and Leonard — Representative Nebraskan mollusks.

FRYE AND LEONARD — Representative Kansan mollusks.

of Kansas; there is a record of a single living animal of this genus from a lake in Douglas County, where it may have been artifically introduced. In southeastern Kansas, *Amnicola* is relatively common as a fossil in post-Bradyan Wisconsinan stream terraces.

Since there are no terrestrial species known from Nebraskan sediments in the Iowa Point area, there is no evidence from which inferences can be drawn relative to the nature of the floral cover prevalent there in Nebraskan time.

In the Kingman County deposits, the molluscan faunule likewise indicates the presence of permanent bodies of water, for *Amnicola crybetes, Ferrissia rivularis, Menetus kansasensis,* and *Promenetus blancoensis* occur there, as well as several species of *Lymnaea* whose water requirements are not surely known. In this same assemblage are several terrestrial species, including *Gastrocopta tappaniana, Helicodiscus singleyanus, Retinella electrina,* and *Zonitoides arboreus,* which are known to inhabit woodlands or woodland border areas. Of these species, *Retinella electrina* is most dependent upon woodlands, and it does not occur as far west as Kingman County at the present time. Thus the terrestrial aspect of the molluscan faunule from Nebraskan deposits in Kingman County points to woodlands such as might be found along streams, but there is no indication of extensive forests. The typical forest-inhabiting genera, such as *Anguispira,*

EXPLANATION OF PLATE 15

A representative assemblage of mollusks from Kansan deposits in Kansas. All figures enlarged approximately 5 times natural size.

FIGURE
a—*Gastrocopta contracta* (Say)
b—*Vertigo ovata* Say
c—*Pupilla muscorum* (Linne)
d—*Deroceras aenigma* Leonard
e—*Zonitoides arboreus* (Say)
f—*Helicodiscus parallelus* (Say)
g—*Gyraulus pattersoni* Baker
h—*Gastrocopta proarmifera* Leonard
i—*Pupilla muscorum sinistra* Franzen
j—*Hawaiia minuscula* (Binney)
k—*Pisidium compressum* Prime
l—*Menetus pearlettei* Leonard
m—*Strobilops sparsicosta* Baker
n—*Euconulus fulvus* (Müller)
o—*Pomatiopsis cincinnatiensis* (Lea)
p—*Hendersonia occulta* (Say)

FIGURE
q—*Discus cronkhitei* (Newcomb)
r—*Planorbula vulcanata occidentalis* Leonard
s—*Gyraulus similaris* Baker
t—*Amnicola limosa parva* Lea
u—*Valvata tricarinata* (Say)
v—*Gyraulus labiatus* Leonard
w—*Cionella lubrica* (Müller)
x—*Vallonia gracilicosta* Reinhardt
y—*Helisoma antrosa* (Conrad)
z—*Carychium perexiguum* Baker
aa—*Physa elliptica* Lea
bb—*Lymnaea parva* Lea
cc—*Lymnaea palustris* (Müller)
dd—*Succinea grosvenori* Lea
ee—*Oxyloma navarrei* Leonard

Shells represented by figures g, h, i, l, o, r, t, u, v, and ee are restricted to Kansan faunal assemblages in Kansas. All are extinct in the Great Plains, but species represented by figures o, t, and u are living elsewhere in North America. Species represented by figures d, m, and z make their last appearance in the geologic column in Kansan sediments, while those represented by figures c, i, o, p, q, and u make their first appearance in these deposits.

Mesodon, Mesomphix, Polygyra, and others that live in woodlands in eastern and southeastern Kansas, are not known from the Nebraskan sediments in Kingman County.

The widespread occurrence of *Amnicola crybetes* and other strictly aquatic species in sediments of Nebraskan age in southwestern Kansas is indicative of the presence of permanent ponds and lakes there in late Nebraskan time. It might be inferred that rainfall was considerably higher than now, or more equitably distributed throughout the year, or both, but since the fossiliferous deposits in question lie on the downthrow side of the Crooked Creek fault, permanent ponding of water might have been largely the result of poor drainage conditions rather than the result of any significant increase in rainfall. The availability of water from artesian sources is also a contributing factor, all of which adds to the difficulty of making sound judgment concerning rainfall conditions in the area in late Nebraskan time. The climate may have been somewhat cooler than at present, and perhaps lacked summer extremes of high temperature coupled with low humidity such as characterize the Great Plains today, but no indication of boreal climate may be inferred from the molluscan fauna. In fact, nothing more than cool temperate climate may be inferred from the molluscan assemblage at any of the Nebraskan localities, including the Iowa Point section, where it is obvious that the shells were incorporated in glacial outwash and till itself. This may be interpreted to suggest that the ice advanced rapidly, or that the presumed zone of boreal climate along the advancing ice front was a very narrow one at the latitude of northern Kansas.

A considerable number of terrestrial species of mollusks occurs among the several exposures of Nebraskan sediments in southwestern Kansas. *Cionella lubrica, Strobilops sparsicosta, Retinella electrina, Zonitoides arboreus,* and *Polygyra mooreana* comprise the component of the molluscan assemblage which may be thought of as being most dependent upon woodland habitats. Such species as *Gastrocopta holzingeri, G. paracristata, G. rexroadensis, Helicodiscus singleyanus, Pupoides albilabris, Vallonia gracilicosta,* and possibly *Deroceras aenigma,* although capable of thriving in woodlands, are also known (with reservations as far as the extinct species are concerned) to inhabit woodland borders or even open grasslands. *Hawaiia minuscula* and *Pupoides albilabris* are common although not abundant on the semi-arid prairies of western Kansas today. From these considerations it may be judged that a varied terrain characterized the local areas surrounding the ponds and streams in which the aquatic species of mollusks lived. Floral types ranged from open prairie to woodland border to woodland, but there is no indication of extensive areas of forest. Pollen studies might throw additional light on local vegetative types, but such studies have not been made, and most Nebraskan sediments known are presumed to have been unsuitable for the preservation of pollen.

MOLLUSCAN FAUNAL ASSEMBLAGES IN KANSAN DEPOSITS

Deposits of Kansan age in the State have yielded an abundant and distinctive molluscan fauna; a total of 64 species is known, of which 12 are extinct kinds known only from this Pleistocene stage, and a number of others, although living elsewhere in North America today, are for practical purposes, indices to Kansan sediments in the State. The occurrence and distribution of fossil mollusks at 26 localities in the State are shown on Figure 7, where the total assemblage is divided into a number of categories based on the relative usefulness of the fossils for stratigraphic purposes; a representative faunal assemblage is illustrated on Plate 15. The molluscan fauna associated with Kansan deposits has been previously treated by Frye, Swineford, and Leonard (1948) and by A. B. Leonard (1950) who described and illustrated the faunal assemblages in detail.

Fossiliferous Kansan deposits are rather well distributed over the State (Fig. 5); they occur in the southwest in Clark, Meade, and Seward Counties, in the northwest in Norton County, in the northeastern part of the State in Doniphan County, in the Flint Hills in Wabaunsee County, and many exposures occur in the central part of Kansas. Fossiliferous Kansan deposits are, however, entirely unknown in southeastern Kansas east of the Flint Hills, where deposits known to be of this age are almost entirely limited to terraces of chert gravel, in which shells are not preserved.

Assignment of a late Kansan age to the molluscan faunas under present consideration is based on (1) their direct relation to lentils of Pearlette volcanic ash contained in the Sappa silt member, Meade formation, (2) direct association of a segment of the distinctive elements of the faunal assemblage with Kansas till where stratigraphic relations are firmly established, (3) relation of the fossiliferous silts to Yarmouth soil, and (4) distinctive features of the faunal assemblage which clearly distinguish it from older and from younger molluscan faunas in the Pleistocene.

A significant attribute of the Pearlette volcanic ash is that it has been shown to be petrographically uniform and distinct from other volcanic ashes in the midcontinent region (Swineford and Frye, 1946). A natural corollary of this is the assumption that the numerous lentils of this material were deposited in a period of brief temporal magnitude. The relation of Pearlette volcanic ash to Kansas till, and the topographic and stratigraphic relations of the ash and associated Sappa silts, discussed elsewhere in this report, confirm its late Kansan age. Wherever molluscan faunules are associated with Pearlette ash, the relation is an intimate one; while fossils are only infrequently found in the ash itself, they are situated in the silts with which the ash is interstratified, either immediately below or above the ash, but more frequently the former. The lack of weathering in the upper part of ash lentils where they are covered by a significant thickness of Sappa silt and the fact that molluscan faunules are identical in composition when they occur both above and below the ash (for example, SW¼ sec. 35, T. 15 S., R. 2 E., Dickinson County) conclusively demonstrate that no geologically significant interval of time elapsed during the deposition of the silts in which the ash and the shells are incorporated.

At the Iowa Point section in Doniphan County, a small series of species of mollusks has been recovered from lentils of sand in the lower few inches of the Kansas till, which here lies above Nebraska till which contains in its top a mature Afton soil profile. Only five kinds of mollusks have been obtained from Kansas till here, but at least two of them, *Gyraulus labiatus* and *Planorbula nebraskensis*, are restricted to the Kansan faunal assemblage.

At a number of localities (SE¼ sec. 2, T. 31 S., R. 28 W., Meade County; SW¼ sec. 33, T. 1 S., R. 9 W., Jewell County; and others) fossiliferous silts bearing the distinctive late Kansan molluscan fauna occur below truncated Yarmouth soil. At the Meade County locality cited above, weathering has penetrated to the upper portion of Pearlette volcanic ash, and no fossils are found above the ash although they are abundant below; at the Jewell County exposure, fossil shells occur even in the lower portions of the Yarmouth soil which at this place is a poorly drained profile.

In all, 12 species among the total Kansan assemblage are extinct kinds thus far found only in Kansan sediments. The shells of the majority of these mollusks are of common occurrence in the Kansan Stage and often are abundantly represented where they occur. This is particularly true of *Gyraulus labiatus, Gyraulus pattersoni, Gastrocopta proarmifera, Menetus pearlettei,* and the several kinds of *Planorbula,* all of which are easily recognized in the field. *Pupilla muscorum sinistra* and *Oxyloma navarrei* are also easily recognized mollusks, but they are not so widespread in occurrence as those mentiond above. *Gastrocopta falcis* and *G. tridentata,* while distinctive enough in appearance, are so limited in areal distribution that they have little practical value. *Deroceras aenigma, Carychium perexiguum,* and *Strobilops sparsicosta* are not limited to Kansan sediments but they form a characteristic element of the fauna, and all except the first mentioned are numerously represented and conspicuous in most faunules. A number of additional species, although not extinct in the strict sense of the word, are not now living in this region, nor do they occur at other stratigraphic positions within the Pleistocene in Kansas. These species, including *Valvata tricarinata, Lymnaea palustris, Promenetus umbilicatellus, Gyraulus similaris, Amnicola limosa parva, Polygyra texasiana, Aplexa hypnorum, Physa elliptica, Pomatiopsis cincinnatiensis, Valvata lewisi,* and *Lymnaea reflexa,* may be thought of as distinctive of Kansan deposits, at least in the State, and all are useful in recognition of sediments at field exposures. Thus nearly half of the total molluscan assemblage of species in Kansan sediments is practically useful for stratigraphic purposes. It follows, of course, that many species in this assemblage are of little value for purposes of stratigraphic interpretation, especially those which range from Nebraskan to Recent deposits, but even these species provide a basis for interpreting past ecological conditions. In fact such species are superior for this purpose, because their ecological tolerances are well known in most cases.

	Stenotrema leai leai (Binney)	●				●	●			●		●						●					●				●
	Succinea avara Say	●						●		●										●	●			●	●		●
	Succinea ovalis Say	●																								●	
	Vallonia pulchella (Muller)	●	●				●			●														●			
	Valvata lewisi Currier		●				●											●									
	Valvata tricarinata (Say)	●					●											●	●		●		●				
	Vertigo gouldi (Binney)				●		●			●			●	●													●
	Vertigo modesta (Say)	●																					●			●	
	Vertigo tridentata Wolf		●																								
	Zonitoides arboreus (Say)	●	●				●			●									●				●				●
·Restricted to Kansan	*Gastrocopta falcis* Leonard											●															
	Gastrocopta proarmifera Leonard	●			●		●		●	●		●	●		●			●			●	●	●	●	●	●	
	Gastrocopta tridentata (Leonard)																						●				
	Gyraulus labiatus Leonard	●	●	●	●		●	●					●			●				●	●	●		●	●	●	
	Gyraulus pattersoni Baker	●						●		●		●	●					●	●	●	●						
	Menetus pearlettei Leonard		●					●			●		●	●			●	●	●	●	●			●			
	Oxyloma navarrei Leonard	●	●					●												●	●						●
	Physa sp.		●	●																							
	Planorbula nebraskensis Leonard			●																							
	Planorbula vulcanata occidentalis Leonard	●						●		●			●								●						
	Planorbula vulcanata vulcanata Leonard	●	●			●														●							●
	Pupilla muscorum sinistra Franzen	●			●					●										●			●				
Nebraskan to Kansan	*Carychium perexiguum* Baker		●		●	●			●	●		●			●			●	●	●	●				●	●	●
	Deroceras aenigma Leonard	●		●	●	●		●	●	●	●	●		●		●		●	●	●	●						●
	Strobilops sparsicosta Baker				●	●		●		●							●								●	●	
Nebraskan or older to Recent	*Ferrissia parallela* (Haldeman)	●											●							●			●		●		
	Gastrocopta cristata Pilsbry & Vanatta											●												●			
	Gastrocopta holzingeri (Sterki)				●																			●			
	Gastrocopta procera (Gould)						●																		●		
	Gastrocopta tappaniana (C. B. Adams)	●	●		●	●	●	●		●			●											●			
	Hawaiia minuscula (Binney)	●	●		●		●	●		●		●	●		●			●		●	●	●	●	●	●	●	●
	Helisoma antrosa (Conrad)							●		●												●			●	●	
	Lymnaea parva Lea	●			●		●						●							●	●		●	●		●	●
	Physa anatina Lea																		●			●		●	●	●	●
	Pupoides albilabris (C. B. Adams)				●			●																●	●		
	Retinella electrina (Gould)				●		●			●		●	●						●	●			●		●	●	●
	Succinea grosvenori Lea	●			●	●	●	●		●		●	●					●	●	●			●	●			
	Vallonia gracilicosta Reinhardt	●	●		●	●	●	●		●		●	●					●		●	●		●	●		●	
	Vertigo milium (Gould)		●		●		●			●			●					●								●	
	Vertigo ovata Say	●	●			●				●		●	●					●				●		●			●

FIG. 7.—Occurrence of fossil mollusks in Kansan deposits at 26 localities in

tus" read

Kansan to Recent																								Molluscan species
Sphaerium sp.	*Pupilla muscorum* (Linne)	*Pupilla blandi* Morse	*Promentetus umbilicatellus* (Cockerell)	*Pomatiopsis cincinnatiensis* (Lea)	*Polygyra texasiana* (Moricand)	*Pisidium compressum* Prime	*Physa elliptica* Lea	*Lymnaea reflexa* Say	*Lymnaea palustris* (Muller)	*Lymnaea caperata* (Say)	*Lymnaea bulimoides* Lea	*Hendersonia occulta* (Say)	*Helisoma wisconsinensis* Winslow	*Helisoma trivolvis* (Say)	*Helicodiscus parallelus* (Say)	*Gyraulus similaris* (Baker)	*Gastrocopta contracta* (Say)	*Gastrocopta armifera* (Say)	*Euconulus fulvus* (Muller)	*Discus cronkhitei* (Newcomb)	*Cionella lubrica* (Muller)	*Aplexa hypnorum* (Linne)	*Amnicola limosa parva* Lea	Faunal localities
●					●	●			●		●			●	●						●	●		SW ¼ sec. 13, T. 30 S., R. 23 W., Clark
			●	●					●					●	●		●	●	●					SW ¼ sec. 35, T. 15 S., R. 2 E., Dickinson
●																								SE ¼ sec. 6, T. 2 S., R. 20 E., Doniphan
	●																		●	●	●			SW ¼ sec. 21, T. 13 S., R. 26 W., Gove
	●															●			●	●				SW ¼ sec. 33, T. 1 S., R. 9 W., Jewell
●	●					●								●	●		●		●	●				NW ¼ sec. 28, T. 13 S., R. 10 W., Lincoln
●	●					●		●	●		●			●	●	●	●			●			●	SW ¼ sec. 34, T. 30 S., R. 26 W., Meade
							●																	*SW ¼ sec. 31, T. 30 S., R. 26 W., Meade
	●		●			●		●								●			●	●	●	●	●	SE ¼ sec. 2, T. 31 S., R. 28 W., Meade
																			●					*SW ¼ sec. 34, T. 30 S., R. 28 W., Meade
	●					●													●	●	●	●		SE ¼ sec. 35, T. 31 S., R. 28 W., Meade
	●		●			●	●	●	●	●				●		●		●	●	●		●		NE ¼ sec. 26, T. 32 S., R. 28 W., Meade
																								*SW ¼ sec. 33, T. 30 S., R. 29 W., Meade
		●																						*NE ¼ sec. 33, T. 30 S., R. 29 W., Meade
																							●	*NE ¼ sec. 33, T. 34 S., R. 29 W , Meade
																●								*NW ¼ sec. 6, T. 31 S., R. 30 W., Meade
			●			●				●						●				●				SW ¼ sec. 19, T. 5 S., R. 22 W., Norton
	●					●			●			●		●	●	●	●		●	●			●	NW ¼ sec. 11, T. 6 S., R. 13 W., Osborne
●							●	●	●				●			●								NW ¼ sec. 29, T. 10 S., R. 5 W., Ottawa
	●		●			●			●					●		●	●							NE ¼ sec. 1, T. 25 S., R. 7 W., Reno
	●									●	●				●				●					SW ¼ sec. 36, T. 24 S., R. 7 W., Reno
	●			●		●			●	●		●		●	●	●			●	●	●	●	●	NW ¼ sec. 36, T. 14 S., R. 11 W., Russell
		●				●								●		●								NW ¼ sec. 35, T. 33 S., R. 32 W., Seward
●				●										●	●	●	●		●					SE ¼ sec. 28, T. 14 S., R. 21 W., Trego
	●					●				●					●	●			●	●	●			NE ¼ sec. 33, T. 14 S., R. 21 W., Trego
						●		●	●	●	●					●			●	●		●		SE ¼ sec. 22, T. 14 S., R. 12 E., Wabaunsee

Kansas. Asterisk indicates collection from test hole samples. For “Promente-
Promenetus.

