THE GLACIATION OF KANSAS

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INTRODUCTION

During the Ice Ages (*Pleistocene Epoch*: 10,000 to 1.6 million years ago), large ice sheets formed in several parts of the world: northern North America, Greenland, northern Eurasia, Tibet and the Himalayas, and Antarctica. The Antarctic and Greenland Ice Sheets have remained fairly stable throughout this time. Ice sheets in the other areas, conversely, underwent repeated growth and destruction in cyclic manner. Global changes in climate, sea level, and biologic populations accompanied these glacial cycles. At least eight or more such glaciations have taken place during the past one million years. Although many causes have been considered, a scientific explanation for these glacial cycles is not yet fully developed.

In North America, ice sheets formed in eastern and central Canada and spread southward into the northern United States (fig. 1). This happened most recently during the *Wisconsin* glaciation, when a lobe of the ice sheet extended as far south as Des Moines, Iowa, only 14,000 years ago. The largest glacial expansion on the Great Plains took place much earlier, when ice reached as far south as Topeka, Kansas. This *Kansan* glaciation happened more than half a million years ago.

Glaciers in Kansas? The very idea seems preposterous, in a climate where summer temperature routinely reaches 38°C (100°F) and winter snowfall is sporadic. What was the earth's climate like; what must the climate of Kansas have been like to allow ice sheets to exist? The historical observations of weather and climate are simply inadequate to deal with such questions, and so we must turn to the geological record of ancient glaciations.

The deposits and landscape features created by the Kansan glaciation are so old that they have suffered considerable erosion and weathering, and are in many places mere remnants of the original forms. This has made geologic interpretation of the remaining Kansan glacial features difficult or problematic in some cases. In spite of this handicap, a reasonably good understanding of Kansan glaciation is beginning to emerge.

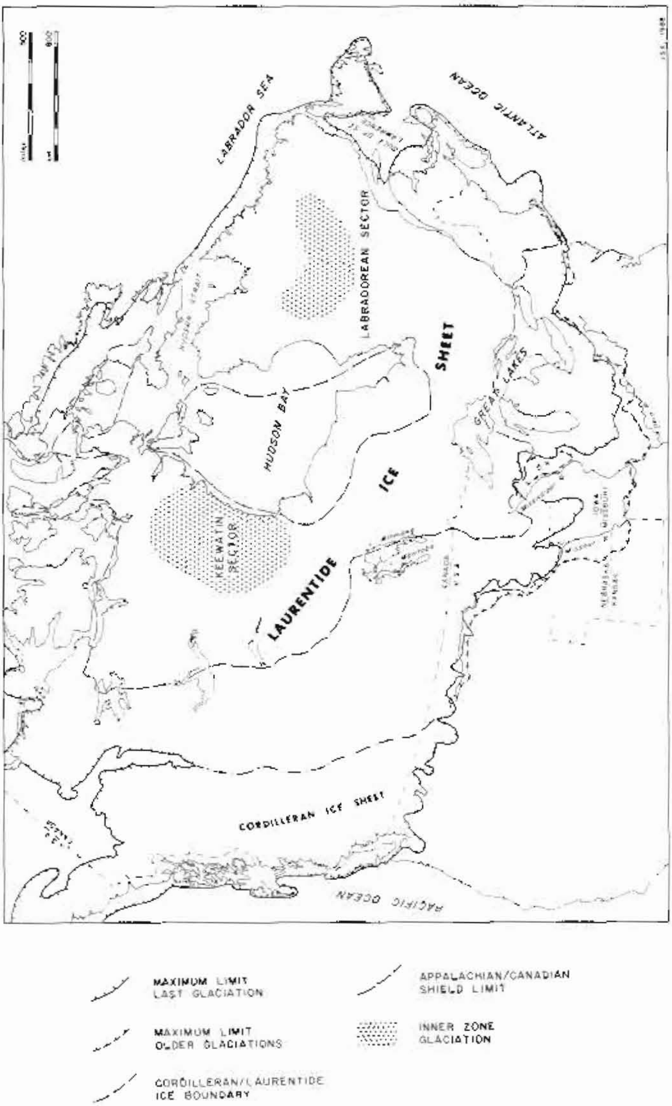


Figure 1. Map of North America (excluding Greenland) showing glaciated region. Last glaciation = Wisconsin, 14,000 to 18,000 years ago. Older glaciation limit west of Mississippi River is the Kansan glaciation, >600,000 years ago. Glaciation of the Great Plains region of United States and Canada was related to ice movement from Keewatin sector. Map compiled mainly from Dyke and Prest (1987a, b).

HISTORY OF GLACIAL STUDIES IN KANSAS

The common red quartzite and granite boulders of northeastern Kansas were first noted by a French explorer, DeBourgmont, in 1724 (Aber 1984). Such *erratic* boulders were usually ascribed to the results of a great flood or other cataclysmic events. The *glacial theory* of the former expansion of glaciers and ice sheets was developed in the Swiss Alps during the 1830s by Jean de Charpentier and Louis Agassiz (Teller 1983), and the idea was brought to North America by Agassiz when he moved to Harvard College. The true glacial character of erratic boulders in northeastern Kansas was recognized by Agassiz during a trip across the Great Plains in 1868. Agassiz also recognized that many rivers of the interior United States owed their creation to glaciation (Aber 1984).

Glacial geology became a subject of considerable scientific interest and research in the United States during the late 1800s. Under the leadership of T.C. Chamberlin, field work from the Atlantic seaboard to the Dakotas was carried out by members of the U.S. Geological Survey. The limits of glaciation were mapped and evidence for multiple ice advances was described. By the end of the 19th century, Chamberlin had named five glacial episodes, of which Wisconsin was youngest and Kansan was next to oldest. Concerning the Kansan glaciation, he stated (Chamberlin 1895):

> The earliest (glacial) formation which has been worked out into sufficient definiteness to merit specific recognition in the United States is an expansive sheet which reaches ... southwesterly beyond the Missouri. The term Kansan has been applied to it ... because it appears in the State of Kansas free from complications with other formations.

The man who actually did most of the field work in the Missouri basin during this period was James E. Todd, who moved to the University of Kansas early in this century. He undertook the first detailed study of glaeial geology in Kansas (Todd 1918). His work was followed closely by that of Walter H. Schoewe, who also mapped the limit of glaciation. However, Schoewe (1941) generally showed the glacial limit slightly farther south and west than did Todd (fig. 2). Other geologists have attempted to map the glacial limit in recent times (Jewett 1964; Dort 1985, 1987a), although the various maps all differ in detail.

The stratigraphy and age of Kansan glacial deposits was systematically studied by Frye and Leonard (1952), who concluded that ice sheets had twice invaded the northeastern corner of the state and deposited a mixture of boulder-clay sediment called *till*. The first glaciation was considered to be Nebraskan and the second was Kansan, and the glacial deposits could be correlated regionally by reference to the Pearlette volcanic ash bed (fig. 3).

This simple stratigraphy began to unravel during the 1960s and 70s, however, with discovery of multiple tills representing more than two glacial advances in Nebraska and Iowa as well as in Kansas (Dort 1966, 1985). Likewise the Pearlette volcanic ash bed was shown to actually be several ashes of greatly different ages

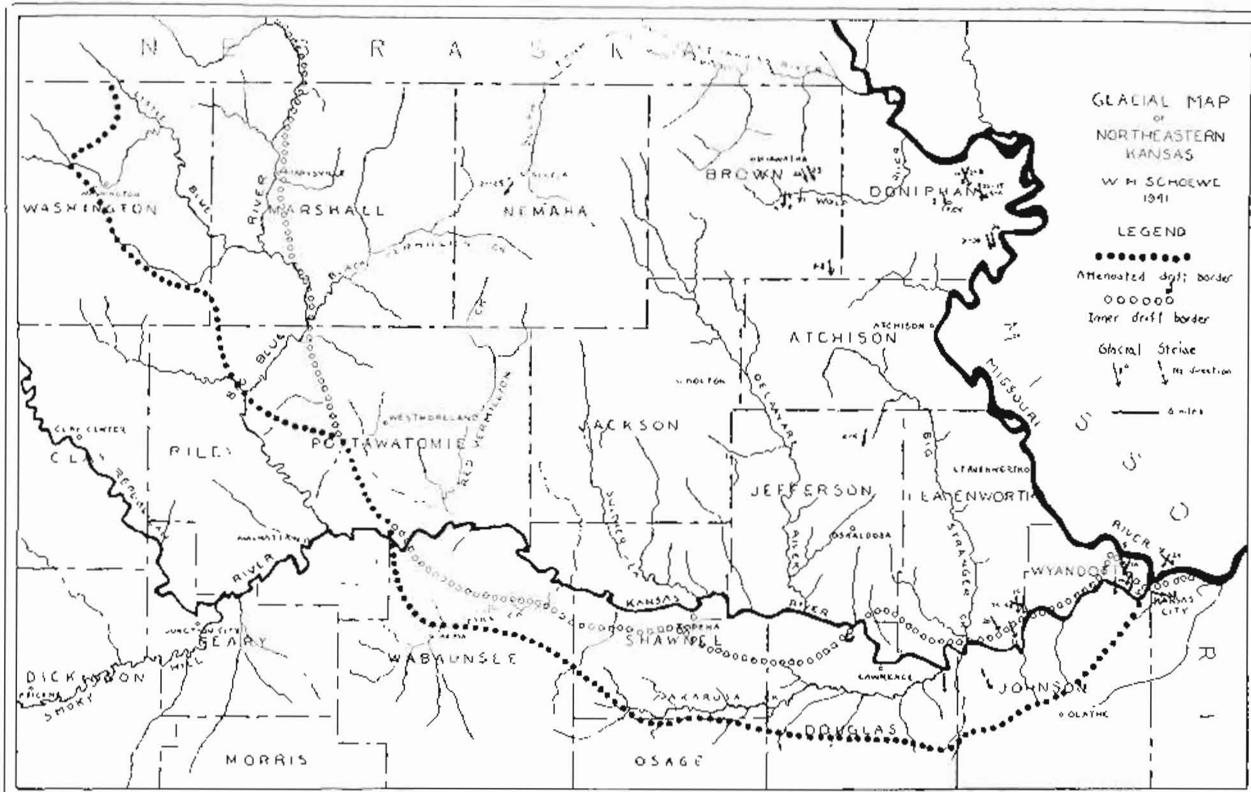


Figure 2. Schoewe's map of glacial features in northeastern Kansas. Inner drift border is glacial limit of Todd (1918); attenuated drift border is the outer limit according to Schoewe (1941, p. 319).

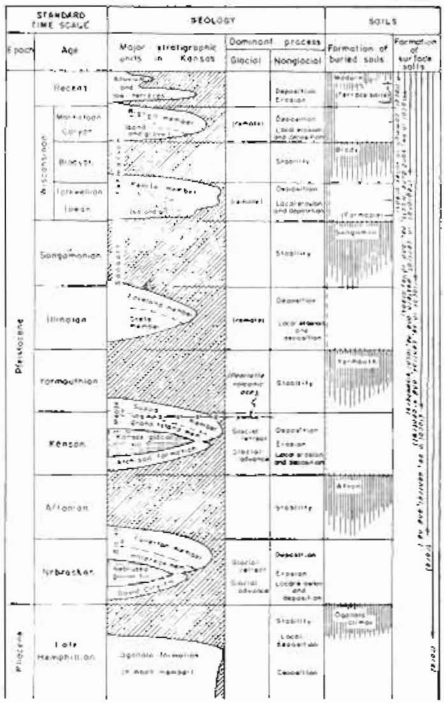


Figure 3. Schematic Pleistocene (Ice Age) stratigraphy for Kansas according to Frye and Leonard (1952, fig. 1). Note two glaciations (Nebraskan and Kansan) and position of Pearlette volcanic ash just above Kansan till.

(Boellstorff 1976). Thus, many of the traditional assumptions or interpretations for the Kansan glaciation are no longer valid.

A new understanding of the Kansan glaciation is developing based on continuing field work and comparison of Kansan features to younger glaciations about which much more is known (Aber 1982, 1985, 1988). Thus, the Wisconsin glaciation and its results serve as a model for interpreting the older and less well preserved Kansan features. New radiometric and geophysical dating techniques have been successfully applied, and the age range of the Kansan glaciation has been narrowed considerably.

GLACIAL FEATURES OF KANSAS

Glaciation modifies the landscape in three fundamental ways: (1) erosion, (2) deformation of pre-existing sediment and bedrock, and (3) deposition of new sediments. All three kinds of glacial features are found in northeastern Kansas,

Figure 4. Photograph of glacially striated surface on quartzite boulder in northeastern Wabaunsee County. Watch is 5 cm (2 inches) in diameter.

Figure 5. Photograph of glacially deformed Tarkio Limestone just west of Topeka. Note thrust and rotated blocks of limestone. Scale pole marked in feet (1 foot = 30 cm); see Fig. 19, site 3 for location.

although the third category is most conspicuous. *Striations, grooves, chatter marks*, and other effects of glacial abrasion are common on many bedrock surfaces preserved beneath till and on stones within till (fig. 4). Such features on bedrock pavements are used to establish the local direction of ice movement at the time of erosion.

Deformed structures due to glaciation are noted at several places involving both consolidated bedrock or unconsolidated sediment (Dellwig and Baldwin 1965). At one site just west of Topeka, a large, thin slab of limestone was thrust horizontally over shale (fig. 5). The thrust slab consists of the Tarkio Limestone Member of the Zeandale Formation. Its exposed dimensions are about 150 m E-W by 50 m N-S with a thickness of only 2-3 m. The slab was presumably moved by dragging underneath ice. Such structures also reveal the direction of local ice movement at the time of deformation.

Glacial deposits are widespread and highly variable in nature throughout northeastern Kansas. Till is the most distinctive glacial sediment, as it was deposited directly from glacier ice with little influence of flowing water. It is typically an unsorted, unstratified mixture of anything and everything over which the ice moved. Thus, till incorporates both local and far-travelled material, with the local material usually dominant.

This means that Kansas till is usually clay rich, owing to abundant shale in the local bedrock, and that limestone and chert (flint) are the most common larger stones. Large, angular limestone blocks were transported only short distances in most cases. Much of the chert along with rare, polished quartzite pebbles were derived from preglacial stream gravels that were common in eastern Kansas.

The most conspicuous glacial features are naturally the erratic boulders of quartzite, granite, and other stones seen throughout the glaciated region. Pink, red, and red-purple quartzite is most distinctive (fig. 6). These boulders were derived from the Sioux Quartzite, a Precambrian bedrock formation in southwestern Minnesota and adjacent South Dakota and Iowa. Quartzite boulders can be quite large. The largest reported one is located in eastern Shawnee County (Johnson and Adkison 1967); its exposed portion measures 7 x 3.4 x 2.5 m, and it must weigh nearly 150 metric tons (about 320,000 lbs.).

Sioux Quartzite erratics vary considerably in texture from fine, sandy quartzite to conglomerates containing pebbles up to 10 cm (4 inches) in length. Another erratic rock type derived from the Sioux Quartzite in Minnesota is pipestone, or catlinite. It is a soft, blood-red, slaty rock that is prized by native Americans for carving ceremonial objects. The Sioux Quartzite erratics were transported some 650 km (400 miles) from their source area directly north of northeastern Kansas.

Figure 6. Photograph showing field of Sioux Quartzite boulders on hill top beside Kansas Highway 99, 8 miles north of Alma, Wabaunsee County. Kansas River valley is in background.

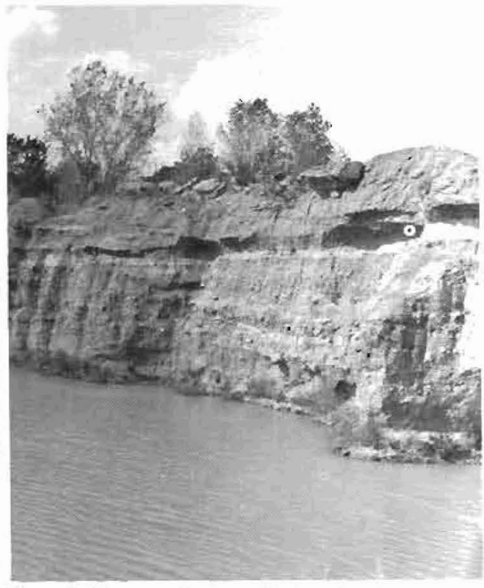


Figure 7. Photograph of stratified sand and gravel deposits which underlie the Menoken terrace within the Kansas River valley near Topeka. These sediments were deposited by melt-water streams draining the ice sheet. See Fig. 19, site 1 for location; height of exposure approximately 10 m (30 feet).

The next most conspicuous erratic is granite, which exists in many varieties and colors, and was transported from northern Minnesota and Wisconsin and from southern Canada. Many other igneous and metamorphic erratics were derived from the same general area: rhyolite, gabbro, basalt, diorite, gneiss, slate, greenstone, *etc.* Great Lakes agate has been found in many places, along with erratics from the Lake Superior iron district (Dort 1987a): hematite, magnetite, and banded jasper. All these erratic types were eroded from Precambrian rocks of the Canadian Shield.

Still other erratics are found in northeastern Kansas. Both rocks and fossils of Cretaceous age are present. Dakota sandstone is particularly common near the western edge of glaciation. Typical Cretaceous fossils, such as shark teeth and ammonites, have also been found in Atchison and Doniphan Counties. These Cretaceous erratics were presumably derived from bedrock outcrops in eastern Nebraska, western Iowa, and the Dakotas.

Glacially related sediments were also deposited from melt-water streams and lakes in the form of *stratified drift*. Gravel, sand, silt and clay deposits are locally thick, especially where filling preglacial valleys or in valleys eroded by melt-water floods (fig. 7). Such deposits exhibit rounding of pebbles and larger stones as a result of abrasion during water transportation and deposition.

A major buried valley crosses northeastern Kansas from Marshall County eastward to Atchison County (fig. 8, centerfold) and continues on into Missouri, where it joins the preglacial Grand River system. This valley is locally filled with >100 m (>300 feet) of till and stratified drift. Most of the stratified sediment was deposited in a large lake, when ice blocked the eastern outlet of the valley. Today the valley is not noticeable at the surface, but the thick sand and gravel fill is an important source of ground water in the area (Denne *et al.* 1982).

GLACIAL SEDIMENT COMPOSITION

Variation in glacial sediment composition has received a fair amount of study (Davis 1951; Aber *et al.* 1982, 1988). The composition is mainly a result of two factors: (1) depositional environment and (2) post-Kansan weathering. The first factor can be seen in a diagram of small-pebble composition for till, sand, and gravel sediment types (fig. 9). Till, which was deposited from ice, has high percentages of such soft rocks as limestone, sandstone, and shale. Gravel, on the other hand, was deposited by melt-water streams that sorted the sediment to a considerable extent. Gravel usually has a high percentage of chert. Sand deposits mostly formed in lakes, and thus have received moderate sorting by water transportation. Sand displays intermediate characteristics.