The known faunule in Kansan deposits at the Iowa Point section is too small to be of much value in paleoecological interpretations. It is perhaps worthy of note that *Planorbula nebraskensis* has been reported by A. B. Leonard (1950) from Kansan deposits from western and northwestern Iowa and from extreme northern Nebraska. The known distribution of this aquatic pulmonate might thus suggest that a cooler climate than now existed in Doniphan County in Kansan time, but this is little contribution, since the shells are found in glacial till. Moreover, since the species is known only from a few localities, and because it is extinct and its ecological tolerances hence unknown, interpretations of ecological conditions based on this one species seem hardly worth while.

The widespread occurrence of a number of branchiate snails, including *Valvata tricarinata, V. lewisi, Amnicola limosa parva, and Pomatiopsis cincinnatiensis,* most certainly indicates that permanent, clear ponds and lakes and streams containing little silt were common in late Kansan time. These species, as well as the aquatic pulmonates *Gyraulus similaris* and *Aplexa hypnorum,* are in general distributed in more northern latitudes than Kansas (the former occurs in montane lakes in Colorado) which may point to slightly cooler climate at the time these snails lived in Kansas, but no suggestion of boreal conditions may be inferred from the total molluscan assemblage.

That ecological conditions over the State were conducive to good floral cover is attested by the number and variety of snails of terrestrial habitat which occur in the assemblage. These snails live at the bases of plants, in leaf mold, under the bark of dead trees, or in the upper parts of the soil where humus is abundant. Many terrestrial snails feed on decaying organic matter or upon the fungus which grows where organic matter such as dead leaves and grass forms a thick mat. Moisture is not only necessary for the growth of the fungus, but terrestrial snails are dependent upon such conditions for proper development of their eggs and young. Slightly more than half of the species represented in the Kansan assemblage are terrestrial in habit: they range from kinds known to be tolerant of a wide variety of ecological conditions to those more or less restricted to some special ecological situation, such as prairie, woodland border, or woodlands. The occurrence of *Cionella lubrica, Zonitoides ar-*

boreus, Hendersonia occulta, Stenotrema leai, Retinella electrina, and *Polygyra texasiana* is indicative of woodland habitats or perhaps woodland border situations, or both. *Zonitoides arboreus, Retinella electrina, Cionella lubrica, Stenotrema leai,* and *Polygyra texasiana* live in woodlands under bark or in leaf mold near fallen tree trunks. *Hendersonia occulta* occurs in shrubs, especially near streams on flood plains. However, there is nothing in the molluscan assemblage to suggest extensive forests, and none of the genera so common in the forested areas of eastern parts of the Missouri River Valley are known to be present in the Kansan faunal assemblage. Other terrestrial species, such as *Pupilla muscorum, Discus cronkhitei, Succinea grosvenori,* and the several species of *Vallonia, Vertigo,* and *Gastrocopta* prefer relatively open situations, such as woodland borders or even dense growth of herbs in meadows or near streams. *Vallonia* frequently occurs in dense growth of grass on open prairies, as does *Hawaiia minuscula, Pupoides albilabris,* and *Gastrocopta armifera.* Possibly *G. proarmifera* had similar ecological requirements.

In summary, a reconstruction of ecological conditions in most parts of the State in late Kansan time would include the presence of permanent ponds and lakes together with relatively silt-free streams indicating more abundant rainfall, or better distribution of rainfall throughout the year as compared with present rainfall; a slightly lower mean temperature lacking the extremes of summer high temperature and low humidity; and more luxuriant floral cover than at present, especially in the western part of the State, and representing all prevailing types such as prairie, meadow, woodland border, and woodland, but without extensive forests.

It is difficult to compare ecological conditions in the State in Nebraskan time with those in Kansan time. The greater abundance and variety of both branchiate aquatic snails and terrestrial species seems to point to even better rainfall and floral conditions in late Kansan time than in earlier Pleistocene time, but the relatively restricted number of Nebraskan deposits and their more limited areal distribution make direct comparisons difficult and uncertain. It is our judgment, based on available data, that ecological conditions were not significantly different in Nebraskan and Kansan time in most parts of Kansas, at least in the closing phases of these Pleistocene stages.

MOLLUSCAN FAUNAL ASSEMBLAGES IN ILLINOIAN DEPOSITS

The Crete and Loveland members of the Sanborn formation are the depositional representatives of Illinoian time in Kansas, and since the two members are separable only on a textural basis and are gradational with respect to each other, the molluscan fauna discussed here is a composite assemblage from Crete-Loveland deposits. The occurrence and distribution of 25 kinds of mollusks at 10 localities in the State is shown on Figure 8, and illustrations of a representative assemblage appear on Plate 16.

Typically, Crete sands and gravels grade upward into fluviatile silts, which in turn grade into massive, well-sorted silts judged to be eolian in origin. Almost everywhere in the State where these sediments can be recognized, as well as in Nebraska, Iowa, Illinois, and other surrounding states, the Crete-Loveland sequence has developed in its upper part the Sangamon soil. The Sangamon soil is in fact the most reliable stratigraphic datum available for the recognition of Crete-Loveland deposits, and the fauna under present consideration has been in every case collected only where the Sangamon soil was recognizable as a stratigraphic reference.

The Illinoian assemblage of mollusks is less distinctive than that in Nebraskan, Kansan, or Wisconsinan deposits primarily because no segment of the assemblage is restricted to it. However, with care and a reasonably complete faunule, an Illinoian assemblage can be distinguished from other aggregations of Pleistocene mollusks in Kansas. In general, the Illinoian assemblage is intermediate in character between that in Kansan sediments stratigraphically below it and that in Wisconsinan deposits stratigraphically above it. But as inferred above, the age of the assemblage is based largely on its relation to the Sangamon soil.

In spite of its intermediate character, the Illinoian faunal assemblage has a number of distinctive features worthy of note.

(1) About 14 species of common occurrence in Kansan deposits do not appear in the Illinoian assemblages. None of the genera of branchiate gastropods, such as *Amnicola, Pomatiopsis,*

and *Valvata* seems to have survived the Yarmouthian interglacial interval in the midcontinent region. Likewise, aquatic pulmonate snails, such as *Aplexa, Ferrissia, Menetus, Planorbula,* and *Promenetus,* most species of *Gyraulus,* and the larger species of *Lymnaea,* failed to survive the ecological changes that followed the close of deposition of Sappa silts.

(2) Four species, common in Kansan faunules, make their final appearance in the geologic column in Kansas in Illinoian sediments; these include *Carychium perexiguum, Strobilops sparsicosta, Gyraulus similaris,* and *Helisoma antrosa.* The first two species are extinct, *Gyraulus similaris* survives in relict populations in montane lakes in Colorado, and *Helisoma antrosa,* although extinct on the Great Plains, is still a commonly occurring snail in the more humid regions of central and eastern United States.

(3) A number of species, among which may be mentioned *Columella alticola* and *Striatura milium* which are relatively common in Wisconsinan loess (Tazewellian zone of the Peoria silt), are not found in Illinoian assemblages. Furthermore, the slug *Deroceras aenigma,* common in Nebraskan and Kansan faunas, is replaced in Illinoian molluscan assemblages by *Deroceras laeve.*

The small number of localities from which molluscan assemblages of Illinoian age are reported here is no indication of the extent of Illinoian sediments in the State. At most localities where Illinoian sediments can be recognized, the gravels, sands, or silts are nonfossiliferous. The reason for this is not completely understood, but a number of contributing factors are known. It is not surprising that few instances of fossiliferous Crete sand and gravel are known, because the fragile shells of mollusks cannot survive for long the abrasive action of coarse sediments in transit. In fact, it is remarkable that any examples of fossiliferous Crete materials are known, since there is not a single instance known to us of shells occurring in recognizable faunules in the coarse phases of the Holdrege or Grand Island gravels. Another contributing factor is that generally over the State, while Illinoian sediments are widespread, they exist as relatively thin strata. Not infrequently, the weathering that produced the Sangamon soil has progressed completely through the entire Illinoian sequence, which would have destroyed, of course, any

Molluscan species	**Faunal localities**									
	SW ¼ sec. 35, T. 17 S., R. 13 W., Barton	SW ¼ sec. 33, T. 13 S., R. 5 E., Geary	NW ¼ sec. 21, T. 24 S., R. 21 W., Hodgeman	NE ¼ sec. 5, T. 2 S., R. 7 W., Jewell	NW ¼ sec. 2, T. 2 S., R. 9 W., Jewell	SE ¼ sec. 13, T. 1 S., R. 24 W., Norton	NW ¼ sec. 23, T. 2 S., R. 18 W., Phillips	NW ¼ sec. 9, T. 1 S., R. 19 W., Phillips	NW ¼ sec. 9, T. 2 S., R. 16 W., Phillips	NW ¼ sec. 7, T. 18 S., R. 7 W., Rice
Anodonta sp.					●					
Carychium exiguum (Say)		●		●			●		●	
Carychium perexiguum Baker	●							●		●
Deroceras laeve (Muller)		●					●	●		●
Discus cronkhitei (Newcomb)							●		●	
Gastrocopta armifera (Say)		●		●			●	●		
Gastrocopta holzingeri (Sterki)		●							●	
Gastrocopta tappaniana (C. B. Adams)					●		●			
Gyraulus similaris (Baker)	●			●				●		
Hawaiia minuscula (Binney)		●		●				●	●	
Helicodiscus parallelus (Say)		●		●	●		●			
Helicodiscus singleyanus (Pilsbry)				●			●			●
Helisoma antrosa (Conrad)				●			●	●		
Helisoma trivolvis (Say)				●	●		●	●		
Physa anatina Lea				●					●	●
Pupilla blandi Morse				●	●					
Pupilla muscorum (Linne)		●				●		●		
Pupoides albilabris (C. B. Adams)					●				●	
Retinella electrina (Gould)	●			●				●		
Sphaerium solidulum (Prime)	●			●	●					
Strobilops sparsicosta Baker						●			●	●
Succinea grosvenori Lea	●		●	●	●	●	●			
Vallonia gracilicosta Reinhardt		●	●	●	●		●	●		
Vallonia pulchella (Muller)				●						
Vertigo tridentata Wolf		●				●			●	

FIG. 8.—Occurrence of fossil mollusks in Illinoian deposits at 10 localities in Kansas.

shells previously present. Finally, the climate during Illinoian time may have been unfavorable to mollusks, although this seems unlikely in view of the kinds that are known to be present. The absence of molluscan remains in unleached Loveland loess at a number of localities remains unexplained.

It is difficult to escape the conclusion that a profound change in ecological conditions in the Great Plains occurred during or at the close of the Yarmouthian interglacial interval, or at the beginning of the Illinoian cycle of erosion and deposition. Wholesale extinction of great populations of branchiate and other gastropods adapted to life in permanent water, which thrived in western Kansas in late Kansan and early Yarmouthian time, is indicative of a less humid environment, or at least of a marked decline in the prevalence of permanent ponds and lakes of clear water in the Great Plains region. The assemblage of aquatic gastropods in late Kansan silt, the prevalence in them of zygospores of some *Chara*-like alga, and abundance at many exposures of the valves of ostracods all point toward an environment of permanent slow-flowing or ponded water, without excessive siltation, and perhaps with an average temperature somewhat below that prevalent in the same region today or in Illinoian time. By contrast, the aquatic gastropods in Illinoian deposits indicate an environment of ephemeral ponds and silt-laden streams. *Anodonta,* a lammellibranch pelecypod, and the pulmonate gastropods *Helisoma trivolvis* and *Physa anatina,* as well as the little clam *Sphaerium solidulum,* are all animals capable of living in heavily silted ponds or streams, and capable also of surviving considerable periods without open water. *Gyraulus similaris* probably was limited to spring-fed ponds or other cooler and clearer waters.

With the exception of *Strobilops sparsicosta,* which probably lived in or near woodlands, the terrestrial fauna associated with Illinoian deposits is adapted for life in prairies, meadows, or perhaps woodland borders or in small areas of shrubs. *Gastrocopta armifera, Hawaiia minuscula,* and *Pupoides albilabris* live in the prairies of western Kansas today, and survive periods of great aridity. *Pupilla muscorum,* however, and *Retinella electrina, Carychium perexiguum, C. exiguum, Helicodiscus singleyanus, Vallonia gracilicosta, Vertigo tridentata,* and others are absent from the living molluscan fauna in the Great Plains, so it must be conceded that in Illinoian time ecological conditions were somewhat more favorable toward mollusks than those prevalent today. Certainly the contrast between ecological conditions in Illinoian time and Kansan as well as Nebraskan time was much greater than that between Illinoian and modern time, and we judge that climatic conditions in Kansas during the Illinoian Age were not significantly different than present-day conditions, except for slightly greater rainfall and greater and more widespread sedimentation. It seems, for example, that the ecological situation in Norton or Phillips County in Illinoian time might have been not unlike that in Dickinson or Marion County today.

MOLLUSCAN FAUNAL ASSEMBLAGES IN WISCONSINAN DEPOSITS

The molluscan faunal assemblage associated with Wisconsinan sediments has been previously treated by Frye and A. B. Leonard (1951), and by A. B. Leonard (1951, 1952). In the present report, the Wisconsinan molluscan fauna is divided into pre- and post-Bradyan assemblages; the occurrence and distribution of 28 kinds of mollusks from pre-Bradyan Wisconsinan silts at 137 localities is shown on Figure 9, and illustrations of a representative assemblage appear on Plate 17. The occurrence and distribution of 16 species of mollusks at 27 localities where post-Bradyan Wisconsinan deposits have been studied is shown on Figure 10, while a representative assemblage of these mollusks is illustrated on Plate 18.

The great majority of the 137 pre-Bradyan Wisconsinan faunal localities discussed here are situated in deposits of loess which in Kansas classification is included in the Peoria silt member of the Sanborn formation. The faunas from terraces of equivalent age have not been studied until recently, and although these studies are incomplete, the molluscan assemblages from terraces have provided a means of determining age and correlation of sediments in local areas where other stratigraphic criteria are lacking or unsatisfactory. For example, in Harper County (SE¼ sec. 35, T. 35 S., R. 8 W.) the principal terrace along a branch of Plum Creek is determined to be pre-Bradyan Wisconsinan in age from the characteristics of the contained molluscan assemblage, which includes *Pupilla muscorum, P. blandi, Vallonia gracilicosta, Euconulus fulvus,* and *Succinea avara.* The first three of these species are extinct in the State, and *Euconulus fulvus* is now limited in its range in this region to extreme eastern Kansas. By contrast, a post-Bradyan terrace, channeled into these pre-Bradyan sediments, contains *Vallonia parvula, Hawaiia minuscula, Physa anatina,* and *Succinea avara,* all of which are living near the exposure. These data make it possible to date, trace, and correlate terraces throughout the drainage system in this area, and incidentally to date the pediment slope cut in Permian shales which is graded to this terrace complex. Exposures in Clark County (NE¼ sec. 26, T. 33 S., R. 24 W.), Barber County (SW¼ sec. 20, T. 33 S., R. 11 W.), and elsewhere have yielded molluscan faunas which are equally useful for purposes of stratigraphic correlation. The stratigraphic position of the Peoria silt is discussed elsewhere in this report; it has been previously reviewed and discussed at length by Frye and A. B. Leonard (1951) and by A. B. Leonard (1951), and its early Wisconsinan age firmly established.