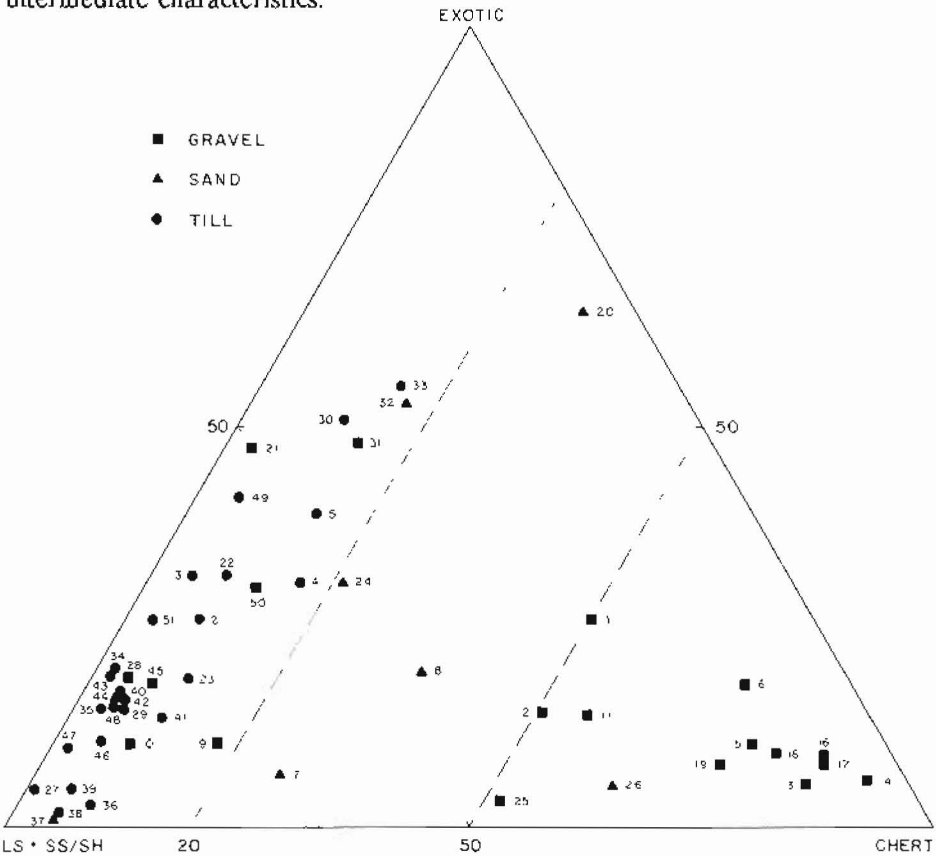


Figure 9. Ternary diagram for small-pebbles (4-8 mm) showing percentages of exotics (granite, quartzite, etc.), limestone + sandstone and shale (LS+SS/SH), and chert for three types of glacial sediment. Percentages are normalized to 100%; dashed lines show 20% and 50% values for chert.

Similar trends in composition according to depositional environment can be seen in other components of the glacial sediments, for example heavy minerals (density >2.85 g/cc) in the very-fine sand fraction. Here unstable minerals (amphibole, epidote, pyroxene, tourmaline) are abundant in till, whereas more stable minerals (garnet and zircon) are most common in gravel. Sand is again intermediate in terms of its heavy-mineral composition.

The second main factor for glacial sediment composition is the degree of alteration of the original sediment due to weathering. The surficial sediments have been exposed to oxidation, leaching, growth of plant roots, freezing/thawing, and other kinds of weathering for more than half a million years. Given a relatively humid climate with strong seasonal contrasts, even resistant rocks have been affected.

Limestone and other soluble rocks have partly or completely disappeared in the upper 3 m (10 feet) of most glacial sediments. Iron-bearing rocks have been oxidized into rusty masses. Even granite has largely decomposed into clay minerals and quartz sand. Boulders of granite, gneiss, rhyolite, and other such rocks that still survive at the surface are often so soft they can be picked apart with bare fingers.

Under these conditions, only the most durable rocks have survived intact, namely quartzite, quartz, and chert. In places where weathering has altered or much reduced the original glacial sediment, quartzite and other resistant stones have accumulated at the surface in a red, sandy, clay matrix. Such surficial deposits are little more than a weathered residue and should not be taken as indicative of the original sediment composition, texture, or color (Davis 1951).

Below the zone of weathering, secondary mineral deposits are common in both till and stratified drift. Gravel deposits are often partly cemented with calcium carbonate and/or iron oxides. Pyrite and gypsum form small (mm size) crystals in till. Only in the deepest exposures or in drill holes >10 m (30 feet) below the present land surface are unweathered sediments preserved. And even in those cases, migrating ground water has caused local changes in sediment composition. In deep sections and drill holes, organic material, including peat and wood, is commonly preserved in glacial sediment (Denne *et al.* 1984).

STRATIGRAPHY OF KANSAN GLACIAL DEPOSITS

Northeastern Kansas has been regarded as the region for recognition and definition of the Kansan glaciation, since the time of Chamberlin (Frye and Leonard 1952). More specifically, a series of exposures immediately west of Atchison is designated as the *stratotype* or reference section for the so-called *Kansas Drift* (Aber 1985, 1988). The Kansas Drift includes all glacial and glacially related sediments in northeastern Kansas.

The exposure at Atchison consists of stream bluffs along White Clay Creek south of U.S. highway 59 (fig. 10). This section has been studied for half a century (Schoewe 1938, Frye and Leonard 1952, Dellwig and Baldwin 1965). Two tills

Figure 10. Photograph of Kansas Drift stratotype, as seen from U.S. highway 59, 2½ miles west of Atchison; see Fig. 8 for location.

Figure 11. Photograph of Kansas Drift stratotype showing intrusion of Lower Kansas Till behind ladder; person is standing at head of intrusion. Intrusion is surrounded by sand of Atchison Formation, and section is capped by Upper Kansas Till; see Fig. 12.

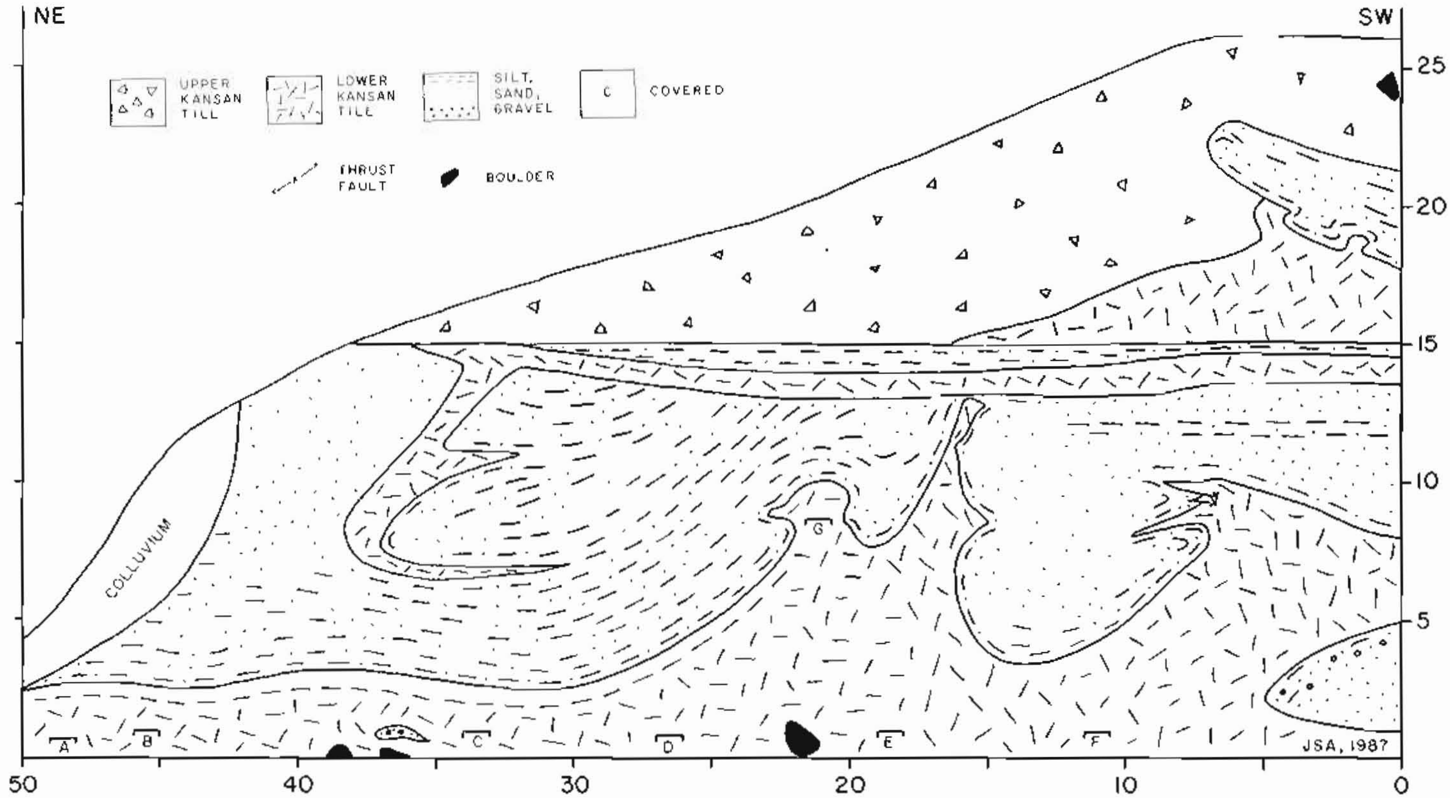


Figure 12. Measured section of the Kansas Drift stratotype near Atchison, as it appeared in 1987. Lower Kansas Till (below) intrudes up into Atchison Formation sand (middle), and Upper Kansas Till (above) caps section. Scale in meters.

separated by stratified sand are presently exposed in one bluff (fig. 11). The *Lower Kansas Till* is gray, clay rich, stony, and wood bearing. This till is dislocated in two large intrusions that are pushed up into the *Atchison Formation* sand in the middle of the exposure (fig. 12). Capping the section is a brown, clay-rich, stony till called the *Upper Kansas Till*.

The Upper and Lower Kansas Tills represent two distinct ice advances into northeastern Kansas, as shown by directional indicators: striations, ice-push structures, and till fabrics. Such features demonstrate northeasterly ice movement for the Lower Kansas Till, whereas the Upper Kansas Till was laid down from the northwest. Atchison Formation sand was deposited in a lake that occupied the major buried valley, when the early (lower) Kansan ice advance dammed the valley's downstream outlet to the northeast.

The regional extent of the early Kansan glaciation is documented by Lower Kansas Till encountered in test drilling and by the distribution of northeasterly striations and ice-pushed structures. This glaciation reached southward into northern Leavenworth, Jefferson, and Jackson Counties, and covered all but the southwestern corner of Nemaha County (fig. 8, centerfold). From Doniphan to central Nemaha Counties, interbedded and locally deformed Atchison Formation sand and Lower Kansas Till fill the major buried valley. Farther west, the buried valley is filled mainly with the Atchison Formation.

Multiple advances by the early Kansan ice sheet seem likely. The initial advance laid down a basal till, and Atchison Formation sand was deposited as deltas in a proglacial lake when the ice retreated slightly. Renewed advances then caused intrusion and disruption of till and sand. Such structures are only seen in the buried valley, where thick Atchison Formation sand is interbedded with till. In the uplands north of Atchison, Dort (1966, 1985) reported multiple tills, shattered limestone masses, and buried weathering zones. These deposits are at least partly equivalent to the Lower Kansas Till in the buried valley.