The 28 species of fossil mollusks which comprise the assemblage associated with pre-Bradyan Wisconsinan deposits are almost without exception gastropods of terrestrial habit. Detailed studies of the early Wisconsinan faunal assemblage have made it possible to divide the massive Peoria silt into three well-characterized zones, which are equivalent to recognized stratigraphic units in the glaciated part of the Mississippi Valley. These faunal zones are here referred to as (1) the basal or Farmdale zone, (2) the lower or Iowan zone, and (3) the upper or Tazewellian faunal zone.

The basal or Farmdale faunal zone.—The Farmdale faunal zone of the Peoria ranges from a few inches to more than 6 feet in thickness, and it consists of loess which has been oxidized to a greater or lesser degree and from which the greater part of the free carbonates have been leached. The greatest degree of leaching occurs near the base of the zone, directly above the A horizon of the Sangamon soil, upon which the Peoria normally rests. Usually no effervescence can be elicited from the silts here by the use of dilute acid, and the color, due to various degrees of oxidation of iron salts, is some shade of pink or red, darkened somewhat with humic stains. All these effects disappear by imperceptible degrees upward into calcareous, unoxidized, and fossiliferous loess. The basal part of this zone is typically devoid of fossil shells, but etched fragments may appear in the upper part of the Farmdale zone. It may be inferred, since vertebrate fossils occur in this material (Condra, Reed, and Gordon, 1947) that gastropods also lived during the interval when this silt was being deposited, and that the shells were subsequently destroyed by weathering processes. The molluscan fauna may have been sparse, however, since the fauna in the lower part of the Iowan zone above it is not a rich one.

In some places along the bluffs of Platte and Missouri Rivers in Nebraska and Iowa, the Farmdale zone silts are thicker than they are anywhere in Kansas, and it is obvious that they were there deposited more rapidly, for at several such places the loess is calcareous and fossiliferous below an incipient soil. Wherever a molluscan fauna has been observed in the Farmdale zone, it has been found to be essentially similar to the molluscan assemblage in the Iowan zone.

The lower or Iowan faunal zone.—The lower molluscan faunal assemblage consists of 14 species of small size and terrestrial habit, two of which are restricted to this zone, while the remainder also appear in the upper or Tazewellian zone. The presence of these restricted species, however, and the universal absence of at least 14 species known to occur only in the Tazewellian zone make the Iowan faunal zone distinctive enough for practical purposes and readily discernible on outcrops of the loess.

Among the Iowan zone species, *Vallonia gracilicosta, Pupilla muscorum, P. blandi,* and *Vertigo gouldi paradoxa* are presently absent from Kansas; the remainder are restricted to favorable situations in the eastern part of the State, except *Succinea avara, Hawaiia minuscula,* and *Deroceras laeve,* which are widely dis-

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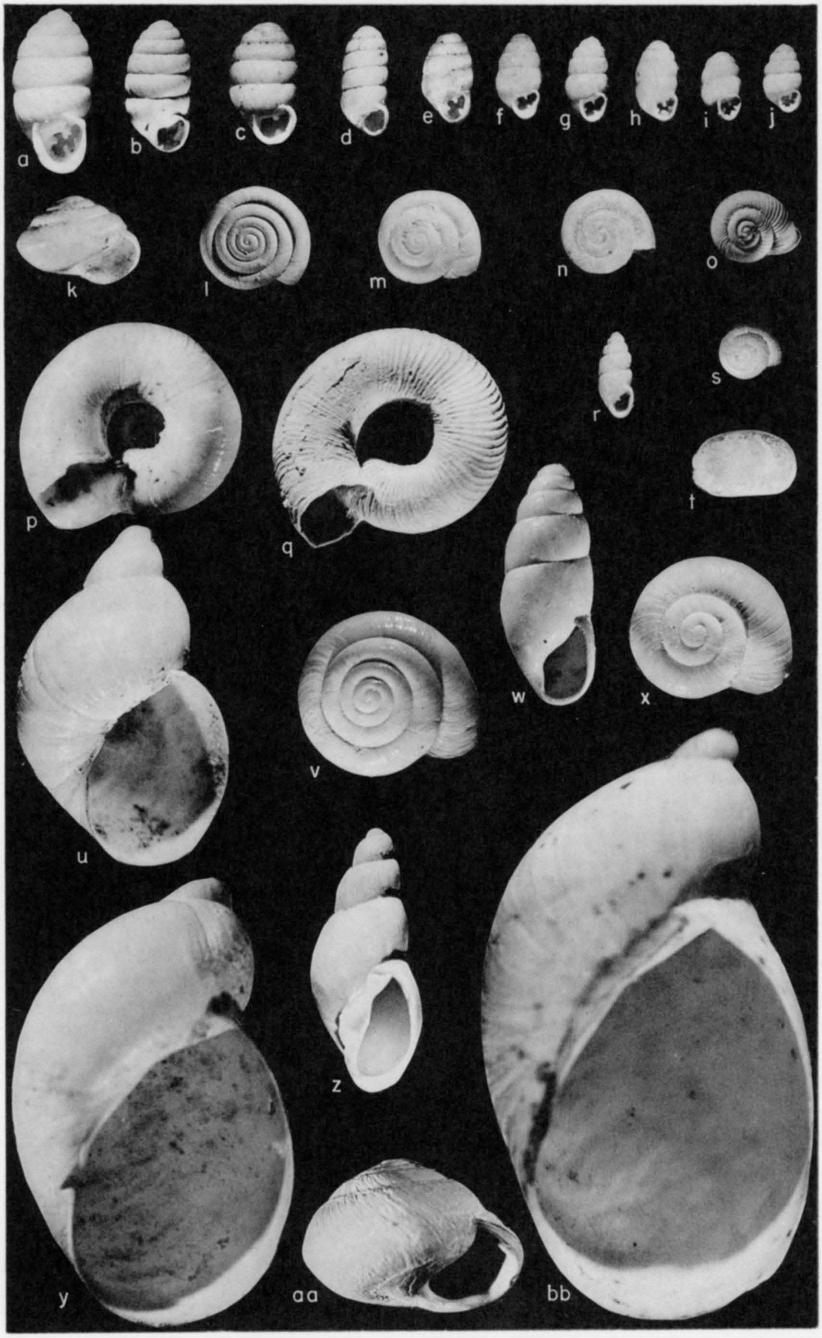
EXPLANATION OF PLATE 16

A representative assemblage of mollusks from Illinoian deposits in Kansas. All figures enlarged approximately 5 times natural size.

FIGURE
a—*Gastrocopta armifera* (Say)
b—*Pupilla muscorum* (Linne)
c—*Pupilla blandi* Morse
d—*Vertigo tridentata* Wolf
e—*Gastrocopta tappaniana* (C. B. Adams)
f—*Gastrocopta holzingeri* (Sterki)
g—*Vallonia gracilicosta* Reinhardt
h—*Vallonia pulchella* (Müller)
i—*Helicodiscus singleyanus* (Pilsbry)
j—*Deroceras laeve* (Müller)
k—*Pupoides albilabris* (C. B. Adams)

FIGURE
l—*Retinella electrina* (Gould)
m—*Helicodiscus parallelus* (Say)
n—*Hawaiia minuscula* (Binney)
o—*Strobilops sparsicosta* Baker
p—*Carychium exiguum* (Say)
q—*Discus cronkhitei* (Newcomb)
r—*Helisoma antrosa* (Conrad)
s—*Physa anatina* Lea
t—*Sphaerium solidulum* Prime
u—*Gyraulus similaris* Baker
v—*Helisoma trivolvis* (Say)
w—*Succinea grosvenori* Lea

FRYE AND LEONARD — Representative Illinoian mollusks.



FRYE AND LEONARD — Representative pre-Bradyan Wisconsinan mollusks.

tributed over the State, even on the semi-arid High Plains. Strangely, *Pupoides albilabris,* which today lives on the western prairies, has not been found in the Peoria loess.

The most widespread species in the Iowan faunal zone are *Vallonia gracilicosta, Succinea avara, Pupilla muscorum, P. blandi,* and *Hawaiia minuscula,* which occur at almost every locality studied, including those in southwestern Kansas, where conditions then as now, seem to have been unfavorable for terrestrial gastropods. Since all of these but *Hawaiia minuscula* and *Succinea avara* are extinct in the State, the Iowan faunal zone is readily recognizable in southwestern Kansas where the loess is thin and the molluscan fauna sparse.

Above the Farmdale zone, the Iowan zone assemblage increases progressively upward, both in numbers of species and in individuals. For example, in an exposure in Decatur County (NE¼ sec. 1, T. 3 S., R. 28 W.) the lower 5 feet of a 25-foot exposure of Peoria loess contains no shells (Farmdale zone); 7 feet above the base, 139 shells grouped in four species were recovered from a cubic foot of loess, while 13 feet above the base, a cubic foot of loess yielded 753 shells belonging to six species (Iowan zone). At this same locality, the transitional area between the Iowan and Tazewellian zones contained 5,079 shells

EXPLANATION OF PLATE 17

A representative assemblage of mollusks from pre-Bradyan Wisconsinan deposits in Kansas. All figures enlarged approximately 5 times natural size.

Figure
a—*Gastrocopta armifera* (Say)
b—*Pupilla muscorum* (Linne)
c—*Pupilla blandi* Morse
d—*Columella alticola* (Ingersoll)
e—*Vertigo gouldi paradoxa* Sterki
f—*Vertigo tridentata* Wolf
g—*Vertigo modesta* (Say)
h—*Vertigo gouldi coloradensis* (Cockerell)
i—*Vertigo milium* (Gould)
j—*Gastrocopta holzingeri* (Sterki)
k—*Euconulus fulvus* (Müller)
l—*Helicodiscus parallelus* (Say)
m—*Hawaiia minuscula* (Binney)
n—*Helicodiscus singleyanus* (Pilsbry)

Figure
o—*Vallonia gracilicosta* Reinhardt
p—*Discus shimeki* (Pilsbry)
q—*Discus cronkhitei* (Newcomb)
r—*Carychium exiguum* (Say)
s—*Striatura milium* (Morse)
t—*Deroceras laeve* (Müller)
u—*Succinea avara* Say
v—*Zonitoides arboreus* (Say)
w—*Cionella lubrica* (Müller)
x—*Retinella electrina* (Gould)
y—*Succinea grosvenori* Lea
z—*Lymnaea parva* Lea
aa—*Hendersonia occulta* (Say)
bb—*Succinea ovalis* Say

Species represented by figures b, c, l, m, o, t, u, and z characterize the faunal assemblage of the Iowan faunal zone. All but those represented by figures u and z may also appear in the Tazewellian faunal zone, but species indicated by figures a, d, e, g, h, i, j, s, w, y, aa, and bb do not occur below the transitional zone between the Iowan Tazewellian faunal zones, and may be thought of as characterizing the Tazewellian faunal assemblage.

Molluscan species / Faunal localities	SW ¼ sec. 30, T. 3 S., R. 38 W., Cheyenne	SE ¼ sec. 28, T. 3 S., R. 39 W., Cheyenne	SE ¼ sec. 17, T. 1 S., R. 41 W., Cheyenne	SE ¼ sec. 16, T. 1 S., R. 42 W., Cheyenne	NW ¼ sec. 6, T. 30 S., R. 23 W., Clark	NW ¼ sec. 20, T. 33 S., R. 23 W., Clark	NE ¼ sec. 26, T. 33 S., R. 24 W., Clark	NW ¼ sec. 31, T. 5 S., R. 3 W., Cloud	NE ¼ sec. 3, T. 3 S., R. 27 W., Decatur	NE ¼ sec. 6, T. 3 S., R. 27 W., Decatur	NW ¼ sec. 35, T. 3 S., R. 27 W., Decatur	SW ¼ sec. 23, T. 4 S., R. 27 W., Decatur
Gastrocopta holzingeri (Sterki)												
Succinea ovalis Say											●	
Gastrocopta armifera (Say)												
Hendersonia occulta (Say)								●				
Discus shimeki (Pilsbry)								●	●			●
Succinea grosvenori Lea								●	●	●	●	●
Vertigo modesta (Say)									●	●		●
Discus cronkhitei (Newcomb)								●			●	●
Columella alticola (Ingersoll)									●			
Striatura milium (Morse)										●		
Retinella electrina (Gould)												
Cionella lubrica (Muller)												
Vertigo gouldi coloradensis Cockerell											●	
Zonitoides arboreus (Say)												
Vertigo milium (Gould)								●				
Vertigo tridentata Wolf											●	
Carychium exiguum (Say)										●		
Deroceras laeve (Muller)								●				
Helicodiscus singleyanus (Pilsbry)								●				
Vertigo gouldi paradoxa Sterki						●		●	●			
Helicodiscus parallelus (Say)		●				●		●	●			
Euconulus fulvus (Muller)							●		●	●	●	
Hawaiia minuscula (Binney)	●	●			●	●	●		●			
Pupilla muscorum (Linne)	●	●			●	●	●		●	●	●	●
Pupilla blandi Morse			●	●	●	●			●	●		
Vallonia gracilicosta Reinhardt	●		●	●	●	●	●	●	●	●	●	●
Succinea avara Say	●	●	●	●	●	●	●		●	●		●
Lymnaea parva Lea						●						

FIG. 9.—Occurrence of fossil mollusks in pre-Bradyan Wisconsinan deposits at (Continued on

SW 1/4 sec. 26, T. 4 S., R. 27 W., Decatur	SW 1/4 sec. 7, T. 5 S., R. 27 W., Decatur	NE 1/4 sec. 1, T. 3 S., R. 28 W., Decatur	NW 1/4 sec. 23, T. 5 S., R. 28 W., Decatur	NE 1/4 sec. 14, T. 5 S., R. 29 W., Decatur	SE 1/4 sec. 6, T. 2 S., R. 20 E., Doniphan	NE 1/4 sec. 8, T. 1 S., R. 19 E., Doniphan	SW 1/4 sec. 29, T. 15 S., R. 18 W., Ellis	SW 1/4 sec. 18, T. 14 S., R. 19 W., Ellis	SW 1/4 sec. 24, 8. 21 S., R. 29 W., Finney	NE 1/4 sec. 34, T. 22 S., R. 30 W., Finney	SE 1/4 sec. 4, T. 24 S., R. 32 W., Finney	SW 1/4 sec. 9, T. 24 S., R. 32 W., Finney	NW 1/4 sec. 16, T. 29 S., R. 24 W., Ford	NE 1/4 sec. 2, T. 27 S., R. 22 W., Ford	NE 1/4 sec. 35, T. 15 S., R. 27 W., Gove	SW 1/4 sec. 36, T. 14 S., R. 29 W., Gove	SW 1/4 sec. 23, T. 9 S., R. 21 W., Graham	NE 1/4 sec. 28, T. 9 S., R. 22 W., Graham	SE 1/4 sec. 28, T. 27 S., R. 35 W., Grant	*NE 1/4 sec. 1, T. 25 S., R. 29 W., Gray	NW 1/4 sec. 9, T. 16 S., R. 40 W., Greeley	*NW 1/4 sec. 19, T. 21 S., R. 40 W., Hamilton	SE 1/4 sec. 12, T. 25 S., R. 41 W., Hamilton	SW 1/4 sec. 36, T. 25 S., R. 41 W., Hamilton	SE 1/4 sec. 35, T. 35 S., R. 8 W., Harper	NW 1/4 sec. 3, T. 28 S., R. 32 W., Haskell	NE 1/4 sec. 22, T. 30 S., R. 34 W., Haskell
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137 localities in Kansas. Asterisk indicates collection from hand auger samples. next page.)

NE ¼ sec. 27, T. 23 S., R. 22 W., Hodgeman	NW ¼ sec. 26, T. 23 S., R. 25 W., Hodgeman	NE ¼ sec. 4, T. 1 S., R. 7 W., Jewell	SW ¼ sec. 19, T. 5 S., R. 8 W., Jewell	*NW ¼ sec. 31, T. 23 S., R. 38 W., Kearny	NW ¼ sec. 3, T. 28 S., R. 9 W., Kingman	SW ¼ sec. 18, T. 16 S., R. 28 W., Lane	NW ¼ sec. 7, T. 20 S., R. 28 W., Lane	SE ¼ sec. 29, T. 20 S., R. 28 W., Lane	SW ¼ sec. 2, T. 16 S., R. 29 W., Lane	NW ¼ sec. 3, T. 16 S., R. 29 W., Lane	NE ¼ sec. 15, T. 16 S., R. 29 W., Lane	SE ¼ sec. 15, T. 16 S., R. 30 W., Lane	*NE ¼ sec. 17, T. 17 S., R. 30 W., Lane	SE ¼ sec. 27, T. 11 S., R. 32 W., Logan	NW ¼ sec. 13, T. 12 S., R. 32 W., Logan	SE ¼ sec. 3, T. 14 S., R. 32 W., Logan	NW ¼ sec. 27, T. 15 S., R. 32 W., Logan	NE ¼ sec. 2, T. 14 S., R. 35 W., Logan	NE ¼ sec. 9, T. 15 S., R. 35 W., Logan	SE¼ sec. 3, T. 11 S, R. 36 W, Logan	NE ¼ sec. 32, T. 12 S., R. 37 W., Logan	NE ¼ sec. 8, T. 33 S., R. 27 W., Meade	NE ¼ sec. 11, T. 30 S., R. 28 W., Meade	SW ¼ sec. 30, T. 31 S., R. 28 W., Meade	NW ¼ sec. 6, T. 30 S., R. 30 W., Meade	NW ¼ sec. 28, T. 8 S., R. 8 W., Mitchell	NW ¼ sec. 10, T. 16 S., R. 22 W., Ness
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Fig. 9.—Occurrence of fossil mollusks in pre-Bradyan Wisconsinan deposits at (Continued on

NE 1/4 sec. 16, T. 16 S., R. 22 W., Ness	NE 1/4 sec. 29, T. 16 S., R. 24 W., Ness	NW 1/4 sec. 26, T. 2 S., R. 23 W., Norton	NW 1/4 sec. 11, T. 3 S., R. 23 W., Norton	NE 1/4 sec. 10, T. 4 S., R. 23 W., Norton	SE 1/4 sec. 27, T. 4 S., R. 23 W., Norton	SE 1/4 sec. 13, T. 1 S., R. 24 W., Norton	NE 1/4 sec. 7, T. 5 S., R. 24 W., Norton	SE 1/4 sec. 5, T. 2 S., R. 17 W., Phillips	NW 1/4 sec. 23, T. 2 S., R. 18 W., Phillips	NE 1/4 sec. 25, T. 1 S., R. 20 W., Phillips	NE 1/4 sec. 2, T. 3 S., R. 31 W., Rawlins	NW 1/4 sec. 8, T. 5 S., R. 31 W., Rawlins	SW 1/4 sec. 2, T. 3 S., R. 33 W., Rawlins	NE 1/4 sec. 9, T. 3 S., R. 33 W., Rawlins	NW 1/4 sec. 20, T. 4 S., R. 33 W., Rawlins	NE 1/4 sec. 8, T. 3 S., R. 34 W., Rawlins	NE 1/4 sec. 29, T. 3 S., R. 36 W., Rawlins	NW 1/4 sec. 5, T. 3 S., R. 4 W., Republic	SE 1/4 sec. 7, T. 10 S., R. 16 W., Rooks	SW 1/4 sec. 30, T. 9 S., R. 19 W., Rooks	SW 1/4 sec. 28, T. 17 S., R. 19 W., Rush	SE 1/4 sec. 17, T. 18 S., R. 31 W., Scott	SE 1/4 sec. 6, T. 17 S., R. 32 W. Scott	*SW 1/4 sec. 31, T. 20 S., R. 34 W., Scott	SW 1/4 sec. 15, T. 6 S., R. 28 W., Sheridan	SW 1/4 sec. 3, T. 7 S., R. 28 W., Sheridan	SE 1/4 sec. 28, T. 7 S., R. 28 W., Sheridan
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137 localities in Kansas. Asterisk indicates collection from hand auger samples. next page.)

NW 1/4 sec. 34, T. 8 S., R. 28 W., Sheridan	SW 1/4 sec. 10, T. 9 S., R. 28 W., Sheridan	NE 1/4 sec. 33, T. 10 S., R. 28 W., Sheridan	NW 1/4 sec. 19, T. 8 S, R. 29 W., Sheridan	NE 1/4 sec. 13, T. 6 S., R. 30 W., Sheridan	NW 1/4 sec. 14, T. 6 S., R. 30 W., Sheridan	NW 1/4 sec. 15, T. 6 S., R. 30 W., Sheridan	NW 1/4 sec. 31, T. 8 S., R. 30 W., Sheridan	SE 1/4 sec. 34, T. 10 S., R. 37 W., Sherman	SW 1/4 sec. 26, T. 10 S., R. 38 W., Sherman	NW 1/4 sec. 32, T. 7 S., R. 39 W., Sherman	SW 1/4 sec. 36, T. 6 S., R. 39 W., Sherman	SW 1/4 sec. 20, T. 7 S., R. 40 W., Sherman	SE 1/4 sec. 28, T. 1 S., R. 13 W., Smith	SW 1/4 sec. 11, T. 27 S., R. 39 W., Stanton	NE 1/4 sec. 2, T. 29 S., R. 40 W., Stanton	NW 1/4 sec. 12, T. 28 S., R. 41 W., Stanton	SE 1/4 sec. 25, T. 29 S., R. 43 W., Stanton	SE 1/4 sec. 21, T 7 S., R. 31 W., Thomas	NE 1/4 sec. 27, T. 7 S., R. 31 W., Thomas	NW 1/4 sec. 10, T. 8 S., R. 32 W., Thomas	NE 1/4 sec. 17, T. 8 S., R. 32 W., Thomas	NW 1/4 sec. 31, T. 7 S., R. 33 W., Thomas	NW 1/4 sec. 18, T. 9 S., R. 33 W., Thomas	SE 1/4 sec. 27, T. 10 S., R. 33 W., Thomas	NW 1/4 sec. 8, T. 8 S., R. 35 W., Thomas	SW 1/4 sec. 8, T. 8 S., R. 35 W., Thomas	SW 1/4 sec. 32, T. 7 S., R. 36 W., Thomas
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	●	●	●			●		●	●				●	●	●	●	●	●		●	●	●	●	●	●	●	●
										●	●		●						●		●						

FIG. 9.—Occurrence of fossil mollusks in pre-Bradyan Wisconsinan hand auger

SW ¼ sec. 7, T. 8 S., R. 36 W., Thomas	SW ¼ sec. 19, T. 8 S., R. 36 W., Thomas	NW ¼ sec. 3, T. 11 S., R. 23 W., Trego	SW ¼ sec. 5, T. 12 S., R. 24 W., Trego	NW ¼ sec. 26, T. 15 S., R. 38 W., Wallace	SW ¼ sec. 35, T. 11 S., R. 40 W., Wallace	SW ¼ sec. 23, T. 12 S., R. 40 W., Wallace	NW ¼ sec. 1, T. 15 S., R. 40 W., Wallace	*SE ¼ sec. 35, T. 20 S., R. 35 W., Wichita	SW ¼ sec. 12, T. 17 S., R. 37 W., Wichita	SE ¼ sec. 1, T. 19 S., R. 37 W., Wichita	NE ¼ sec. 12, T. 19 S., R. 37 W., Wichita	SE ¼ sec. 32, T. 16 S., R. 38 W., Wichita	**Faunal localities** **Molluscan species**
													Gastrocopta holzingeri (Sterki)
													Succinea ovalis Say
													Gastrocopta armifera (Say)
													Hendersonia occulta (Say)
			●										*Discus shimeki* (Pilsbry)
						●							*Succinea grosvenori* Lea
			●										*Vertigo modesta* (Say)
													Discus cronkhitei (Newcomb)
													Columella alticola (Ingersoll)
													Striatura milium (Morse)
													Retinella electrina (Gould)
													Cionella lubrica (Muller)
													Vertigo gouldi coloradensis Cockerell
													Zonitoides arboreus (Say)
													Vertigo milium (Gould)
							●						*Vertigo tridentata* Wolf
													Carychium exiguum (Say)
													Deroceras laeve (Muller)
							●		●				*Helicodiscus singleyanus* (Pilsbry)
					●								*Vertigo gouldi paradoxa* Sterki
●	●					●					●		*Helicodiscus parallelus* (Say)
													Euconulus fulvus (Muller)
		●		●	●		●	●	●		●		*Hawaiia minuscula* (Binney)
●	●	●	●	●	●	●	●	●	●	●	●	●	*Pupilla muscorum* (Linne)
			●		●		●						*Pupilla blandi* Morse
●	●	●	●	●	●	●	●	●	●	●	●	●	*Vallonia gracilicosta* Reinhardt
●	●	●	●		●	●	●	●	●	●	●	●	*Succinea avara* Say
													Lymnaea parva Lea

deposits at 137 localities in Kansas. Asterisk indicates collection from samples. (Concluded.)

per cubic foot, belonging to 11 species; the Tazewellian zone fauna was comprised of 14 species, numbering 1,578 shells per cubic foot of loess.

There is in the Peoria loess no definite faunal unconformity between the Iowan and Tazewellian faunal zones, but the two are associated through a transitional faunal zone where the molluscan fauna gradually changes in character. *Discus cronkhitei,* followed by *D. shimeki* are the first of the Tazewellian zone species to appear in the transitional zone, usually in association with *Succinea avara,* which is otherwise restricted to the Iowan zone. *Succinea grosvenori* and *S. ovalis* appear higher in the transitional zone, usually after the disappearance of *Succinea avara,* but this is not invariable. The order of appearance of other Tazewellian zone species seems to follow no definite pattern, and perhaps reflects local conditions more than anything else.

The upper or Tazewellian faunal zone.—The upper or Tazewellian faunal zone assemblage comprises 26 species, of which 14 do not occur in the Iowan zone. Four species, *Columella alticola, Striatura milium, Vertigo gouldi coloradensis,* and *Discus shimeki,* which are restricted to this zone, do not now live in the Great Plains region. Such species as *Discus cronkhitei, Pupilla muscorum, P. blandi, Hendersonia occulta, Vallonia gracilicosta,* and *Vertigo modesta* are likewise extinct in the State, but they are known from earlier Pleistocene horizons in Kansas. In all, 11 of the 26 species in the Tazewellian faunal assemblage are absent from the living molluscan fauna of the State, making the Tazewellian zone assemblage easily recognizable in the field. The remaining species are not generally present over the State in the

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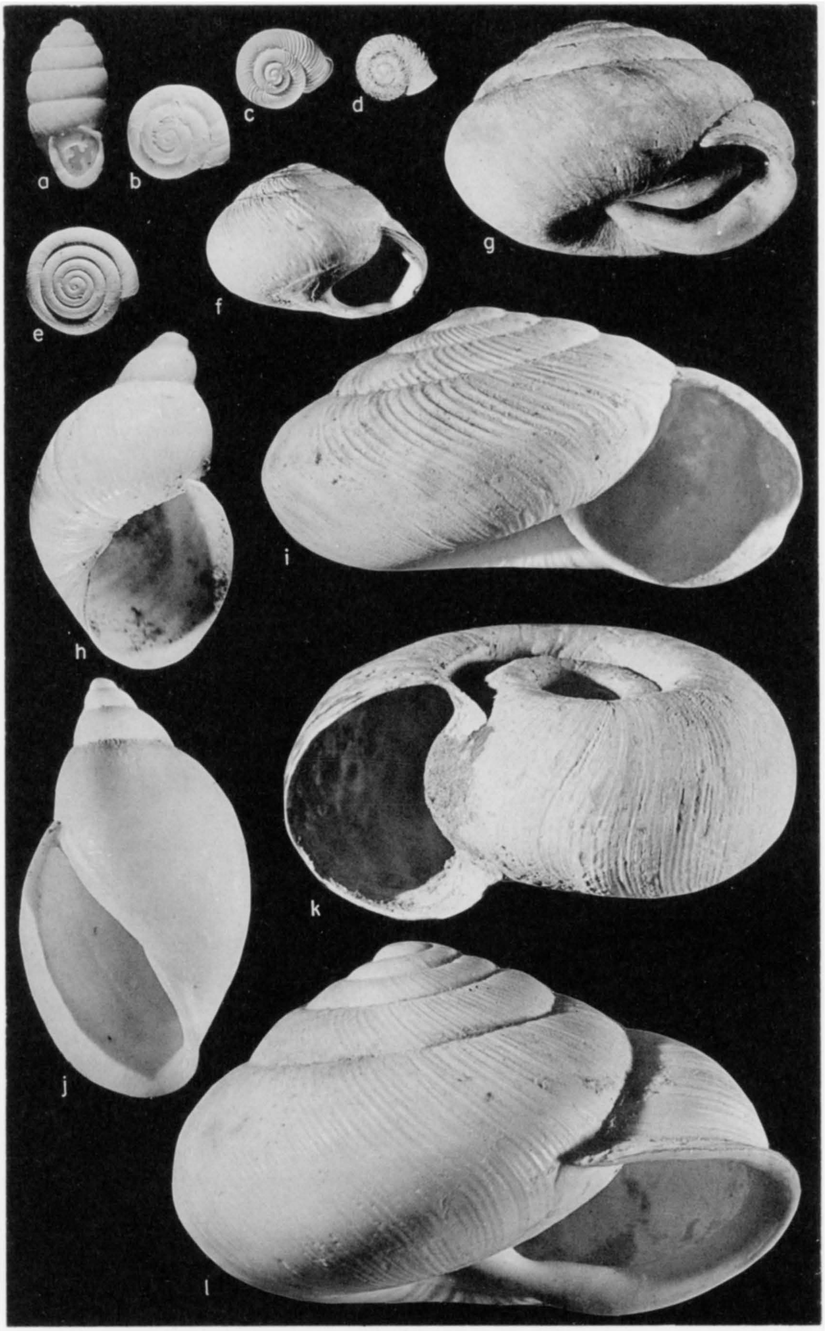
EXPLANATION OF PLATE 18

A representative assemblage of mollusks from post-Bradyan Wisconsinan deposits in Kansas. All figures enlarged approximately 5 times natural size.

FIGURE
a—*Gastrocopta armifera* (Say)
b—*Hawaiia minuscula* (Binney)
c—*Vallonia gracilicosta* Reinhardt
d—*Vallonia parvula* Sterki
e—*Helicodiscus parallelus* (Say)
f—*Hendersonia occulta* (Say)

FIGURE
g—*Stenotrema leai aliciae* Pilsbry
h—*Succinea avara* Say
i—*Anguispira alternata* (Say)
j—*Physa anatina* Lea
k—*Helisoma trivolvis lentum* (Say)
l—*Tridopsis multilineata* (Say)

Species represented by figures c, f, g, i, and l are found in Kansas only in extreme northeastern Kansas in Bignell loess near the Missouri River. Those represented by figures a, b, d, e, and h comprise the characteristic sparse fauna found in post-Bradyan deposits in the Great Plains region.



Frye and Leonard — Representative post-Bradyan Wisconsinan mollusks.

living fauna, but are more or less limited to local favorable habitats.

It is clear that ecological conditions in the State in pre-Bradyan times were more favorable to mollusks than at present. Even the Iowan zone assemblage, sparse in the lower part of the Peoria loess, is more varied than Recent faunas in the same area. It is likely that population density was also greater than now, judging from samples of loess which yield as many as 5,000 shells per cubic foot, but since the rate of deposition is not known, this figure may be somewhat misleading.

A reasonable amount of rainfall, at least more than present average amounts, and a floral cover somewhat denser than that on the Great Plains today may be inferred from the molluscan faunas in pre-Bradyan sediments. The climate may also have been somewhat cooler than that which characterizes the Great Plains today. Two kinds of faunal evidence support these views: (1) the pre-Bradyan species now extinct in Kansas presently live at higher altitudes or latitudes (A. B. Leonard, 1952, figs. 7-15), and (2) *Bulimulus dealbatus,* a southern gastropod adapted to survive long periods of drouth which has reached the northern border of Kansas in Recent time, is absent in the Wisconsinan faunal assemblages.

The Iowan faunal zone has been traced from northeastern Kansas through central, western, and southwestern Kansas. The same faunal assemblage is known to occur in northwestern Oklahoma in Dewey County, in northern Texas in Sherman County, and in Frontier and Lincoln Counties, Nebraska.

The Tazewellian faunal zone is much more restricted in its distribution in Kansas but is known from southern and central Nebraska, western Iowa, and central Illinois. This assemblage can be traced across the northern border of Kansas except for Cheyenne County in the extreme northwestern part of the State, and southward to Rush, Lane, Gove, and Logan Counties. It might be concluded from this faunal evidence that these places mark the approximate southern extent of the influence of Tazewellian ice upon loess deposition in Kansas. However, since the loess of southwestern Kansas is thin, nearly half of its thickness being involved in the weathering of the soil profile in its top, it is possible that loess blown from valley trains produced by the melting of Tazewellian ice was carried even farther south, faunal evidence of it having been lost by the weathering of the shells. Further evidence of this possibility is seen in deposits in a dissected sink (NE¼ sec. 8, T. 33 S., R. 27 W., Meade County), where the molluscan faunule is known to include *Discus cronkhitei, Succinea grosvenori,* and other elements of the Tazewellian assemblage.

Post-Bradyan molluscan assemblages.—Sixteen species comprise the post-Bradyan Wisconsinan molluscan assemblage, but nearly half of these are limited to Bignell loess in the northeastern part of the State in Doniphan County (Fig. 10). The greater part of the 27 reported faunal localities consists of Bignell loess of local occurrence in many western counties, and work has only begun on the molluscan faunules in terraces of equivalent age. Except at the Iowa Point section described by Frye and A. B. Leonard (1949) the molluscan fauna in most post-Bradyan sediment is sparse, both in species and in individuals. No more than four or five species are typical at any one locality, and frequently a collection at any one exposure may not contain more than a dozen shells, and often less.