Following the northeasterly advances by the early Kansan glaciation, ice retreated from the region for an unknown distance and length of time. The late (upper) Kansan glaciation then entered from the northwest. This glaciation spread well beyond the earlier ice limit to a maximum position south of the present Kansas River and west of the Little Blue River valleys (fig. 8). Nearly all of the surficial glacial deposits and erratic boulders visible in northeastern Kansas are related to this glaciation.

The maximum limit of late Kansan glaciation has been mapped in different positions according to various interpretations of glacially related deposits in the border zone. Often the locations of erratic boulders or supposed till were used to define the glacial limit (Schoewe 1930; Dort 1985, 1987a). However, some of these boulders, particularly well-rounded ones (fig. 13), may have been transported beyond the ice by melt-water floods. Their positions may not always represent a true ice margin.

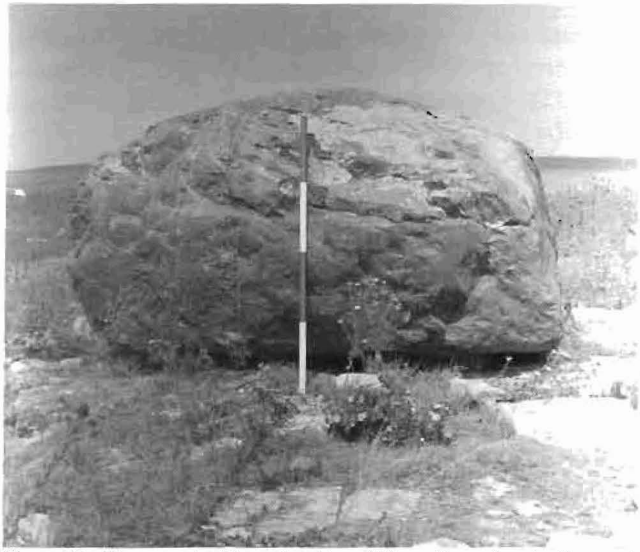


Figure 13. Photograph of large boulder of Sioux Quartzite, 4 miles north of McFarland, Wabaunsee County. Note rounded shape of boulder, which was deposited by a melt-water flood and rests on bedrock. Scale pole marked in feet (1 foot = 30 cm).

Several places south of the Kansas River valley have what appears to be two tills separated by soil or stratified drift (Dort 1985). The genesis of these till-like sediments is problematic, however, as they are all highly weathered. In some places, where till-like sediment grades downward into little altered sand and gravel, the supposed till could be explained as merely a weathered residue of the stratified sediments. Still the possibility of multiple ice advances in the border zone exists, and it is not known if the glacial limit represents a single ice advance or is a composite of multiple advances.

The maximum glacial limit shown in Figure 8 is based on distribution of features associated with direct glacier action, and thus is a conservative interpretation of the ice limit. Such features include: striations on bedrock, ice-push deformation of bedrock, angular stones bearing glacial abrasion features, and little-weathered till. Along the glacial limit in Pottawatomie County, for example, a substantial percentage of quartzite boulders bear glacial markings and are quite angular in shape. Some are little more than unmodified joint blocks.

The maximum limit of glaciation appears to be controlled by five major bedrock escarpments (fig. 8). From west to east, these are: (1) Fort Riley Limestone in southwestern Marshall County, (2) Flint Hills escarpment (Beattie-Grenola Limestones) in north-central Wabaunsee County, (3) Bern Limestone southwest of Topeka, (4) Oread Limestone southwest of Lawrence, and (5) Lansing-Kansas City Groups in north-central Johnson County.

These high, resistant bedrock units blocked southward movement of ice, whereas ice formed small lobes that reached farther south in the relatively lower areas between the escarpments. This is particularly evident in eastern Douglas and western Johnson Counties, where a small ice lobe deposited glacial sediment that forms the Hesper Plain (O'Conner 1960). To the east, the Lansing-Kansas City Groups created a major obstacle. The Kansas River valley narrows there considerably, and the glacial limit is noticeably farther to the north.

Upon the final retreat of the late Kansan ice, a sizable lake developed in northern Jefferson and central Atchison Counties, above the buried valley, and the lake extended eastward into Missouri. This lake is now marked by the Nortonville Clay (Winslow 1972), which mantles much of that area. The various named and unnamed sedimentary deposits of the Kansas Drift are displayed in a schematic cross section from Doniphan to Wabaunsee Counties (fig. 14).

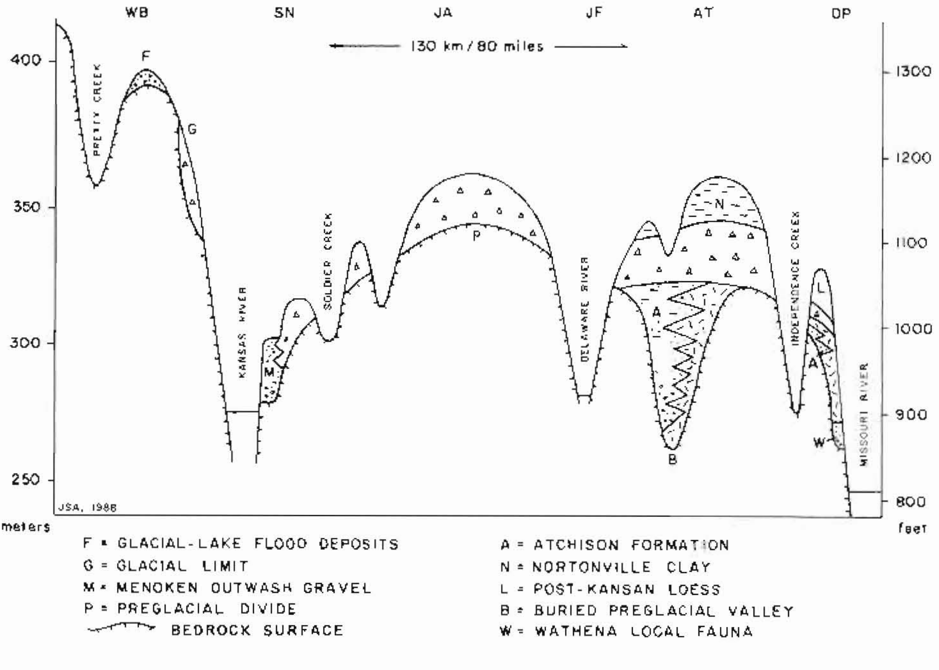


Figure 14. Schematic cross section showing Pleistocene sediments from Doniphan County (DP - northeast) to Wabaunsee County (WB - southwest). Compiled from Johnson and Adkison (1967), Johnson and Wagner (1967), Winslow (1972), Bayne (1973) and Ward (1973) with additions by the author. Horizontal scale is approximate; note large vertical exaggeration. See Fig. 12 for symbols and Fig. 8 for county abbreviations.

AGE OF THE KANSAN GLACIATION

Age of the Kansan glaciation was for many years simply a rough estimate of half a million to one million years. The absolute age is now established within narrow limits on the basis of radiometric dating of volcanic ash, paleontology of fossils, and paleomagnetism of till.

Maximum age is demonstrated in a large gravel-pit exposure south of Wathena (fig. 15). The Lower Kansas Till rests on preglacial stream sediments in which a rich fossil fauna is found. The *Wathena local fauna* includes fish, amphibians, reptiles, birds and mammals, as well as various invertebrates representative of a riverine environment. Comparison of the Wathena local fauna with other dated faunas of the Great Plains indicates an age of about 1.0 million years (Martin and Schultz 1985).

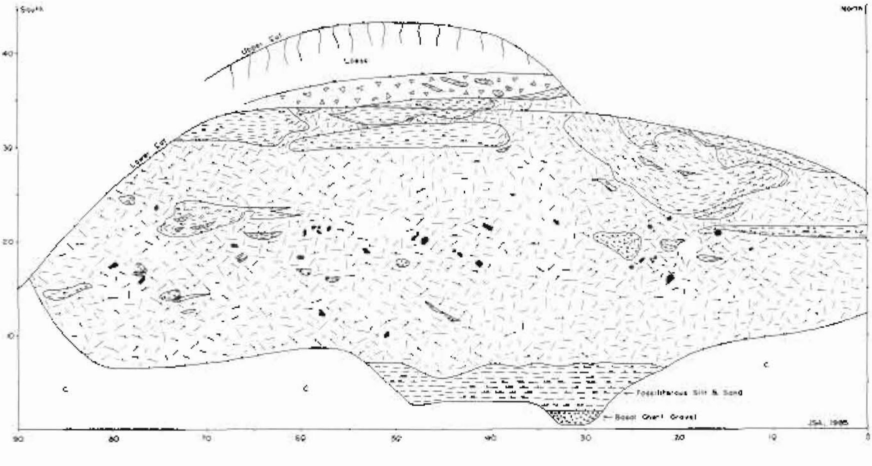


Figure 15. Measured section in gravel pit south of Wathena, as it appeared in 1985. Note position of fossiliferous sediment containing Wathena local fauna below the Lower Kansas Till. Symbols same as Fig. 12; scale in meters; see Fig. 8 for location.

Minimum age of the Kansan glaciation is shown by volcanic ash within a post-Kansan terrace in the Kansas River valley near De Soto (fig. 8). Fission-track dating and petrographic comparison suggest that the De Soto ash correlates to the Lava Creek B ash of the Yellowstone region (Geil 1987). The Lava Creek B ash is widespread in the Great Plains and is dated at 620,000 years old; it represents the last major eruption from Yellowstone. Thus, the Kansas Drift is bracketed between dates of about 0.6 and 1.0 million years. Further limitation of the age is given by paleomagnetism of the Lower Kansas Till (Aber *et al.* 1988).