The great majority of the post-Bradyan mollusks are terrestrial species known to be capable of surviving long periods of aridity. Unlike the pre-Bradyan Wisconsinan faunal assemblage, most post-Bradyan species are now found living in the State, and often near the outcrop from which fossil shells are taken. Everywhere it has been studied, the post-Bradyan fauna bears a close resemblance to the local modern molluscan fauna. Thus, in the timbered loess hills in northeastern Kansas near Missouri River, the fauna is predominantly characteristic of the assemblage of species found today in the local forested areas, while on the Great Plains, the fauna of post-Bradyan loess and terraces of equivalent age is identical with the sparse fauna of minute gastropods which occurs there at the present time. The only exception to this observation is the occurrence of *Hendersonia occulta* in Bignell loess in extreme northeastern Kansas; this gastropod is no longer living in the State.

The paucity of the post-Bradyan fauna except at the Iowa Point exposures does not permit the faunal zonation of the Bignell loess or terraces of equivalent age. All that can be said of the age of the faunal assemblage is that it includes some segment, whether large or small is not known, of Caryan-Mankatoan time.

Molluscan species **Faunal localities**	*Anguispira alternata* (Say)	*Gastrocopta armifera* (Say)	*Hendersonia occulta* (Say)	*Stenotrema leai aliciae* Pilsbry	*Succinea grosvenori* Lea	*Succinea ovalis* Say	*Triodopsis multilineata* (Say)	*Vallonia gracilicosta* Reinhardt	*Vallonia parvula* Sterki	*Hawaiia minuscula* (Binney)	*Helicodiscus parallelus* (Say)	*Physa anatina* Lea	*Succinea avara* Say	*Helisoma trivolvis* (Say)	*Lymnaea* sp.	*Pisidium* sp.
SW ¼ sec. 20, T. 33 S., R. 11 W., Barber										●	●	●	●	●		●
SW ¼ sec. 30, T. 3 S., R. 38 W., Cheyenne											●		●			
NW ¼ sec. 30, T. 33 S., R. 21 W., Clark												●	●	●	●	●
NW ¼ sec. 6, T. 30 S., R. 23 W., Clark										●	●		●			
NE ¼ sec. 26, T. 33 S., R. 24 W., Clark									●	●	●					
NE ¼ sec. 28, T. 4 S., R. 26 W., Decatur		●								●	●					
SW ¼ sec. 23, T. 4 S., R. 27 W., Decatur									●	●	●					
NE ¼ sec. 26, T. 4 S., R. 27 W., Decatur									●	●	●		●			
NE ¼ sec. 8, T. 1 S., R. 19 E., Doniphan		●		●			●	●		●	●	●				
SE ¼ sec. 6, T. 2 S., R. 20 E., Doniphan	●	●	●	●	●	●	●	●		●	●					
SE ¼ sec. 17, T. 2 S., R. 20 E., Doniphan	●	●	●		●	●			●	●						
NE ¼ sec. 2, T. 27 S., R. 22 W., Ford										●		●	●	●		●
NW ¼ sec. 9, T. 16 S., R. 40 W., Greeley										●	●		●			
SE ¼ sec. 35, T. 35 S., R. 8 W., Harper		●							●	●	●	●	●	●	●	●
NE ¼ sec. 27, T. 23 S., R. 22 W., Hodgeman									●	●		●	●		●	
SW ¼ sec. 1, T. 15 S., R. 32 W., Logan										●	●		●			
NE ¼ sec. 32, T. 12 S., R. 37 W., Logan										●	●	●	●			
SE ¼ sec. 9, T. 21 S., R. 5 W., McPherson													●	●	●	●
NE ¼ sec. 29, T. 16 S., R. 24 W., Ness										●	●		●			
SW ¼ sec. 23, T. 2 S, R. 23 W, Norton		●							●	●	●		●			
NW ¼ sec. 26, T. 2 S., R. 23 W., Norton										●	●		●			
SE ¼ sec. 27, T. 4 S., R. 23 W., Norton		●									●	●	●			
SW ¼ sec. 2, T. 3 S., R. 33 W., Rawlins									●				●			
SE ¼ sec. 6, T. 17 S., R. 32 W. Scott									●				●			
NW ¼ sec. 30, T. 4 S., R. 14 W., Smith										●	●		●			
NE ¼ sec. 7, T. 8 S., R. 35 W., Thomas										●	●		●			
NW ¼ sec. 7, T. 8 S., R. 35 W., Thomas		●								●	●		●			

FIG. 10.—Occurrence of fossil mollusks in post-Bradyan Wisconsinan deposits at 27 localities in Kansas.

The final stage in the progressive dessication of the Great Plains which seems to have begun after Yarmouthian time and to have culminated in the semi-arid climate of modern time, took place during or after the Bradyan interglacial interval. The great populations of *Discus, Pupilla, Vertigo,* and *Vallonia gracilicosta,* together with less widespread populations of *Hendersonia occulta, Columella alticola, Striatura milium, Euconulus fulvus,* and several other species, completely vanished from the Great Plains at the close of Tazewellian or during Bradyan time. As we interpret conditions from the molluscan faunal assemblages the vegetative cover became reduced at this time or shortly thereafter, the climate became somewhat warmer, and it is probable that a biologically severe climate, characterized by extremes of aridity and high temperatures in summer, followed by cold, dry winters, began after Bradyan time. Only a few species of gastropods can endure the rigors of the existing Great Plains environment, and because molluscan assemblages in post-Bradyan sediments are nearly everywhere identical with the local modern fauna, the conclusion is inevitable that the environment at the time of deposition of post-Bradyan sediments was not unlike that at the present time.

SUMMARY OF PLEISTOCENE DRAINAGE CHANGES

The present stream pattern of Kansas has evolved almost entirely as a result of events during Pleistocene time. However, in order to view in proper perspective this relatively short interval of rapid evolution of the present drainage, we should look farther back into the geologic record.

The earliest drainage that has a bearing on present stream patterns is that which existed on the early Cretaceous erosion surface. This surface in central and eastern Kansas beveled Pennsylvanian and Permian rocks. It was a surface of moderate relief and in central Kansas it is preserved along a northeasterly trend by progressively overlapping Cheyenne sandstone, Kiowa shale, and Dakota formation. The contact of Cretaceous on Permian is exposed in a belt extending from Comanche County on the Oklahoma state line to Washington County on the Nebraska state line. At many localities the basal few feet of Cretaceous rocks contains pebbles and cobbles of a size and type unknown in the remainder of the Kansas Cretaceous section. These pebbles are genetically related to the erosion surface rather than to any stratigraphic position within the Cretaceous as indicated by the fact that they are found only adjacent to the unconformable surface. They occur in the Cheyenne, Kiowa, and Dakota where each of these units is in contact with pre-Cretaceous rocks, but are never found in the Dakota or Kiowa where these units are underlain respectively by Kiowa and Cheyenne.

The pebbles and cobbles found above the pre-Cretaceous erosion surface are well rounded, smooth, and in size are as much as 4½ inches in maximum diameter. They consist predominantly of chert, quartz, and quartzite, and siliceous cemented quartz sandstone. In two chert pebbles from Rice County in central Kansas fusulines have been identified by M. L. Thompson (personal communication) who states that the particular species are known to occur only in lower Permian limestones more than 100 miles farther east in Kansas. The occurrence of eastern fusulines is association with metamorphic rocks strongly suggests a source to the northeast, thus establishing the direction of major drainage in early Cretaceous time as southwesterly across eastern and central Kansas.

The alignment of lenticular sand bodies in the Dakota formation confirms this interpretation. Channel sands display a general southwest-northeast trend whereas beach and bar sands are commonly at right angles to this trend (Norman Plummer, personal communication).

LATE TERTIARY DRAINAGE

There is no direct evidence to indicate whether or not drainage lines extended themselves as consequents across the Cretaceous sediments and thus returned to a southwesterly trend as Cretaceous seas withdrew. Data bearing on this point have been removed by erosion. However, strong evidence indicates that, in any event, such a trend was not in existence in late Tertiary time. In central and western Kansas Pliocene sediments of the widespread Ogallala formation are composed of coarse clastic materials derived predominantly from a western source in the Rocky Mountain region and from local bedrock. In marked contrast to the lithology of the Ogallala formation, the late Ter-

Molluscan species	Blanco	Sappa	Crete-Loveland	Peoria-lower	Peoria-upper	Bignell
Anguispira alternata						■
Stenotrema leai aliciae						■
Triodopsis albolabris						■
Vallonia pulchella		■				■
Gastrocopta armifera		■	■		■	■
Hendersonia occulta		■			■	■
Succinea grosvenori	■	■	■		■	■
Succinea ovalis		■			■	■
Hawaiia minuscula	■	■	■	■	■	■
Helicodiscus parallelus		■	■	■	■	■
Gastrocopta holzingeri	■	■	■		■	
Columella alticola					■	
Striatura milium	■				■	
Vertigo gouldi coloradensis					■	
Vertigo modesta		■			■	
Carychium exiguum		■	■		■	
Cionella lubrica	■	■			■	
Pupilla blandi		■	■	■	■	
Discus cronkhitei		■	■		■	
Discus shimeki					■	
Vertigo tridentata		■	■	■	■	
Euconulus fulvus				■	■	
Helicodiscus singleyanus	■			■	■	
Vertigo gouldi paradoxa		■		■	■	
Vertigo milium		■		■	■	
Deroceras laeve		■	■	■	■	
Pupilla muscorum		■	■	■	■	
Retinella electrina	■	■	■	■	■	
Zonitoides arboreus	■	■	■	■	■	
Vallonia gracilicosta	■	■	■	■	■	
Succinea avara		■		■		
Lymnaea parva		■		■		
Helisoma trivolvis		■	■			
Physa anatina	■	■	■			
Pupoides albilabris	■	■	■			
Strobilops labyrinthica			■			
Carychium perexiguum	■	■	■			
Gastrocopta cristata		■	■			
Gyraulus similaris		■	■			
Helisoma antrosa	■	■	■			
Sphaerium solidulum		■	■			
Gastrocopta tappaniana	■	■	■			
Strobilops sparsicosta	■	■	■			
Vertigo ovata		■	■			
Ferrissia parallela	■	■				
Gastrocopta contracta		■				

Gastrocopta falcis		■
Gastrocopta proarmifera		■
Gastrocopta procera		■
Amnicola limosa parva		■
Gastrocopta tridentata		■
Gyraulus labiatus		■
Gyraulus pattersoni		■
Helisoma wisconsinensis		■
Lymnaea bulimoides		■
Lymnaea caperata		■
Lymnaea palustris		■
Lymnaea reflexa		■
Polygyra texasiana		■
Menetus pearlettei		■
Oxyloma navarrei		■
Physa elliptica		■
Pisidium compressum		■
Planorbula nebraskensis		■
Planorbula vulcanata vulcanata		■
Planorbula vulcanata occidentalis		■
Pomatiopsis cincinnatiensis		■
Promentetus umbilicatellus		■
Pupilla muscorum sinistra		■
Stenotrema leai leai		■
Aplexa hypnorum		■
Valvata lewisi		■
Valvata tricarinata		■
Deroceras aenigma	■	■
Amnicola crybetes	■	
Ferrissia rivularis	■	
Gastrocopta paracristata	■	
Gastrocopta rexroadensis	■	
Gyraulus enaulus	■	
Lymnaea diminuta	■	
Lymnaea humilis modicella	■	
Lymnaea macella	■	
Lymnaea parexilis	■	
Lymnaea turritella	■	
Menetus kansasensis	■	
Polygyra mooreana	■	
Promenetus blancoensis	■	
Vertigo hibbardi	■	

FIG. 11.—Check list of fossil mollusks arranged according to their stratigraphic occurrence in the Pleistocene deposits of Kansas. For "*Lymnaea parexilis*" read *Lymnaea perexilis*, and for "*Promentetus*" read *Promenetus*.

tiary sediments in the eastern one-fourth of Kansas are entirely attributable to the Permian and Pennsylvanian rocks eastward from and including the Herington limestone.

The fact that the locally derived high level chert gravels in eastern Kansas are Tertiary in age is demonstrated by their physiographic position. A prominent terrace occurring about 40 feet above the present flood plain has been studied along much of the Cottonwood-Neosho River Valley by H. G. O'Connor. This terrace has been dated as Kansan by petrographically distinctive Pearlette volcanic ash (Frye, Swineford, and Leonard, 1948) contained in the sediments at Emporia. Also, vertebrate fossils from the same level in Lyon County have been examined by R. W. Wilson. Remnants of a distinct chert gravel veneered terrace that may be Nebraskan in age occur along the same valley system at a level 80 to 100 feet above the present flood plain. Other chert gravels occur at several higher positions and in Coffey, Anderson, and Allen Counties they cap divide areas at elevations as much as 300 feet above the same reference flood plain level. Above the Emporia (40-foot) terrace all surficial deposits are severely weathered throughout their thickness. They consist only of chert (of types characteristic of the Herington and stratigraphically lower limestones) in a reddish clay matrix, and therefore their dating rests solely on their physiographic position.

The high level gravels at positions as much as 300 feet above flood plain level and judged to be pre-Pleistocene because as much as 200 feet of bedrock incision occurred after their deposition and prior to the deposition of Nebraskan terrace gravels. The high level gravels are considered to be late Tertiary in age because Cretaceous sediments which approached or overlapped the western part of the Flint Hills region were removed and the resistant cherty Florence, Fort Riley, and adjacent limestones were etched into strong relief prior to the deposition of these high level gravels. No stream-rounded chert gravels occur on the crest of the Flint Hills even though broad gently sloping surfaces are common. These relationships show that some time during the Tertiary the Flint Hills became a major divide separating two strongly contrasting depositional provinces. The western of these two provinces discharged drainage southward from Kansas into Oklahoma, and the eastern province discharged its drainage eastward into Missouri, Although data on the pre-Pleistocene history north of Kansas River Valley are obscured by glacial deposits a similar erosional history is known to have obtained. Detailed studies of pebble lithologies by Davis (1951) show that even along the Kansas River Valley, now the only valley carrying western drainage through the Flint Hills, western materials were not deposited until after the Kansan glacial age and that the late Tertiary drainage pattern was similar to that farther south.

Details of the pre-Pleistocene drainage are not known but the regional distribution of Pliocene sediments, Ogallala stratigraphy, and lithologies of clastic sediments show clearly that streams flowing toward the east or southeast from the Rocky Mountain region crossed western and central Kansas and left the State toward the south. The early Pliocene drainage was localized in valleys in an erosional topography of gentle slopes but with divides as much as 300 to 400 feet above the major valley floors. This is attested by the stratigraphic overlap of the several members of the Ogallala on the former bedrock surface. As alluviation proceeded through Pliocene time these erosional valleys were filled so that the resulting plains of alluviation generally coalesced over the former divides. Thin deposits of uppermost Ogallala are relatively common along the crest of the Greenhorn limestone (Cretaceous) cuesta showing that this present scarp-forming formation, as well as the Fort Hays limestone, exerted little influence on regional topography by the end of Ogallala deposition.

However, late Tertiary drainage that flowed eastward from the Flint Hills crest was much less effective in obliterating the bedrock topography as the deposits of these streams were restricted to valley bottoms. Thin chert gravel deposits at several levels above the terrace presumed to be Nebraskan in age indicate that the late Pliocene topography of eastern Kansas was essentially erosional on the Paleozoic bedrock with a maximum local relief of less than 200 feet and that the major valleys were flanked by two or perhaps more terraces thinly veneered with chert gravels.

NEBRASKAN DRAINAGE

As the Nebraskan glacier started to accumulate, Kansas was a region of subdued topography and with much less relief than that existing at the present time. The western third of the State was an extensive alluvial plain with perhaps a few low gently rounded divides underlain immediately by Cretaceous rocks. This surface was not without character, however, as such a plain developed by laterally shifting depositing streams must have displayed features such as natural levees, abandoned channel segments, and intra-channel "backswamp" areas typical of surfaces built by stream deposition. The water table under this surface must have been quite shallow (as it now is under parts of the Arkansas River alluvial plain) and standing bodies of water must have occurred in disconnected low places.

If this surface were warped along an east-west axis in northwestern Kansas, and tilted gently toward the east, as suggested by Smith (1940), drainage of essentially a consequent origin may have developed and so given rise to a semi-radial stream pattern in northwestern Kansas. This conclusion is strengthened by the fact that northwestern Kansas was never crossed by a major through-flowing stream during Pleistocene time.

In central Kansas, this western alluvial plain merged laterally with an erosional plain of almost equally subdued relief. In central Kansas broad alluviated valleys were joined by alluviated tributaries which were filled to shallow depths with locally derived materials. A major stream flowed south across central Kansas (Fig. 12) parallel to the strike of the bedrock, in a belt of shales which occur at the foot of the long dip slope west of the Flint Hills.

Deepening of all major stream channels occurred generally in Kansas at about the beginning of the Pleistocene. The depth of this incision ranged widely in different places. For example, in the filled Chase channel in central Rice County described by Fent (1950), late Nebraskan sediments are the lowest part of the fill of a valley cut 200 feet below thin Ogallala on adjacent uplands; in eastern Ellis County Nebraskan stream sediments occur about 150 feet below Ogallala beds capping the adjacent Fort Hays limestone scarp (A. R. Leonard and D. W. Berry, in preparation); in the northwestern corner of Ness County a remnant of a Nebraskan terrace is less than 75 feet below the Ogallala; while along Cimarron River Valley in southwestern Kansas and in north-central McPherson County Nebraskan stream sediments rest on eroded Ogallala formation.

In the glaciated area Nebraskan deposits are obscured except along the Missouri River Valley in Doniphan and northern Atchison Counties. In that area David City (Nebraskan) sand and gravel occur below Nebraska till and rest on Pennsylvanian bedrock about 35 feet above the flood plain of Missouri River (Frye and A. B. Leonard, 1949), whereas in the same area chert gravels overlain by glacial deposits and judged to be pre-Nebraskan in age occur 25 to 50 feet higher above the same datum. These data also indicate moderate bedrock incision during earliest Pleistocene time.

The cause of this early Pleistocene stream incision is not known. It can hardly be attributed to lowering of sea level because most of the downcutting was accomplished by the time the Nebraskan ice had reached its maximum extent; furthermore the maximum depths of downcuttings in Kansas were in the central area. Neither is crustal warping alone an adequate explanation. The maximum unwarping of the late Pliocene surface was in the northwestern part of the State (Smith, 1940) and that area contains the least evidence of marked early Pleistocene valley deepening. Although several factors probably contributed to the early Pleistocene downcutting, the principal causes are judged to be changes in stream regimen—that is, the relation of volume to load—and generally accentuated gradients produced by regional eastward tilting.

The inferred reconstruction of the late Nebraskan drainage is shown on the map in Figure 12. Much of the reconstruction of this drainage pattern is based on subsurface data obtained in the course of test drilling by the cooperative State and Federal Geological Surveys' Ground-Water Division (Fent, 1950, 1950a; Frye and Walters, 1950). Other parts of the pattern are based on terrace remnants and on projections from known deposits (e.g., Sumner County). Along the Smoky Hill Valley in Gove, Ness, and Trego Counties remnants of a Nebraskan terrace have been observed and studied in detail in the vicinity of Antonino in Ellis County (A. R. Leonard and D. W. Berry, in preparation). Another arm of this late Nebraskan system is represented by alluvial deposits in east-central Ellis County and near Galacia in northwestern Barton County (Latta, 1950) where a stream crossed the present divide separating Smoky Hill from Arkansas drainage. From the "Galatia channel" the stream flowed southeastward through Chase channel across Rice County and joined the north-south master stream in Sedgwick County.

In southwestern Kansas another major north-south drainage line extended south through the Scott-Finney depression (Waite, 1947) and seemingly spread laterally to alluviate an extensive basin lying west of the Crooked Creek and Fowler faults (Frye, 1942) in central Meade County. In strong contrast to the present drainage pattern the general grain of the Nebraskan drainage of southern and central Kansas was north-northwest to south-southeast. As the Nebraskan glacier entered only the northeastern corner of the State, it was presumably served by an eastern spillway along its southern limit defined by test drilling (Frye and Walters, 1950), and now buried under Kansas till. Outwash of Nebraskan continental glaciers does not occur beyond the limits of Kansan glaciation (Davis, 1951).

KANSAN DRAINAGE

Events directly and indirectly related to Kansan glaciation initiated the sequence of drainage adjustments, perhaps still in progress, that gave rise to the present stream systems of the State. Kansan ice entered Kansas from the northeast but advanced well beyond the limit of Nebraskan glaciation, overrode the Flint Hills upland into Washington County, and covered important parts of this earlier divide in Marshall and Pottawatomie Counties. The western and southern extremities of the Kansan glacier produced the eventual integration of the Kansas River system.

The stream pattern at the beginning of Kansan time is judged to have been similar to that of late Nebraskan time. During the advancing phase of Kansan glaciation Kansas streams generally deepened their channels; the prominent valley across southern Nemaha and northern Jackson Counties was deepened and then alluviated with pro-Kansan (Atchison formation) sands, and eventually overridden by the ice. Locally the Kansan glacier extended across the position of the Kansas River Valley and forced meltwaters into a temporary spillway to the east along Wakarusa Valley (Todd, 1911). This spillway, however, was not available to the meltwaters from the western edge of the lobe because it was effectively blocked by the ice mass itself. Available evidence indicates that the only avenue of escape for the meltwaters and outwash from the Washington and Marshall County area was toward the southwest and thence southward along the line of the formerly well-established drainageway across Saline, McPherson, Harvey, and Sedgwick Counties. Such a spillway course reversed the direction of flow through the headwaters of an "ancestral Kaw Valley" in the Flint Hills area and spilled into the headwaters of a tributary to the major south-flowing stream through central Kansas. At least two other important spillways, later abandoned, carried meltwater and outwash westward from the western margin of the Kansan glacier in Kansas (Fig. 13). These temporary drainage lines originated along the ice margin where it extended west of the Flint Hills divide and as they were heavily alluviated and soon abandoned they had little influence on the future stream pattern. The spillway westward along the present course of the Smoky Hill Valley past Junction City, however, had a profound effect on later drainage as the temporarily large volume of water and sediment deeply notched the major divide and provided the mechanism for the integration of the present Kansas River system.

Evidence for this western spillway is fragmentary but nevertheless quite strong. Regional examination of chert gravels and physiography in eastern Kansas, and particularly studies of pebble lithology by Davis (1951) along the Kansas River Valley, show that drainage from west of the Flint Hills did not come east across the divide until after retreat of the Kansan glacier. Outwash sand and gravel on bedrock occur high above the valley flat of the Smoky Hill River west of Junction City, and the former McPherson valley across McPherson County is filled to a depth of 150 feet with sand, gravel, and silt dated as late Kansan in age by more than a half dozen localities of Pearlette volcanic ash. The late Kansan drainage through McPherson valley is known to have been southward because of the gradients of bedrock floors and its integration with the drainage pattern demonstrated by extensive terrace deposits along Smoky Hill Valley, abandoned Wilson valley, and widespread test drilling.

Present elevations do not indicate a gradient from the Flint Hills area toward the McPherson channel as the bedrock floor under the Kansan stream sediments in that abandoned valley is as high, or higher, than the level of the outwash deposits west of Junction City. This is the expectable relationship if the drainage history is as shown in Figure 13. The Smoky Hill Valley spillway toward the west was in use at the time of the Kansan glacial maximum and it is safe to infer that isostatic adjustments to this ice mass—the greatest to invade the midwest—were at least as great as those that have been determined to have been associated with late Wisconsinan glaciers (Flint, 1947, pp. 409-427). The area where this spillway crossed the crest of the Flint Hills is within 25 miles of the glacial margin and should have had maximum effect of the marginal isostatic bulge, whereas the McPherson channel is more than 100 miles from the nearest point along the ice front and may have been beyond the effects of superelevation. As 100 feet of temporary elevation is indeed a conservative figure for the marginal zone of a glacial mass as large as the Kansan, a temporarily adequate gradient toward the south undoubtedly existed during the time southern drainage occurred.

It is well known that deep incisions have been made in glacial spillways in relatively short periods. Such an incision along the course of the present Smoky Hill produced a channel that, when lowered by isostatic adjustment due to the retreat of the Kansan ice mass, allowed the establishment of a competent eastward-flowing stream through the Flint Hills. This eastward-flowing stream reversed the direction of flow through the temporary spillway.

The fact that most of the fill of McPherson channel was contributed from the northeast (Lohman and Frye, 1940) as Kansan outwash is demonstrated by quantitative relations. McPherson valley, which is 4 to 5 miles wide, contains in its deepest part more than 100 feet of sand and gravel overlain by more than 50 feet of sand, silt, and volcanic ash. The principal western tributary to this channel was the ancestral Smoky Hill and its large tributary through the abandoned Wilson valley (Fig. 13). The Kansan terrace fill has been studied westward along more than

200 miles of Smoky Hill Valley. Here the Kansan sediments fill a narrow channel which in the western part of the State averages less than one-fourth mile in width and the sand and gravel fill only about 25 feet in thickness. East of the junction of the Wilson valley channel the Grand Island (Kansan) gravels are somewhat thicker and wider but even here, insignificant in comparison to the imposing quantity of material in abandoned McPherson valley. It is significant that westward along the Smoky Hill Valley the Crete (Illinoian) gravels that overlie the Grand Island-Sappa (Kansan) are quantitatively more extensive. These facts emphasize the importance of northern and northeastern sources in the filling of abandoned McPherson valley.

Kansan outwash moved across Kansas not only from the continental glacier in the northeastern corner of the State but also from the Rocky Mountain region to the west. That Rocky Mountain outwash did not come down the Smoky Hill Valley is indicated by the relative insignificance of the Grand Island gravels, previously described. However, a vast quantity of Grand Island gravels attaining thicknesses as much as 100 feet and overlain by Sappa silts that locally contain Pearlette volcanic ash and characteristic molluscan faunas occurs in south-central Kansas. The quantity of Kansan gravels in this region is entirely too great to have been derived from the relatively thin and commonly finer textured Ogallala that is adjacent to it. The only explanation that adequately accounts for such a quantity of coarse-textured arkosic material of known Kansan age is the assumption that Arkansas River was integrated to approximately its present course across western Kansas eastward to the region of the great bend during Kansan time. This integration probably took place on the surface of the rapidly accumulating alluvial fill. Some drainage in Kansan time went southward through the area of important Nebraskan drainage in Gray and Meade Counties, but in this area the Kansan sediments are predominantly silts, clays, and fine sands, and such coarse gravels as do occur are relatively thin and not widespread. This suggests that the principal drainage line along the course of the Arkansas alluviated sufficiently to spill over a low divide and continue eastward, thus allowing the accumulation of fine-textured local materials and large quantities of Pearlette volcanic ash in the slackened waters of a former major drainageway (Fig. 13) southward across Meade County.

The same process was probably repeated in southeastern Ford County depriving a former major valleyway across Comanche County of further western sediments after the first influx of Kansan outwash. Thus the later stages of Rocky Mountain outwash moving down the Arkansas Valley were carried eastward to join near the Oklahoma state line with the major outwash spillway from the continental glacier to the northeast. In much of northern Kiowa, southern Edwards, Stafford, Reno, northern Barber and Harper, and nearly all Pratt and Kingman Counties, Kansan outwash gravels (Grand Island member, Meade formation) form an almost coalescent sheet. In most of these counties the surficial deposits have been test drilled extensively by the State and Federal Geological Surveys' Ground-Water Division and details of this drilling are reported in the respective county bulletins. Throughout this region there is no indication of structural or stratigraphic control—in fact quite the opposite is the case as the bedrock beneath these sediments (where they do not rest on older Nebraskan alluvium) is relatively nonresistant beds of Cretaceous and Permian age. The most logical explanation seems to be that in a region of lessened gradient heavily outwash-laden streams repeatedly shifted their courses on the surface of their own alluvial fills and locally may have developed distributary systems. Progressive shifting toward the east was probably assisted by regional eastward tilt judged to have accompanied the early Pleistocene uplift of the Rocky Mountain region.

During late stages of Kansan glacial retreat Arkansas River maintained an easterly course. However, profound changes occurred in the stream pattern or northeastern Kansas. The temporary spillway along Wakarusa Valley was abandoned and drainage was permanently established eastward along the Kaw Valley. Missouri River took its present course across the Kansas till plain, probably influenced locally by sags in the till plain surface over earlier Nebraskan valleys. Spillways across Republic and Washington Counties were abandoned and a major stream was formed, in part on the till plain surface and in part by integration of spillway channels, in the present position of Blue River. The most important modification, however, was along the Smoky Hill Valley westward from Junction City. As isostatic adjustment is judged to proceed more slowly than unloading by glacial retreat, the channel cut by westward-flowing meltwater probably remained high long after the Kaw Valley was freed from ice and Missouri River carried the drainage eastward from the formerly glaciated area of Kansas. At this stage a divide probably existed on the floor of this former spillway in the vicinity of Junction City or somewhat west of that point, drainage west of the divide continued southwest through McPherson channel, and that east of the divide became a part of Missouri River drainage. As the former marginal bulge subsided this divide shifted westward and progressively more of the former tributaries to McPherson valley became integrated with Kansas-Missouri River drainage. This progressive diversion or "piracy" had a double effect; by decreasing the available volume of water through the already heavily alluviated McPherson valley it allowed still further accumulation of finer sediments in that area while promoting valley incision to the east in the Kaw Valley. Just how fast this divide shifted toward the west is not known, but the evidence indicates that by late Illinoian time the divide was located south of Salina and north of Lindsborg and that Saline River flowed eastward through the Kaw Valley to Missouri River while the upper Smoky Hill continued to flow southward through the McPherson channel.

ILLINOIAN DRAINAGE

Illinoian and later stream patterns in Kansas have been controlled primarily by a continuation of adjustments to the events associated with Kansan glaciation. The progressive southward shifting of the divide along the Smoky Hill spillway had reached southern Saline County by Illinoian time. This is attested by the facts that Crete (Illinoian) gravels consistently overlie Kansan sediments in the terraces along Smoky Hill Valley westward and through the now-abandoned McPherson valley southward (O. S. Fent, personal communication), showing that the Illinoian drainage along the Smoky Hill from the west followed—without incision—the same course as the Kansan drainage (Fig. 14). In Saline Valley, a Crete (Illinoian) terrace occurs more than 100 feet below the bedrock floor of the dissected north end of Wilson

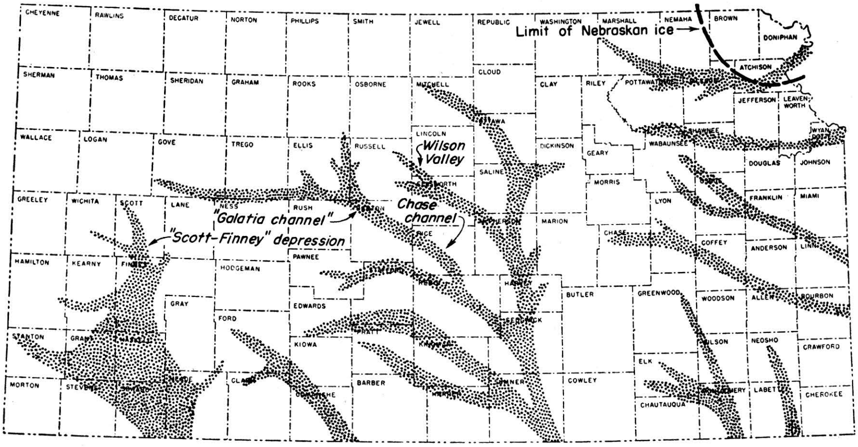


Fig. 12.—Reconstructed major drainage lines in Kansas in late Nebraskan time. Dashed line is maximum extent of Nebraskan glacier. Names refer to abandoned valley segments.

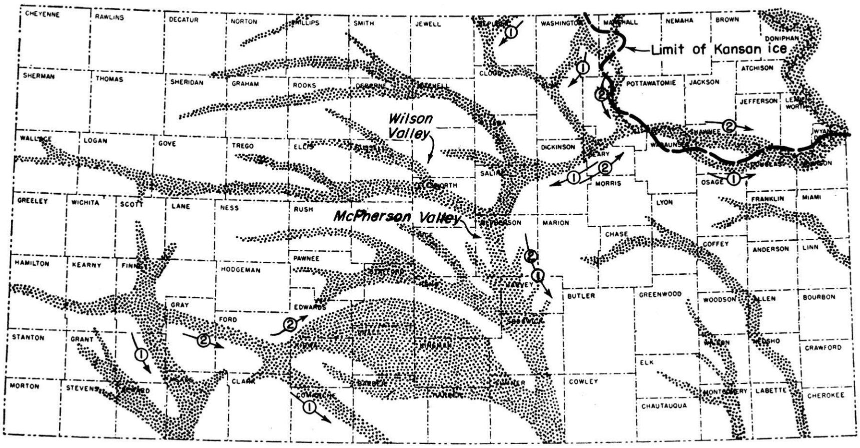


Fig. 13.—Reconstructed major drainage lines in Kansas in late Kansan time. Arrows and numbers refer to direction and position of stream flow during early stage of Kansan glacial retreat (1), and during latest stage of Kansan retreat, or during early Yarmouthian time (2). Dashed line is maximum limit of Kansan glacier. Names refer to abandoned valley segments.