The earth's magnetic field is known to periodically reverse its polarity. In other words, during a reversed epoch a compass needle would point south instead of north (fig. 16). Such reversals take place every half to one million years; the last such reversal was about 0.7 million years ago. Iron-bearing rocks and sediments, including till, acquire a natural magnetism at the time of formation. This magnetism preserves the polarity of the earth's field at the time the till was deposited. By measuring a till's paleomagnetism, its age relative to the magnetic time scale may be determined. As an example, the type Nebraskan Till in eastern Nebraska has reversed polarity (Easterbrook and Boellstorff 1981), and so must be at least 0.7 million years old.

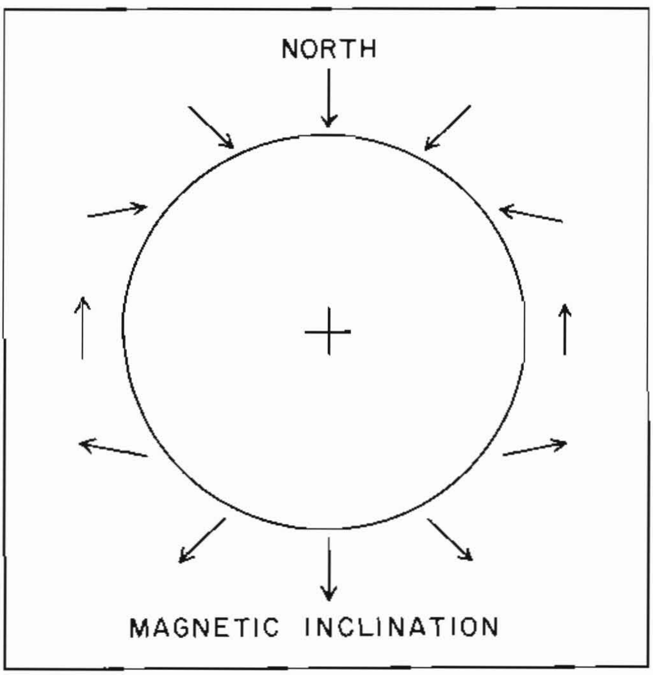


Figure 16. Schematic diagram of the earth's dipole magnetic field. During an epoch of reversed polarity, the direction of arrows would be opposite that shown.

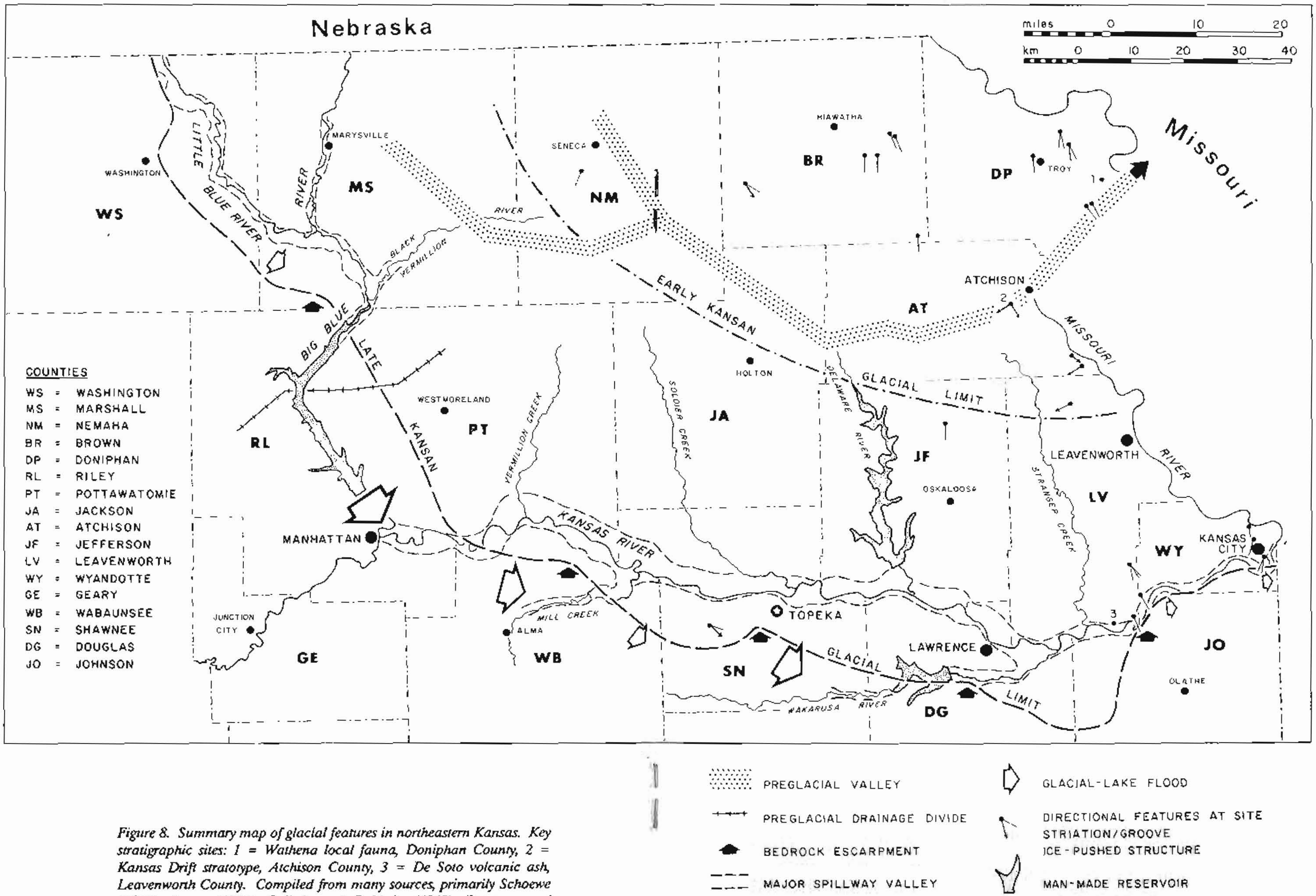


Figure 8. Summary map of glacial features in northeastern Kansas. Key stratigraphic sites: 1 = Wathena local fauna, Doniphan County, 2 = Kansas Drift stratotype, Atchison County, 3 = De Soto volcanic ash, Leavenworth County. Compiled from many sources, primarily Schoewe (1941), Jewett (1964), Dellwig and Baldwin (1965), Dreeszen and Burchett (1971), Chelikowski (1976), with additions by the author.

Lower Kansas Till has been sampled for paleomagnetism at several surface and subsurface sites in Atchison and Nemaha Counties (Aber *et al.* 1988). Two paleomagnetic patterns are apparent: (1) normal polarity in undisturbed tills, and (2) mixed polarity in structurally disturbed tills. No tills with primary reversed polarity have been found in Kansas. Given the maximum and minimum ages, normal polarity of Lower Kansas Till further restricts age of the Kansas Drift to the range 0.6 to 0.7 million years. This makes the Kansan one of the oldest Pleistocene glaciations with a regionally preserved record on land. The paleomagnetic results also suggest that older Nebraskan Till is not present in Kansas.

DRAINAGE DIVERSIONS

The preglacial drainage of northeastern Kansas and adjacent areas was dominantly west to east, as shown by the system of buried valleys leading to the ancestral Grand River in northwestern Missouri (fig. 17). These valleys are now filled with glacial sediment and are barely visible at the surface. The major modern rivers of the north-central United States, including the Missouri, upper Mississippi, and Ohio, developed as ice-marginal drainage systems during the Pleistocene. The same holds true for the Blue, Kansas, Wakarusa and some other rivers in northeastern Kansas. These rivers simply did not exist in any recognizable form prior to the Kansan glaciation.

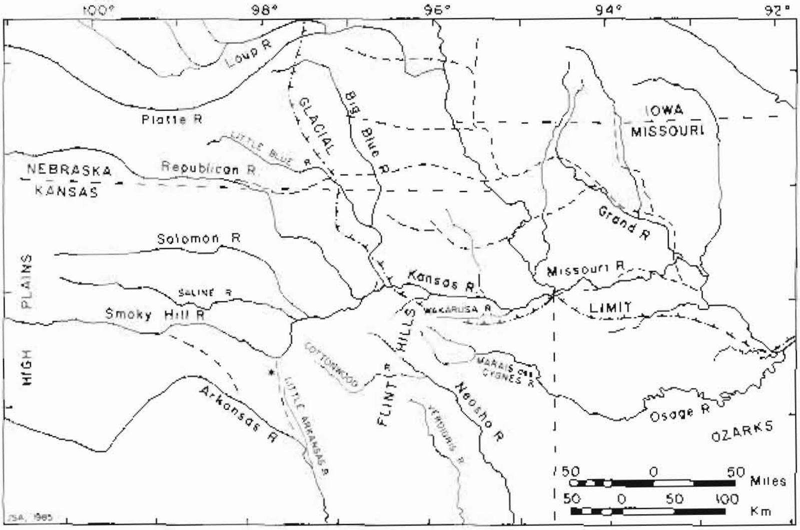


Figure 17. Map of Kansas and adjacent areas showing modern drainage (solid lines) and major buried valleys (dashed lines). West-to-east preglacial drainage was diverted around the Kansan ice sheet into the Blue/Kansas/Missouri River valleys. Buried valleys in glaciated region from Dreeszen and Burchett (1971); asterisk shows buried McPherson channel.

As the early Kansan ice sheet advanced into the area, it blocked the outlet of the major buried valley in northeastern Kansas. A large lake was impounded in this valley, as demonstrated by thick sediments of the Atchison Formation that fill the valley from Doniphan and Atchison Counties as far west as Marshall County. Glacial *Lake Atchison* was contained to the south by a bedrock drainage divide, remnants of which are preserved in western Pottawatomie and northern Riley Counties (fig. 8, centerfold). Prior to glaciation, drainage north of this divide went eastward into the now-buried valley (Chelikowski 1976).

Lake Atchison received drainage from a huge basin, including melt water from the Kansan ice sheet as well as run-off from the northern Great Plains and Rocky Mountains. The lake must have filled rapidly and overflowed a saddle in the divide near Randolph in northern Riley County. Rapid erosion of a spillway channel (lower Big Blue River valley) through limestone and soft shale bedrock caused catastrophic downstream flooding. The magnitude and results of such floods are documented for similar glacial-lake floods during the Wisconsin glaciation of North Dakota and adjacent areas (Kehew and Lord 1986). A characteristic assemblage of spillway channels, gorges, and flood deposits are well preserved (fig. 18).