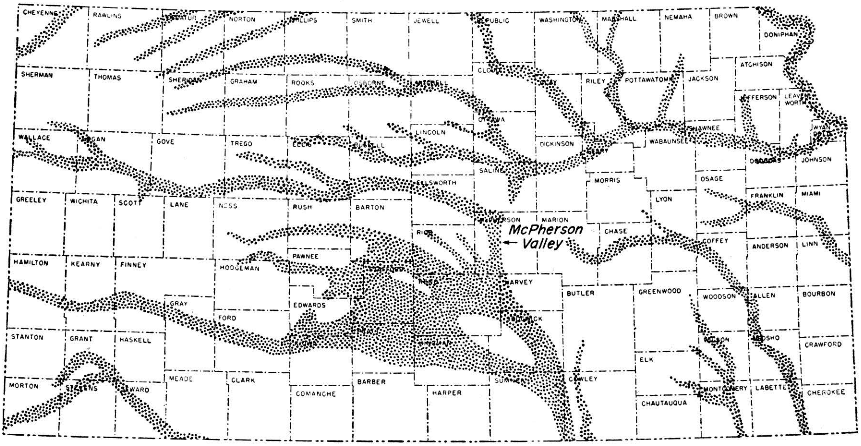


FIG. 14.—Reconstructed major drainage lines in Kansas in late Illinoian time. Name refers to abandoned valley segment.

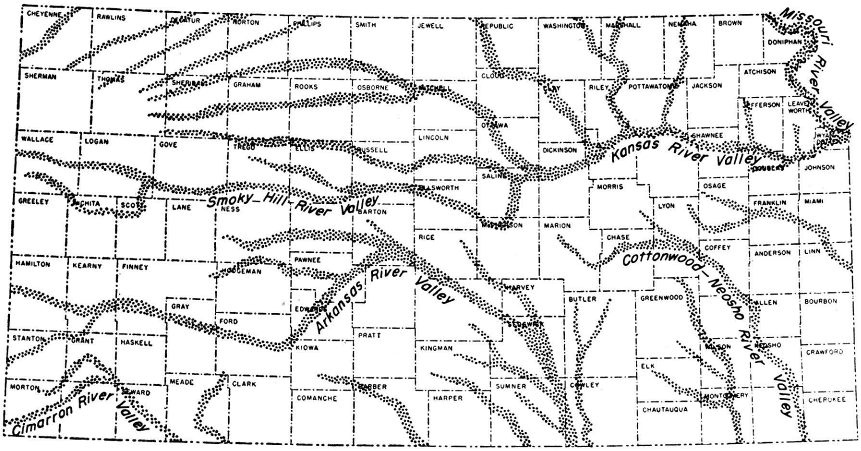


FIG. 15.—Major drainage lines in Kansas in Wisconsinan time. Names are of principal rivers.

valley. The now abandoned Wilson valley, which carried a Kansan tributary to the Smoky Hill across the present Saline-Smoky Hill divide, preserves a thick fill of Kansan sediments dated both by Pearlette volcanic ash and faunas. This relationship demonstrates clearly that by late Illinoian time all drainage in the region from the Saline to the Republican had become part of the Kansas River system, and as evidence along the Kansas River Valley (Davis and Carlson, 1952) shows that the bedrock floor of the Illinoian valley was cut more than 90 feet below the bedrock floor of the Kansan terrace deposits, all these northern valleys display a normal terraced or physiographic sequence—i.e., the succeedingly younger deposits occur on succeedingly lower terraces, which is not true in the south-central and southwestern valleys. The terraces along some of these northern valleys, particularly the Solomon (A. R. Leonard, 1952) and Prairie Dog (Frye and A. R. Leonard, 1949), have been studied in detail.

Although the direct evidence is inconclusive it seems probable that McPherson valley was finally abandoned by through-flowing drainage in late Illinoian time as the added fill of Crete gravels perched this stream well above the eastern drainage lines adjacent to the north, and the low divide on the former spillway valley floor would have presented little obstruction to such an adjustment.

In south-central and southwestern Kansas the Illinoian drainage was closely similar to the latest Kansan pattern. The formerly important stream course southward through the "Scott-Finney depression" and on across Gray and Meade Counties was finally abandoned as was major drainage southeastward from Ford County across Comanche County. Arkansas River was established along its present course as far east as Kiowa County, and eastward in the region south of the great bend the Illinoian channels again shifted laterally spreading an extensive sheet of coarse alluvium. Judging from the present distribution of Crete gravels the Illinoian channels shifted less extensively than did the Kansan channels and the principal drainageways were farther north. The present course of Arkansas River may have been established by laterally shifting channels in this region during late Illinoian time. Early Wisconsinan terraces occur along some stream valleys incised through the Crete gravels and show that the Arkansas was near its present position by early Wisconsinan time.

In eastern Kansas south of the Kaw Valley there is little evidence of important stream action during Illinoian time. The prominent Emporia terrace of late Kansan age extends along the Cottonwood-Neosho at an average height of about 40 feet above the present flood plain but a prominent lower terrace does not exist except as a part of the flood plain complex.

WISCONSINAN DRAINAGE

In northern Kansas the Wisconsinan drainage was closely similar to the Illinoian (Fig. 15). Bedrock floors below the Wisconsinan terrace sediments show that some valley cutting occurred after development of the Crete (Illinoian) terraces (Frye and A. R. Leonard, 1949; A. R. Leonard, 1952; Davis and Carlson, 1952) but that the position of valleys remained fixed. If the northward diversion of the Smoky Hill to join the Saline at Salina did not take place in latest Illinoian time on the surface of the Crete fill, it certainly had occurred by Iowan time as shown by the position of Peoria loess through this part of the valley and by the deeper bedrock incision of the Wisconsinan Smoky Hill below the Crete terrace as compared with the other valleys of the Kansas River system to the north.

Along the valleys of the region south of Kaw Valley and east of the Flint Hills the Wisconsinan sediments are included entirely within the flood plain complex.

It is in south-central Kansas that the Wisconsinan drainage presents the most striking contrast to the Illinoian pattern. Arkansas River became integrated on the surface of the Illinoian alluvial plain, perhaps in latest Illinoian time, and certainly by early Wisconsinan time and has undergone slight modification since. However, the streams draining the region southward from Kiowa, Pratt, and Kingman Counties, have been importantly modified since the close of Illinoian alluviation. Most valleys in this region are flanked by low terraces at two distinct levels that have been dated at many placed by molluscan faunas as early and late Wisconsinan. These well-developed terraces show that the streams of this area preserve in the main the early Wisconsinan drainage pattern, but that this pattern differs radically from the Illinoian drainage and is incised deeply below it. Perhaps the maximum deepening occurred in Barber County where the level of Crete alluvium is the upland plain to the north and the level of the Wisconsinan terraces in the central part of the county is 300 feet lower (Pl. 2). The valleys of Chikaskia and Ninnescah Rivers and Slate Creek to the east and Salt Fork River and Kiger and Bluff Creeks to the west were all incised a lesser amount. Crooked Creek in southern Meade County took its present course by the integration of several solution-subsidence basins and a depressional area along the Crooked Creek fault. Cimarron River across southern Clark and Comanche Counties integrated drainage from formerly isolated solution-subsidence areas, and this valley was deepened westward across the State.

Inconclusive evidence suggests an important diversion in southwestern Cowley County. Here the alluviated surface, well below the level of Kansan sediments that occur immediately adjacent to the west, extends southward into Oklahoma from the point where Arkansas River turns sharply eastward (Fig. 15). As the present Arkansas Valley is sharply constricted between bedrock bluffs east and south from this point, and as Walnut River swings sharply west to its juncture with the Arkansas, it seems likely that the Arkansas was diverted to the rapidly downcutting Walnut on the surface of its alluvial plain. Although this diversion could have occurred as early as Illinoian time it seems more likely from regional relationships to have happened during early Wisconsinan time.

The present drainage pattern of Kansas, although internally anomalous, is fairly well stabilized. Further diversion of Arkansas tributaries to the Kansas River basin seems effectively barred by the breadth and character of the present Smoky Hill-Arkansas divide in spite of the discrepancy in altitude and regimen of the two streams. The Arkansas has been consistently alluviated throughout late Pleistocene time and as its tributaries heading south of it have been eroding during much of this time the Arkansas channel is perched with respect to adjacent drainage (Pl. 2A, 2B). Although diversions may eventually result from this unbalanced condition the existing divide areas are of sufficient breadth to protect present drainageways for an indefinite period of time.

The regional implications of Kansas drainage history as outlined are not clear. Existing Kansas streams flow toward the south and east and as detailed studies of Pleistocene drainage have not been made in Missouri or Oklahoma, it is impossible to know the correlation of the history reconstructed for Kansas with these downstream areas. It is not known that major drainage entered northern Kansas from the Nebraska region during early Pleistocene time and therefore an important east-west divide may have existed in northern Kansas or southern Nebraska. If this were the case the headwaters of southern drainage were located in northern Kansas and the region to the north drained eastward and northward as was suggested many years ago by Todd (1914).

The progressive eastward shift of Kansas drainage throughout Pleistocene time resulted in progressively more western drainage entering the central Mississippi Valley. Oklahoma is a region replete with drainage problems. As early Pleistocene drainage, including sizable quantities of outwash, left Kansas to the south, and as the present valley of Arkansas River across Arkansas does not present the appearance of having earlier carried a much greater volume of water—in contrast to the Red River Valley which is flanked by broad alluvial terraces—one may speculate that future work in Oklahoma will reveal abandoned stream courses from the north that carried drainage southward into Red River Valley.

THE KANSAS LANDSCAPE

The Kansas landscape is the most ever-present product of geological processes operating during Pleistocene time. The plains and prairies of Kansas, although they do not possess strong relief, display striking contrasts among the several regions of the State (Pl. 19; Figs. 16, 17). Each of these several regions displays some distinguishing internal features of topography and they approximately coincide with the several geologic and climatic regions of the State. The surface of Kansas in general slopes upward from elevations of 700 to 1,000 feet above sea level in the east and southeast to elevations exceeding 4,000 feet in the west near the Colorado state line. The rainfall belts also show a gradation from east to west with the normal rainfall being more than 40 inches per year in the southeast and 15 to 20 inches per year

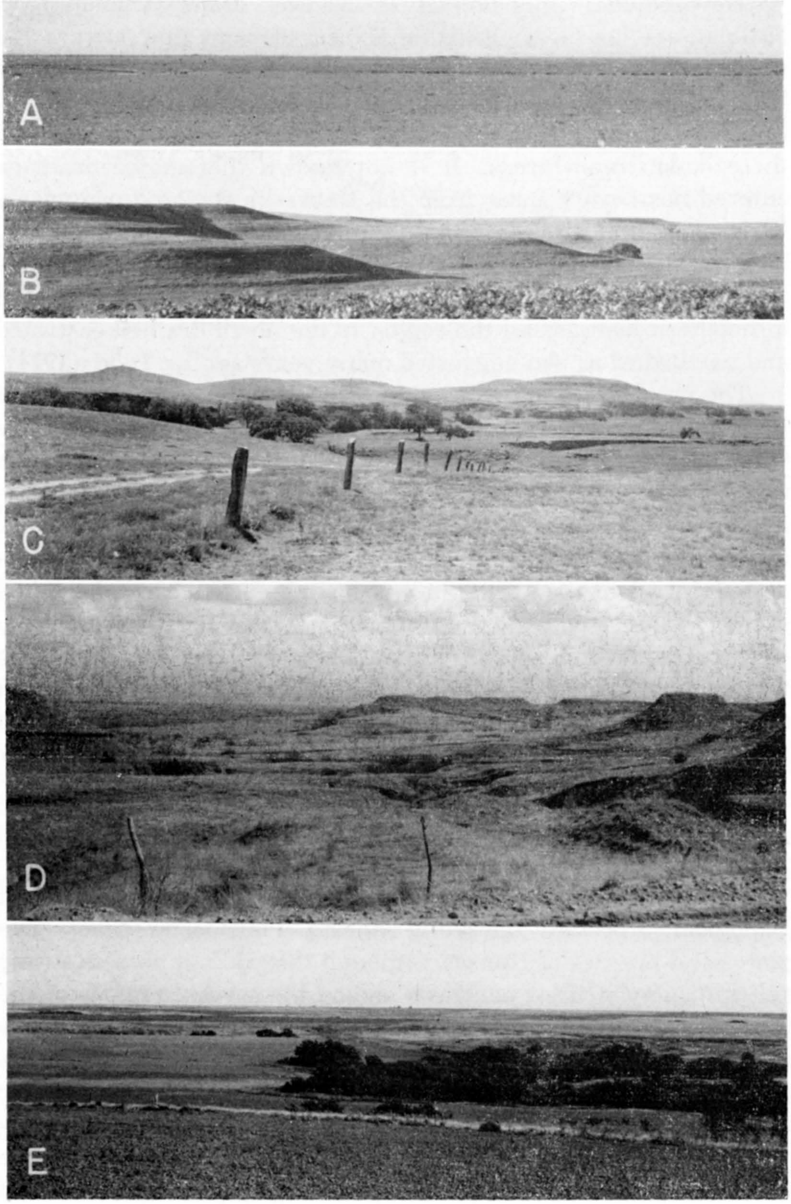


Plate 19. **Kansas landscape. A,** High Plains surface, central Lane County. The surface is a thin cover of eolian silt and sand on Ogallala formation. (1946.) **B,** Flint Hills Upland in sec. 8, T. 31 S., R. 8 E., Cowley County. Surface cut in Permian cherty limestones and shales. (1950.) **C,** Smoky Hills topog-

in the west. The pre-Pleistocene areal geology changes from Pennsylvanian and Permian rocks in the east, through Cretaceous rocks in the central region, to Pliocene rocks in the western region. The several physiographic, or topographic, provinces of Kansas are also general north-south belts that change in character toward the west.

In order to discuss these physiographic regions it is necessary to assign names to them. Fenneman (1931), in his map of the physiographic subdivisions of the United States, placed eastern Kansas in the Central Lowlands province and western Kansas in the Great Plains province. He further subdivided the Central Lowlands of the State into the Dissected Till Plains section (roughly the area north of Kansas River Valley) and the Osage Plains, and in the Great Plains province he recognized the Plains Border section in central Kansas and the High Plains section in the far west. Other schemes of physiographic subdivision have been discussed by Adams (1903), Frye (1946a), Frye and Swineford (1949), and Schoewe (1949). In the following discussions (Fig. 16) Adams' (1903) usage (also, Frye and Swineford, 1949; Schoewe, 1949) of High Plains, Red Hills, Flint Hills Upland, Osage (Prairie) Cuesta Plains, and Cherokee Plain are adopted. "Dissected Till Plains" is retained for the northeastern glaciated area, "Great Bend Region" is applied to the extensive sand dune tract and associated territory in the central part of the State, and "Smoky Hills" is used as defined by Adams (1903). The Arkansas River alluvial plain, which lies adjacent to the Wellington Area, is of sufficient size to merit special notice in part of central Kansas.

The High Plains (Frye, 1946a) include approximately one third of the area of Kansas; they occur in the western part of the State and extend into contiguous parts of Oklahoma, Colorado, and Nebraska. The High Plains constitute a plateau bounded by distinct scarps on the east and west. Their eastern limit is defined by the prominent scarp of the Fort Hays limestone

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raphy in sandstones, shales, and siltstones of Dakota formation, east-central Russell County. (Norman Plummer, 1940.) **D**, Red Hills topography in Permian red shales and siltstones and gypsum; central Barber County. The flanking pediment slopes developed in late Pleistocene time, dissected by younger erosion. The resistant caprocks are gypsum beds. (S. W. Lohman, 1939.) **E**, High Plains near Nebraska state line in Norton County. Late Pleistocene loess mantle on Ogallala formation, on Cretaceous chalky shale. (1946.)

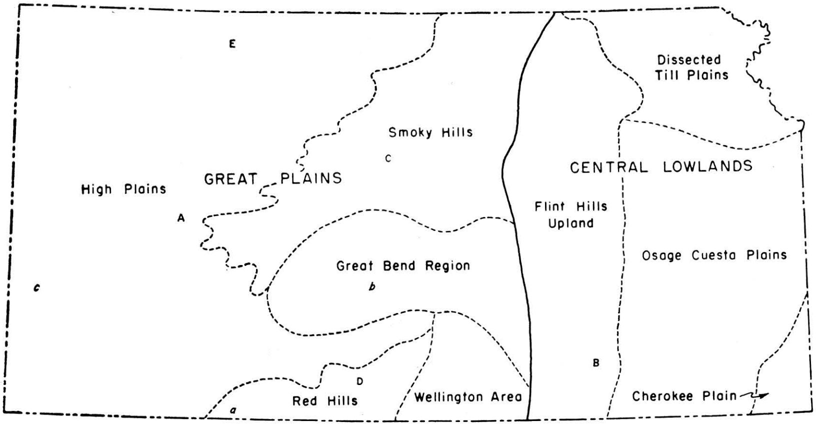

FIG. 16.—Physiographic regions of Kansas. These generalized regions of internal topographic homogeneity are modified from Adams (1903) and Schoewe (1949). Small letters show location of photographs on Plate 13 and large letters show location of photographs on Plate 19.

(Niobrara formation, Cretaceous) for 150 miles northeastward from Finney County and by scarps formed by Ogallala formation overlying relatively nonresistant Cretaceous and Permian rocks southward from northern Clark County to the Oklahoma state line. In the vicinity of Arkansas River Valley a distinct eastern boundary does not exist.

The topography of the broad interfluves in the High Plains section is monotonously regular (Pl. 19A, 19E) with a regional eastward slope of about 10 feet to the mile. In much of the region the surface is underlain by late Pleistocene loess and locally by eolian sand resting on earlier Pleistocene deposits or Pliocene Ogallala formation. However, in the northern tier of counties, the loess mantle transgresses without noticeable topographic break onto the eroded surface of Cretaceous chalky shales and extends to the crest of the Fort Hays limestone escarpment. Much of the High Plains upland surface is not drained by integrated surface channels, and two sizable drainage systems (Whitewoman Creek and Bear Creek) are not integrated with any through-flowing stream.

Arkansas River is the only Kansas stream that completely crosses the High Plains region from a source in the Rocky Mountains but its level is only slightly below the upland surface (Pl. 2). In striking contrast, Smoky Hill River, which originates on the plains surface in Colorado, occupies a valley 15 to 20 miles wide cut in Cretaceous bedrock. The Smoky Hill River Valley is characterized by a series of sweeping flanking pediments thinly veneered with colluvium and loess (Fig. 4). The Cimarron River Valley, to the south of Arkansas River, is also cut well below the level of the Arkansas (Pl. 2) and is characterized by flanking pediments (Frye and Smith, 1942), as are Pawnee River and Walnut Creek, tributaries to the Arkansas from the north. The valleys adjacent to Nebraska lack well-developed flanking pediments but contain a sequence of alluvial terraces.

In spite of the general monotony of High Plains topography it possesses distinctive and almost unique features. The major valleys, with the exception of the Arkansas, slash the upland surface abruptly, and the upland surface is marked by many thousand depressions of various sizes. These depressions have attracted the notice of geologists for more than half a century (Haworth, 1897a; Johnson, 1901; Darton, 1905; Smith, 1940; Frye and Schoff, 1942; Evans and Meade, 1945; Frye, 1950) and have been attributed to many causes including the wallowing of buffalo, solution-subsidence, wind scour, differential eolian deposition, differential compaction, and silt infiltration. Most, if not all these processes have had a share in the development of High Plains depressions (Frye, 1950), but the most important factor permitting the widespread development and preservation of surface depressions is the general absence in this region of processes that tend to inhibit or destroy such features. Erosion by lateral stream planation is effective in a very small part of the region and, as much of the upland surface lacks integrated surface drainage, erosion along defined stream channels is small. Pedimentation has been important in shaping the major valleys and only solution-subsidence depressions have been observed on the flanking pediment surfaces. On the flat uplands, even sheet erosion is of relatively small importance and the persistent mantle of eolian silt is subject to shifting during periods of excessive drought. Evidence from the stratigraphy of the loesses and buried soils shows that the majority of High Plains depressions developed during late Pleistocene time.

The Red Hills (Pl. 19D) in the south-central area exhibit some of the most rugged and striking topography in Kansas. The strong red color of the exposed Permian bedrocks makes the

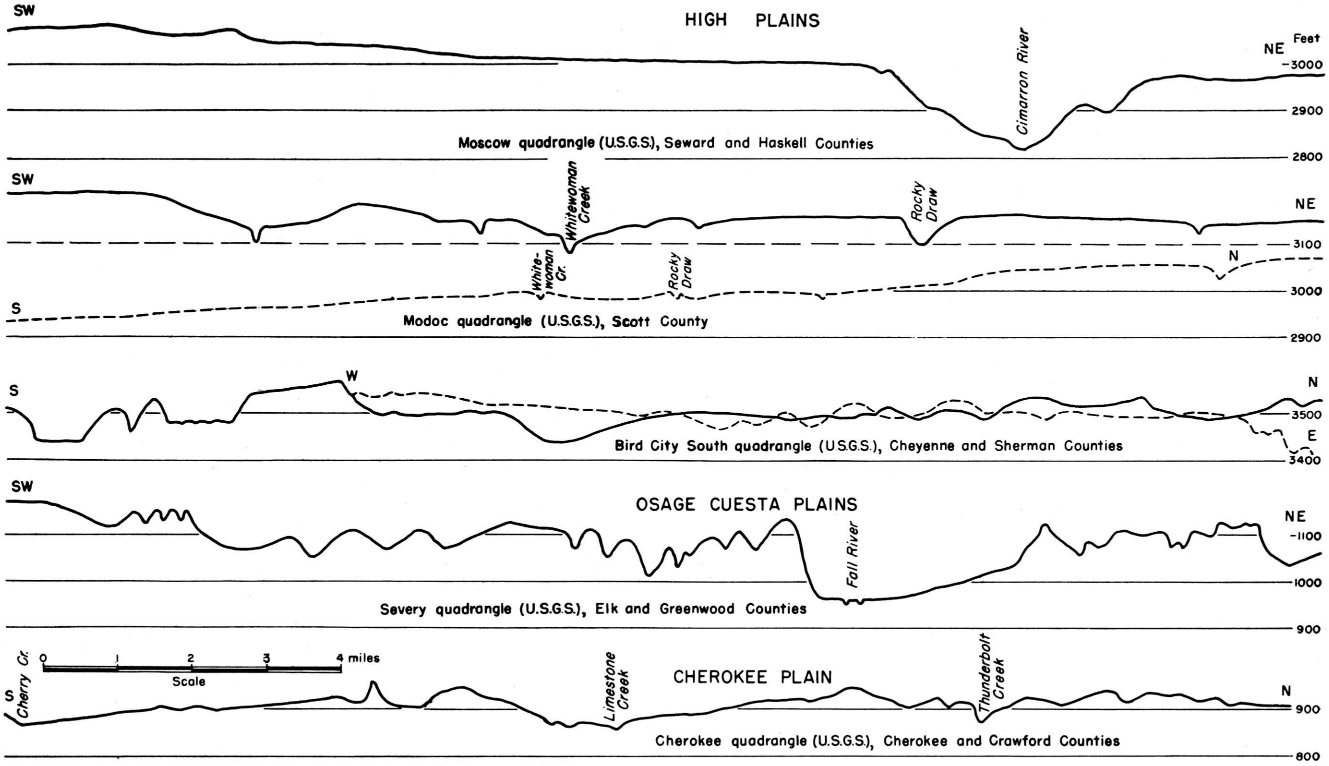

FIG. 17.—Surface profiles in High Plains, Osage Cuesta Plains, and Cherokee Plain. Profiles plotted from U. S. Geological Survey quadrangls of the 15-minute series. Adequate maps are not available to illustrate the topography of the other physiographic subdivisions of the State.

section a scenic attraction. The Red Hills are essentially the belt of dissected terrain associated with the retreating scarps of the High Plains. In this area the Ogallala formation (Clark County) and early Pleistocene deposits (Comanche, Barber, and Kingman Counties) cap the westernmost scarp which defines the edge of the High Plains, but resistant beds of Permian gypsum, and locally siltstone, cap the secondary scarps and buttes that characterize the section. The crests of the scarps and buttes form a projection of the High Plains surface and flanking pediments of several generations characterize the gentler parts of the topography—slope or pediment processes operating during late Pleistocene time have produced the Red Hills landscape.

The Smoky Hills section in the north-central part of the State is comparable to the Red Hills in that they both flank the scarp of the High Plains on the east. However, this section contrasts strongly with the Red Hills in character because of its greater size and the different bedrock geology. Schoewe (1949, p. 276) calls this area the "Dissected High Plains." He applies the name Blue Hills to the western part of the region and restricts Smoky Hills to the eastern part. His subdivisions follow the stratigraphy of the section closely. The western part (Schoewe's Blue Hills) is limited on the west by the prominent escarpment capped by the Fort Hays limestone (Cretaceous) flanked on the east by a belt of low hills and plains developed on the Carlile shale and interrupted in Mitchell and Osborne Counties by buttes capped by outliers of Fort Hays. Northward from Barton County the section is split into two dissimilar parts by the prominent cuesta scarp of the Greenhorn limestone (Cretaceous). The topography of the eastern part of the section is dominated by irregular hills held up by discontinuous lenticular sandstones in the Cretaceous Dakota formation (Pl. 19C). Except at the eastern edge, the Smoky Hills stand below a projection of the High Plains surface and small remnants of Ogallala on the crest of the Greenhorn scarp serve to define the former position of the late Pliocene surface. This area is well-drained moderate to coarse-textured mature topography, and stratigraphic evidence suggests that dissection has proceeded throughout Pleistocene time.

The Great Bend Region, like the Red Hills and Smoky Hills, stands at the eastern margin of the High Plains. But, in strong contrast to these regions to the north and south, the Great Bend

Region is a relatively flat plain standing at or slightly below an eastward projection of the High Plains surface. The Great Bend Region is an upland alluvial plain when compared to the topography both north and south of it (Pl. 2) and has received extensive alluviation during each of the glacial ages of the Pleistocene. During late Pleistocene time this alluvial plain was integrated with the present valley of Arkansas River, both to the east and west, and therefore the Great Bend Region serves as a topographic transition from the Central Lowlands province on the east to the Great Plains province, and particularly the High Plains section, on the west. In this area the High Plains do not have a definite boundary on their eastern side.

The topography of the Great Bend Region is dominated by sand dunes (Pls. 1, 13B), derived from late Pleistocene alluvium, that mantle the surface of more than half of the region. A narrow belt extending westward through the High Plains, along Arkansas River, and bordering sand dunes (Pl. 13C) is genetically a part of the Great Bend Region but because of its small area is not separated from the High Plains.

The Wellington Area (primarly in Harper and Sumner Counties) is genetically related to the Red Hills to the west, with which it is gradational, because the topography is primarily erosional on Permian shales. It is judged advisable to consider it a separate section because the topography is predominantly a complex of intersecting flanking pediments of several generations which lack the prominent scarps and buttes that characterize the Red Hills. The different topographic expression may be due in part to the westward retreat of scarps, but probably more so to the lack of rock layers that could serve as resistant cap rocks. On the east the Wellington Area is terminated by the narrow southern extension of the Arkansas alluvial plain which flanks the Flint Hills on the west.

The Flint Hills Upland, extending in a north-south belt across the State from the Oklahoma state line in Cowley County to the Nebraska state line in Marshall County, effectively separates the Central Lowlands from the Great Plains. The Flint Hills are classed within the Central Lowlands because of their genetic and geologic similarities to the Osage Cuesta Plains to the east. In fact the Flint Hills can be described as a series of prominent cuesta scarps and dip slopes developed on resistant cherty limestones of early Permian age (primarily Wreford, Florence, Fort Riley, and Herington). The east face of the upland typically consists of a series of stratigraphically controlled benches, as shown in Plate 19B, and the western part of the upland in some places is a relatively smooth series of dip slopes on the Florence, Fort Riley, and Herington limestones that terminate westward under alluvial veneer or the Wellington shale plain. The western limit of this upland is drawn at the termination of the dip slope where it joins the plain developed on Permian shales or Tertiary, Quaternary, or Cretaceous sediments.

In strong contrast to the Great Plains of central and western Kansas, the Flint Hills have been a positive element of the topography subject to subareal erosion since mid-Tertiary time or earlier. Cenozoic alluvial deposits have not been found on the crest of the Flint Hills and the level of chert gravels, judged to be of Tertiary age, that cap cuestas in the Osage Cuesta Plains has been traced into a terrace position near the Flint Hills divide. Where the dip slope upland is well developed (for example in the vicinity of Rosalia, east-central Butler County) it is extensively veneered with angular residual chert derived from the underlying Florence limestone. This residual chert represents a deeply weathered soil profile that in some areas may have been developing throughout late Tertiary and Pleistocene time. The A horizon is commonly only a few inches thick, but in our judgment as much as 3 to 6 feet of angular chert in a matrix of red clay may properly be regarded as the B horizon. This material grades downward into partly weathered limestone that retains clear evidence of stratification. In Pottawatomie County where the Kansan glacier overrode such a surface the basal part of thin Kansas till consists almost entirely of angular chert (Pl. 6B).

Kansas River is the only through-flowing stream that crosses the Flint Hills Upland. Its course is the result of Kansan glaciation. The headwaters of Cottonwood River by headward erosion have extended themselves through the Flint Hills, but the complete absence from all the terrace deposits of western type sediments that are now available to these headwaters indicates that the transgression of the upland by the Cottonwood River system was accomplished in late Pleistocene time.

The Osage Cuesta Plains include the region south of Kansas River Valley, east of the Flint Hills, and northwest of the scarp of the Fort Scott limestone. This scarp marks the westward limit of the Cherokee Plain. The cuestas of the Osage section have much similarity to the Flint Hills except in magnitude. They are developed on limestones of Pennsylvanian and earliest Permian age and are separated by plains developed on the intervening shales. In the east-central part of the area stream-rounded late Tertiary chert gravels occur on the highest elements of the topography (Pl. 1) and indicate that there has been some topographic inversion during Pleistocene time—that is the chert gravels derived from the Permian limestones to the west are more resistant than the local limestones. As the grain of the drainage is generally transverse to the strike of the bedrock the resistant chert gravels have served as a local cap rock and the present valleys are in the positions of former divides.

Within this section a unique topography is developed on thick sandstones of the Douglas group of rocks in adjacent parts of Chautauqua and Montgomery Counties and northward. This area of rugged but rounded hills that lack the cuesta form has been called the "Chautauqua Hills."

The Cherokee Plain is a relatively flat area east of the Fort Scott limestone escarpment, on which is developed the last prominent Pennsylvanian limestone cuesta. It lies to the west of the cherty Mississippian limestones that enter Kansas in the extreme southeastern corner. The sharp contrast in topography is particularly apparent to one traveling eastward through Oswego, Labette County, where the plain may be viewed from the crest of the Fort Scott cuesta scarp. Much of the surface of the Cherokee Plain is thinly veneered with Pleistocene deposits.

The Dissected Till Plains in the northeast present a topography unlike any other part of the State. This section presents a view quite similar to adjacent parts of Missouri and Nebraska and southern Iowa. The section is bounded on the south by the broad and distinctive Kaw Valley which marks the general southern limit of the Kansas till, and on the west by the sharp diminution in thickness of Kansas till at the edge of the Flint Hills. In northern Marshall County the Dissected Till Plains transgress the Flint Hills Upland and contact the Great Plains section at the Nebraska state line. Here, thick Kansas till overlaps the Flint Hills belt from the northeast, and from the west Cretaceous sediments overlap the Permian rocks as far as the

Herington limestone. Except in some divide areas the topography of the Dissected Till Plains section is well drained, moderately fine-textured, mature, and is a well-rounded rolling surface. For the most part it is developed in glacial till with Pennsylvanian or Permian rocks exposed along the lower parts of the deeper valleys. In northeastern Doniphan County thick loess deposits impart a distinctive character to the topography, but elsewhere in the section the thin loess deposits veneer rather than modify the surface developed on Kansas till.

The Kansas landscape is for the most part a product of erosion and deposition during Pleistocene time and has evolved to its present aspect by pulses of accelerated erosion and sedimentation during each of the glacial ages of the Pleistocene. In latest Tertiary time the Kansas landscape was truly a plain. A vast expanse of alluvial plain in the region of the present High Plains and adjacent areas merged in Colorado with an erosion surface in the Rocky Mountain region (Rocky Mountain peneplain) and in eastern Kansas with the erosion surface in the Flint Hills divide area. This surface, in turn, graded eastward into the area of the Osage Cuesta Plains and the area now buried beneath glacial till. Early in Pleistocene time valley deepening occurred along major streams in all parts of the State. The relative incompetence of streams in the western third of Kansas left broad areas undissected but in the eastern part virtually all the area was eroded and in central Kansas valley deepening exceeded 200 feet. In the Flint Hills Upland, Osage Cuesta Plains, and Cherokee Plain each succeeding glacial age produced an episode of downcutting of diminishing intensity. The same general erosional history has obtained in the central and northern High Plains and the Smoky Hills but in these areas has been modified somewhat by the accumulation of loess.

In the Great Bend Region the erosional history was quite different. Here the maximum valley cutting took place at the beginning of Pleistocene time and in each succeeding glacial age sedimentation has exceeded erosion. In the Red Hills and Wellington Area maximum erosion took place in late Pleistocene time and obliterated the effects of earlier cycles of erosion and sedimentation.

In the Dissected Till Plains section the influence of the Kansan glacier has overpowered all other factors. The post-Kansan history of this region has been primarily dissection of Kansas till, deepening of valleys, and relatively minor alluviation of valleys.

The net effect of Pleistocene events on the Kansas landscape has been a strong increase in topographic relief and the placement of most deposits that contain large supplies of ground water, sand and gravel, volcanic ash, and some of our ceramic raw materials. The surface soils of Kansas, the most valuable single mineral resource in the State, are almost entirely a product of processes operating during Pleistocene time.

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Stratigraphic names and time terms in italics are names not now in use in Kansas. Page numbers in bold face type refer to the principal description of the unit.