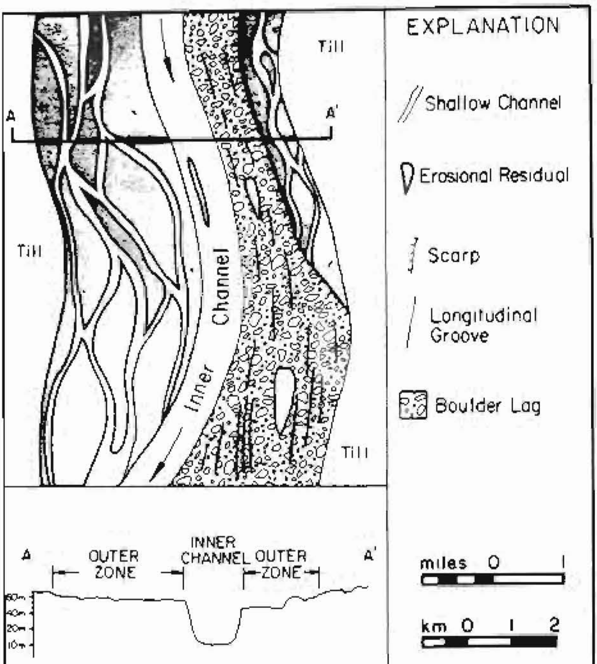


Figure 18. Model for landscape features resulting from catastrophic glacial-lake flooding during the Wisconsin glaciation in the northern Great Plains. Adapted from Kehew and Lord (1986, fig. 5).

Figure 19. Map of Topeka vicinity, southern Shawnee and adjacent Jefferson Counties showing features related to late Kansan glaciation. Elevation contours in meters; for symbols see Fig. 8. Numbered sites for self-guided tour:

1. Menoken terrace stratotype. Approximately 10 m (30 feet) of outwash sand and gravel exposed in old gravel pit (see fig. 7). One mile north of Menoken; SW¼ Sec. 9, T11S/R15E, Silver Lake Quadrangle. Note this site is on private land.

2. Hamm limestone quarry. 2-3 m (6-10 feet) of glacial lake sediment exposed at top of quarry excavation. Two miles east of Grantville, ½ mile north of U.S. highway 24; SW¼ Sec. 15, T11S/R17E, Grantville Quadrangle. Note this site is on private land.

3. Tarkio Limestone exposed in roadcut. Deformed Tarkio Limestone rests on undisturbed Elmont limestone (see fig. 5). East side of county road about 200 m (220 yards) south of intersection with Kansas highway 4, 1.3 miles east of Mission Creek bridge; SE¼ Sec. 10, T12S/R14E, Silver Lake Quadrangle.

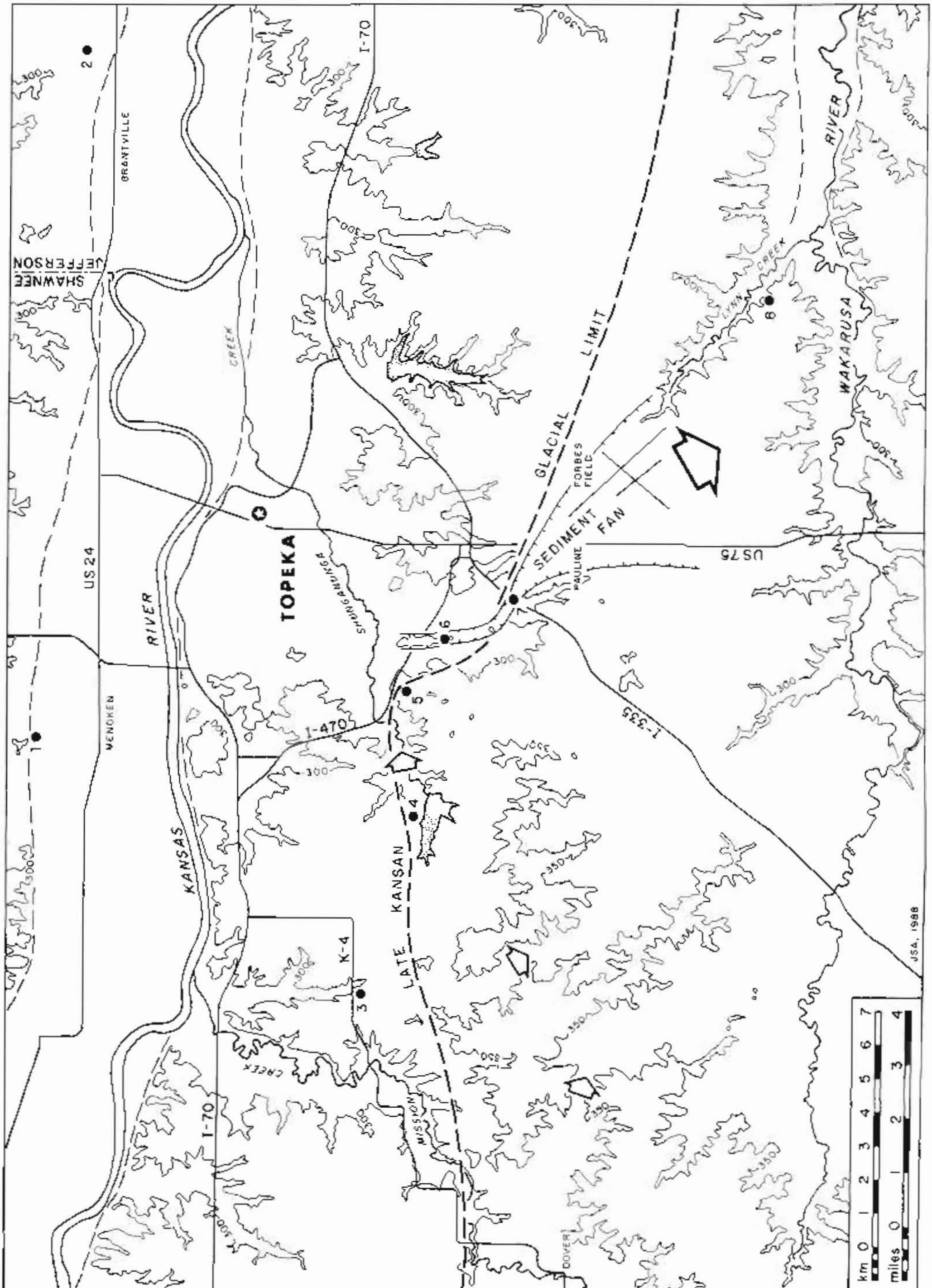
4. North edge of Lake Sherwood. Ice-contact gravels containing erratic stones. Suburban roads immediately north of Lake Sherwood; SE¼ Sec. 18 and SW¼ Sec. 17, T12S/R15E, Silver Lake Quadrangle.

5. Burnett Mound. Northern tip of escarpment formed on Bern Limestone, from which an excellent overview of ice-margin features can be seen. Kansan ice sheet reached a maximum limit at base of escarpment, approximately where I-470 is now located; low ridge of flood-deposited sediment is visible to east and southeast. Skyline Park, Topeka; NW¼ Sec. 15, T12S/R15E, Topeka Quadrangle.

6. Western side of South Branch Shunganunga Creek. Proximal portion of fan flood deposit with many large (>1 m), rounded boulders of quartzite, granite, and limestone. Suburban streets in southwestern Topeka with access from 37th, about ½ mile east of Gage Blvd. SW¼ Sec. 14 and NW¼ Sec. 23, T12S/R15E, Topeka and Wakarusa Quadrangles.

7. Eastern side of South Branch Shunganunga Creek. Proximal portion of fan flood deposit with many large (>1 m), rounded boulders of quartzite, granite, and limestone. Along Kansas Turnpike (I-335) about 1 mile south of South Topeka Interchange; also access from county road 1 mile west of U.S. highway 75, 0.8 mile south of I-470 overpass. NE¼ Sec. 26 and NW¼ Sec. 25, T12S/R15E, Wakarusa Quadrangle.

8. Northern side Wakarusa River valley. Distal end of fan flood deposit composed of sand and gravel with well-rounded cobbles and a few small boulders. Surficial sediment strongly weathered; deeper sediment is cemented into conglomerate. County road 5 miles east of U.S. highway 75, 5.3 miles south of I-470 overpass; NE¼ Sec. 23, T13S/R16E, Richland Quadrangle.



TOPEKA
KANSAS
RIVER
US24
I-70
I-470
K-4
I-335
US75
GLACIAL LIMIT
LATE KANSAN
SEDIMENT FAN
FORBES FIELD
PAULINE
SHUNGANUNGA
CREEK
MISSION
LYNN CREEK
WAKARUSA
RIVER
SHAWNEE
JEFFERSON
GRANTVILLE
MENOKEN
DOVER
1
2
3
4
5
6
300
350
km 0 1 2 3 4 5 6 7
miles 0 1 2 3 4
JSA, 1988

Similar featnres were created by repeated glacial-lake floods in northeastern Kansas. The Blue/Kansas River valleys were eroded as a major spillway system by flooding from Lake Atchison during the early Kansan glaciation. Once formed, the Blue/Kansas spillway carried melt water and run-off from all the northern Great Plains region (Dort 1987a). This spillway system was perhaps initially eroded downward to the bedrock level below the Menoken terrace (fig. 19). This bedrock surface is slightly higher in elevation (3-12 m) than the present floodplain of the Kansas River (Dort 1987b).

Some geologists earlier suggested that glacial melt water was diverted to the southwest through a now buried valley in the McPherson vicinity of central Kansas (fig. 17). This is unlikely, however, as the elevation of the McPherson channel is considerably higher than the glacial limit near Manhattan, and no glacial erratics have been found in the sediments filling the McPherson channel (Williams and Lohman 1949).

During the late Kansan glaciation, the Blue/Kansas spillway again served as the primary route for melt water and diverted Great Plains drainage. Outwash sand and gravel accumulated, as the ice sheet approached, to a thickness of at least 25 m, and the outwash sediment is locally interbedded with till. These sediments are preserved as fill beneath the Menoken terrace (fig. 7), the surface of which is up to 30 m (100 feet) above the present Kansas River floodplain (Dort 1987b).

The Blue/Kansas spillway was locally blocked in several places by ice lobes that crossed the valley; this caused the formation of short-lived lakes. Attempts have been made to reconstruct the positions of such lakes (Todd 1918; Dort 1987a) in the Manhattan vicinity and elsewhere. At times, the Kansas valley itself contained a lake, as shown by lake sediments preserved in southwestern Jefferson County (fig. 19). However, detailed interpretation for most of these lakes is impossible due to scanty preservation of lake sediments and shoreline features.

The results of downstream flooding from ice-dammed lakes are well developed in several places. A particularly good example is located in southern Shawnee County (fig. 19). At its local maximum, the Kansan ice sheet pressed against the Bern Limestone escarpment (Burnett Mound) and impounded a lake of unknown size to the west. When the ice dam broke, a great flood deposited a wedge-shaped fan of sediment toward the southeast.

This sediment forms a narrow ridge of bouldery gravel in southwestern Topeka. Large, rounded boulders, up to 3 m (10 feet) in diameter and bearing percussion fractures, are common near the northern end of this ridge. At the time of deposition, the flood waters may have been confined to a crevasse between blocks of stagnant ice. This would account for the narrow character of the ridge. Toward the southeast the ridge spreads out into a level plain underlain by thick outwash sediment. This plain is conspicuous in the Pauline/Forbes Field vicinity. The outwash sediment extends, with steadily smaller and better rounded boulders, to near the Wakarusa valley. The Wakarusa valley was itself eroded as a temporary spillway during this or other flood events.

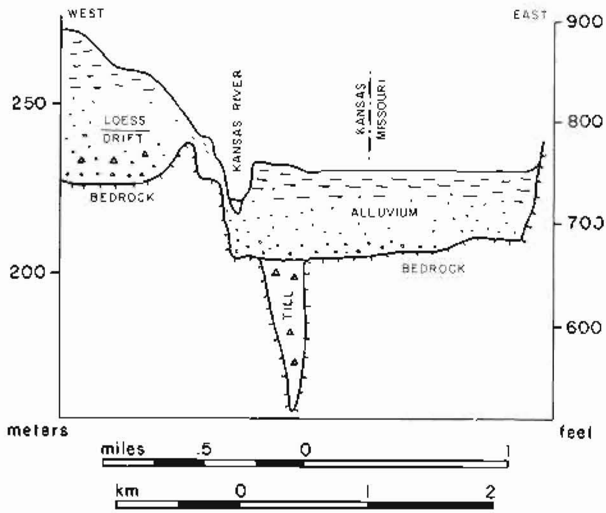


Figure 20. Cross section of the Kansas River valley at Kansas City, Kansas showing deep inner gorge that is filled with till. Note large vertical exaggeration; adapted from Jewett et al. (1965, fig. 8).

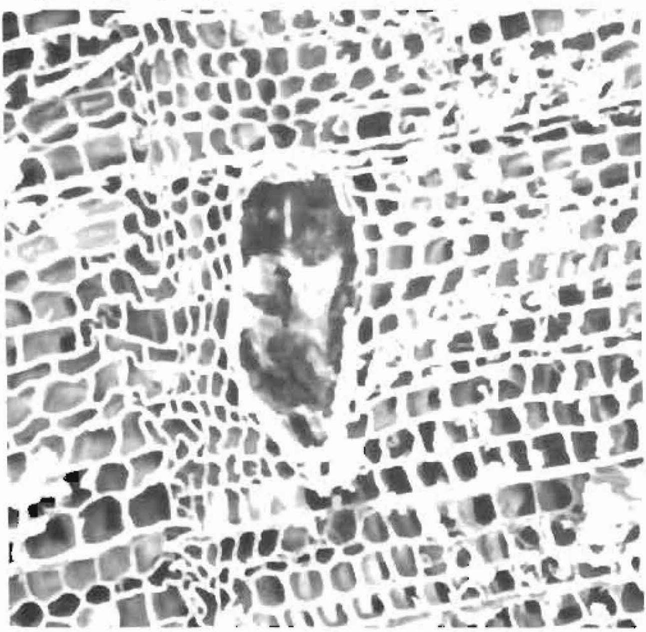


Figure 21. Scanning electron photomicrograph of spruce wood in cross section from till near Fremont, Nebraska. Note large resin canal near center and growth ring in vertical position to left. Resin canal is approximately 0.2 mm across (vertically).

Failure of ice dams led to catastrophic downstream flooding elsewhere along the glacial border zone. Many temporary spillway valleys were eroded and the Blue/Kansas valley was deepened. In several places inner gorges were cut as much as 45 m (150 feet) below the bedrock floor of the Kansas River valley (fig. 20). The abandoned portion of Turkey Creek valley in central Kansas City, Missouri was deeply eroded and then filled with up to 74 m (242 feet) of outwash sediment (O'Conner and Fowler 1963). Deep gorges were also cut below the Blue River valley in the Manhattan vicinity (Chelikowski 1976). Other catastrophic floods can be identified by the positions of spillways, thick outwash sediment, and boulder concentrations in several places along the glacial border zone (fig. 8).

The exact sequence of glacial-lake floods is not known. It is possible that floods derived from upstream lakes may have triggered floods in lakes to the east in a dominolike fashion (Kehew and Lord 1986). Due to oscillations of local ice lobes, repeated flooding of particular areas may have taken place. All of the drainage diversions along the maximum late Kansan ice limit appear to have been temporary events, as the Blue/Kansas River spillway remained the primary drainage route during and after the Kansan glaciation.

ENVIRONMENT OF THE KANSAN GLACIATION

Few clues are available for deciphering the environmental conditions that existed during the Kansan glaciation. Perhaps the best sources of information are wood pieces found in deeper till deposits, particularly in Atchison and Doniphan Counties and in the buried valley to the west. Such buried wood is common in the Lower Kansas Till, wherever weathering has not destroyed the original organic material. Similar wood is also common in equivalent till in eastern Nebraska and northern Missouri.

The wood is invariably spruce (fig. 21), most likely *Picea glauca* (Hedstrom 1986), in the form of twigs and broken branches up to 50 cm (1.6 feet) long. Spruce forest grows today in a subarctic environment across central Canada, which indicates a much colder climate existed in the Great Plains preceding the Kansan glaciation. Although much bare wood is present in till, no cones, needles or bark have yet been found. This suggests the early Kansan ice sheet overran remnants of a forest that had died due to deteriorating climate as the ice approached.

Beyond the limits of Kansan glaciation, very little evidence regarding the *periglacial* environment is preserved. A broad zone extending 100 km (60 miles) beyond the glacial limit has scattered evidence for strong winds. On the western side of the Flint Hills in east-central Kansas, many residual cobbles and pebbles bear the glossy polish and facets of sand blasting. Similar wind polish is seen on some boulders in the glacial border zone (Schoewe 1932). Although it is impossible to date the time of this wind erosion, it could certainly relate to the presence of the Kansan ice sheet. Features associated with permafrost are generally lacking, although Dort (1987a) did report some "ice wedge patches" from southeastern Shawnee County.

TWO-ICE-LOBE MODEL FOR KANSAN GLACIATION

The Kansan glaciation clearly consisted of two major advances in northeastern Kansas (Schoewe 1931; Dellwig and Baldwin 1965; Aber 1988). This must have been related in some way to the dynamic structure of the Kansan ice sheet. The *Laurentide Ice Sheet* of late Wisconsin age (14,000-18,000 years ago) could be used as a model for what the Kansan ice sheet may have looked like. The Laurentide Ice Sheet had two main centers--Labradorean and Keewatin, from which ice spread outward (fig. 1). The Keewatin center was dominant in the Great Plains region. Concentrated movement formed ice streams along bedrock troughs, such as the Great Lakes troughs. At the margin of the ice sheet, these streams pushed out elongated ice lobes.

The Laurentide Ice Sheet developed two prominent lobes in the Great Plains (fig. 22): (1) Des Moines lobe, an extension of the Lake Winnipeg ice stream and (2) James lobe, an extension of the Lake Manitoba ice stream (fig. 1). These two lobes followed broad bedrock depressions either side of the Coteau des Prairies upland. The southern portion of the Coteau des Prairies is cored by a ridge of Sioux Quartzite, a resistant bedrock obstacle up to 535 m (1750 feet) in elevation. To the east, Sioux Quartzite elevations along the Minnesota River valley are only 275 m (900 feet), and along the James River valley to the west bedrock is 365 m (1200 feet). These differences in elevation caused ice flow to split into the Des Moines and James lobes.

It is now believed that these lobes may have advanced very suddenly and repeatedly due to surging over water-lubricated beds (Clayton *et al.* 1985). Advance and retreat of the two ice lobes diverted drainage in a systematic pattern, as shown by modern rivers, which occupy three positions: (1) ice marginal - Missouri River above Sioux City, (2) lobe axis - James, Minnesota and upper Des Moines Rivers, and (3) interlobate - Big Sioux River. Similar ice-lobe development and drainage diversions may have taken place during the Kansan glaciation.

The Kansan ice sheet in the Great Plains region probably consisted of two ice lobes--Minnesota and Dakota, which occupied positions equivalent respectively to the Des Moines and James lobes (fig. 22). The Minnesota lobe extended from Minnesota, through Iowa and Missouri, and entered Kansas from the northeast. Conversely the Dakota lobe moved from the Dakotas, across eastern Nebraska, and advanced into Kansas from the northwest.

The Dakota and Minnesota lobes were able to advance farther south because the Kansan ice sheet was thicker. It completely covered the Coteau des Prairies, but the Sioux Quartzite ridge was still effective in splitting ice flow into discrete lobes. The lobes were likely confluent, flowing side by side southward into Nebraska and

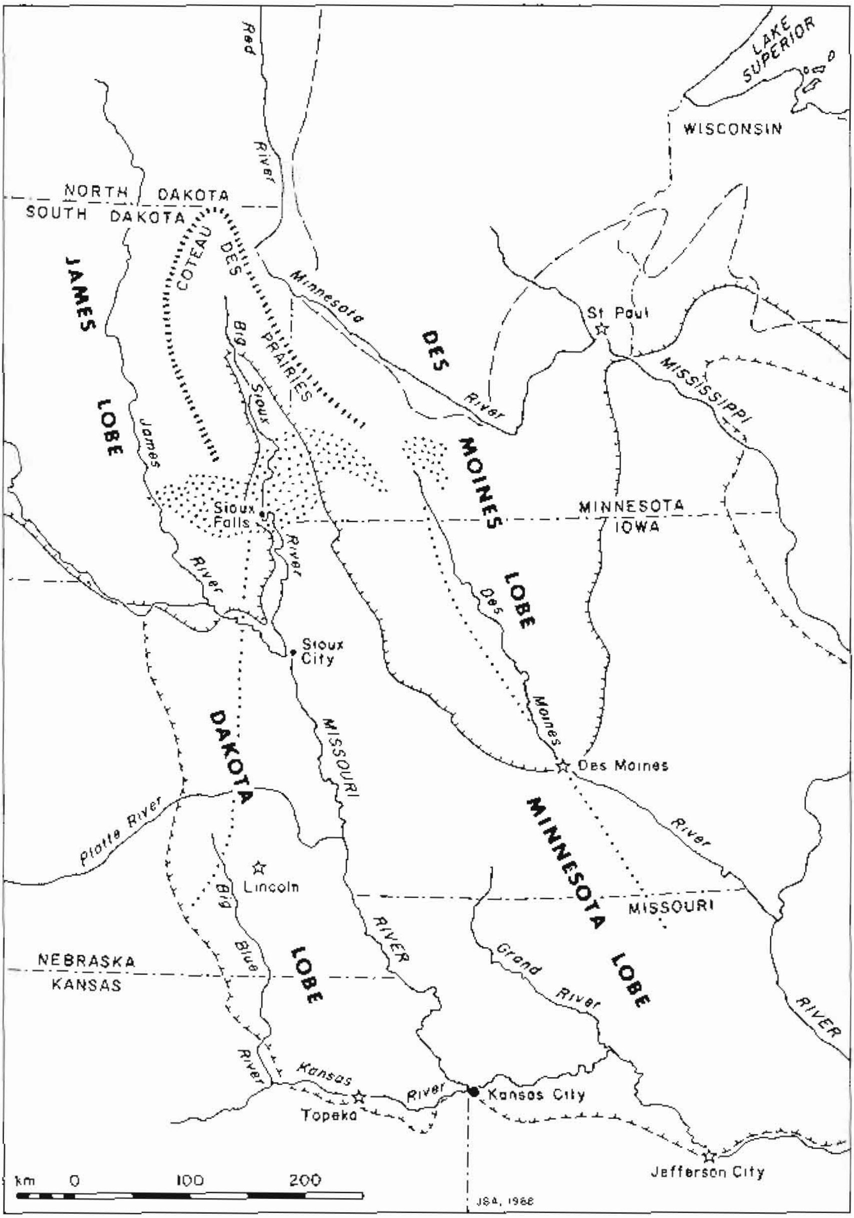


Figure 22. Major ice lobes of the Great Plains region of north-central United States. Des Moines and James lobes of the Laurentide Ice Sheet are Wisconsin in age; Minnesota and Dakota lobes are Kansan. Dotted zones are Sioux Quartzite bedrock; dotted lines show limits of Sioux Quartzite erratic fan (from Willard (1980, fig. 27). Other symbols same as Fig. 1; adapted from Aber (1982, fig. 1).

Iowa; however, farther south the lobes evidently separated. The Minnesota lobe was first to reach Kansas and was responsible for depositing the Lower Kansas Till, for damming Lake Atchison in the preglacial valley, and for causing floods that eroded the Blue/Kansas spillway system. The Minnesota lobe may have advanced repeatedly due to surging into Lake Atchison.

After the Minnesota lobe retreated from northeastern Kansas, the Dakota lobe overran the region. The distribution of Sioux Quartzite erratics forms a broad fan south and southeast of the source area (fig. 22). This is consistent with transportation of these erratics by the Dakota lobe moving from the north-northwest. At its maximum the late Kansan ice sheet reached as far as the Blue/Kansas spillway valley. Local ice lobes pushed across the valley and impounded temporary lakes that generated several catastrophic floods.

The Big and Little Blue, Wakarusa, and Kansas Rivers are certainly ice marginal in position, as is the Missouri River east of Kansas City. However, the origin of the Missouri River north of Kansas City to Sioux City, Iowa is problematic. Its position could be interpreted as either lobe axis in relation to the Dakota lobe (Reed *et al.* 1965) or ice marginal relative to the Minnesota lobe (Todd 1914). Perhaps it developed as an interlobate drainage as ice retreated during the final stages of the Kansan glaciation (Aber 1982).

The Kansan ice sheet was considerably thicker and more extensive than any younger ice sheets in the region west of the Mississippi River. This is not true to the east, however, where later glaciations were nearly as large or even more extensive. This suggests that the Keewatin sector was more active during the Kansan glaciation than later, but the reason for this is unknown. Both climatic or tectonic factors may have been involved.

Greater flow of moisture-bearing wind from the Pacific and Arctic Oceans or higher elevation of the Keewatin area would have enhanced accumulation of snow and growth of an ice sheet in the Great Plains. The Arctic Ocean would have provided a nearby moisture source, as it did not have a perennial cover of sea ice prior to about 400,000 years ago (Scott *et al.* 1989). The greater size of the Kansan ice sheet compared to other glaciations of the Great Plains may have simply been a random variation of the kind found in dynamic systems that are unpredictable or chaotic in nature (May 1976; Gleick 1987). In any event, the Kansan glaciation was certainly one of the most significant environmental events to take place on the Great Plains during the past one million years.

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BRIEF GLOSSARY OF GLACIAL TERMS

Drift: A general term referring to any kind of glacially derived deposits. Comes from early idea that most drift was dropped from melting icebergs drifting in a glacial sea.

Erratic: Any kind of rock or stone that was transported by ice or water a great distance from its origin and now rests on bedrock of different character.

Glacial theory: Scientific concept that during geologic past the earth has suffered widespread ice-sheet glaciation in regions that are now ice free. Global changes in climate, sea level, and biologic populations accompanied these glaciations, and the ice-covered landscape was much modified by glacial erosion, deformation, and deposition.

Glaciation/deglaciation/interglaciation: The process of growth and spreading of ice sheets and glaciers to cover a major portion of the earth's land (app. 30% during height of Pleistocene glaciations). Deglaciation is the opposite, the shrinking of ice sheets and glaciers to uncover land areas; the world is presently in an interglaciation in which roughly 10% of the land is ice covered.

Glacier accumulation/ablation: The gain of ice mass mainly through snowfall on a glacier; ablation is the loss of mass mainly by melting or calving of icebergs.

Glacier ice: Ice formed from the accumulation and recrystallization of snow, which exhibits past or present flow. Typically has a bluish-green color due to tiny gas bubbles or may be dirty with included sediment. Density 0.8-0.9 g/cc.

Glacier surge: Rapid, wavelike movement of ice down a glacier which results in sudden advance of the ice margin. Mass transfer of material from the accumulation zone to the ablation zone with high ice velocities. Occurs cyclically in certain glaciers, but never takes place in others.

Ice lobes, fans, domes, *etc:* Dynamic features within large ice sheets which reflect glacier accumulation and ablation, ice temperature, bedrock topography, marginal seas, and ice flow.

Kansas Drift: Stratigraphic unit of group rank that includes all glacial and glacially derived sediments in northeastern Kansas; stratotype at Atchison, Kansas; age 0.6-0.7 million years old.

Laurentide Ice Sheet: The Wisconsin-age ice sheet that covered all of eastern and central Canada and extended into the north-central and northeastern U.S.A. It may at times have joined with the Greenland and Cordilleran Ice Sheets.

Loess: Silt-sized sediment which mantles uplands in deserts and periglacial regions. Represents wind-blown (aeolian) dust deposits; common in northeastern Kansas.

Moraine: A general term refering variously to glacial deposits or landforms. Used in America mainly for glacial landforms of constructional nature, such as end moraine or ground moraine. Also refers to drift in transport by a glacier, such as medial or lateral moraines. Derived from French for piles of rubbly deposits in front of glaciers.

Paleomagnetism: Earth's magnetic field of the past as shown by natural remnant magnetism in rocks; paleomagnetic reversals of polarity are a common feature, and reversals can be used as stratigraphic markers.

Periglacial: The zone or environment surrounding an ice sheet, often characterized by harsh climate.

Permafrost: Perennially frozen ground, often containing ice-wedge polygons, pingos, and other unusual features.

Pleistocene Epoch: A subdivision of the geologic time scale (10,000 to 1.6 million years ago). Characterized by mostly modern fossils (90% fossils still living organisms), major glaciations of the mid-latitudes with associated climatic and environmental changes, and the appearance of early man (*Homo erectus* followed by *H. sapiens*).

Radiometric dating: Determination of the age of appropriate materials based on radioactive decay of certain isotopes. Common methods used in Quaternary studies include: C-14, fission-track, uranium series, potassium-argon, *etc.*

Stratified drift: Clay, silt, sand, and gravel sediments that were deposited in melt-water streams, lakes or seas. Such sediment usually displays stratification and sorting.

Stratigraphy: The scientific classification of rock or sediment strata according to attributes of the strata, such as: lithology, fossil content, or age.

Stratotype: A specific body of rock or sediment strata used to define a stratigraphic unit and that displays the typical attributes of the unit.

Striation (striae): Small (mm-sized) scatches on bedrock and stones made by glacial scouring, often accompanied by grooves, polish, and fracture marks. Indicators of ice movement direction.

Terrace: A benchlike or flat-topped land surface within a major river valley and above the level of the valley floor. Often a series of terraces within a valley form steps on the valley sides. Terraces may be erosional or depositional in origin.

Till: A general term refering to any kind of sediment deposited directly from glacier ice with little or no influence by running water. Typically unstratified and unsorted; sometimes called boulder-clay.

Till fabric: The alignment of elongated pebbles within till. Thought to be an indicator of direction of ice movement when till was deposited. Both transverse and parallel fabrics commonly developed.

Wisconsin/Illinoian/Kansan/Nebraskan glaciations: Traditional sequence of glacial stages in central North America from youngest to oldest; named after states in which glacial deposits/landforms of a particular glaciation are prominent.

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