Chert Gravel and Neogene Drainage in East-central Kansas

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Abstract

Eastern Kansas has an active geomorphic regime dominated by stream erosion, which is strongly influenced by bedrock structure. Alluvial deposits of chert gravel of presumed Neogene age are widespread and abundant on hill tops and high terraces throughout the region. Many of these gravels contain quartzite and other exotic pebbles derived from western sources. Geographic information system (GIS) techniques are used to document and analyze the spatial distribution of upland chert gravel deposits. On this basis, Neogene drainage routes may be recognized for the ancestral Arkansas, ancestral Verdigris, ancestral Neosho, and ancestral Marais des Cygnes.

These drainages bore little resemblance in position or direction to the modern rivers. Stream captures, valley entrenchment, and wholesale inversion of topography led to the modern drainage systems. During entrenchment, streams have shifted systematically southward and eastward, possibly as a result of long-term and continuing crustal tilting (neotectonism) down toward the Gulf of Mexico.

Eastern Kansas south of the limit of glaciation is part of the Osage Plains of the central United States. This region is commonly portrayed as a tectonically stable terrain of low relief, in which near-peneplain conditions prevail. Widespread seismic activity and recent fault movements (Madole et al., 1991), however, suggest that the region may not be as stable as once thought. In eastern Kansas, considerable erosion of the landscape has taken place since Miocene time. Alluvial deposits of chert gravel of presumed Miocene, Pliocene, and Pleistocene ages are widespread and abundant on drainage divides, isolated hilltops, and high terraces throughout eastern Kansas (fig. 1). High-terrace chert gravels mostly are associated with existing stream valleys. In contrast, hilltop chert gravels in many places bear no obvious relationships to any river systems of today. Many, but not all, of these gravels on high terraces and hilltops contain quartzite and other exotic pebbles derived from the High Plains or Rocky Mountains to the west.

Description of the Study Region

The study region is centered in east-central Kansas and includes Chase, Butler, Lyon, Greenwood, Osage, Coffey, Woodson, Wilson, Anderson, Allen, and Neosho counties, as well as portions of surrounding counties (fig. 2). The study area includes portions of six physiographic regions—Flint Hills, Osage Cuestas, Chautauqua Hills, Wellington-McPherson Lowlands, Arkansas River Lowlands, and Smoky Hills. For purposes of this paper, the Wellington-McPherson Lowlands and Arkansas River Lowlands will be combined as a single unit—the Wellinton-McPherson-Arkansas River Lowlands (fig. 3). This region includes parts of several local drainage basins: Neosho, Cottonwood, Walnut, Verdigris, Fall, lower Arkansas, Smoky Hill, and Marais des Cygnes. The latter two are within the greater Missouri basin; the others are part of the greater Arkansas basin (fig. 2).

The Flint Hills form an erosional massif that stands above lower plains to the east and west. The Flint Hills are underlain by lower Permian limestones, shales, and evaporites. Thick, cherty limestone units weather to produce residual lag deposits composed of angular chert fragments, which are highly resistant to chemical breakdown (fig. 4). Such residual chert is responsible for maintaining high topographic relief and gives the Flint Hills their name. The eastern margin of the Flint Hills is marked by a major escarpment that is especially prominent in northwestern Greenwood and eastern Chase and Butler counties. Divides between the Walnut and the Cottonwood, Verdigris, and Fall drainage basins follow the crest of the Flint Hills escarpment. Maximum elevations exceed 500 m (1,640 ft), relief is locally up to 100 m (330 ft), and stream valleys are deeply entrenched. From their eastern crest, the Flint Hills slope gently westward, down the regional bedrock dip, toward the eastern limit of the Wellington-McPherson-Arkansas River Lowlands.

The Arkansas drainage divide marks a major boundary in the geomorphology of central Kansas. To the west, the Wellington-McPherson-Arkansas River Lowlands form a nearly flat plain that slopes imperceptibly toward the south. It is underlain by unconsolidated Neogene and Quaternary sediments of arkosic composition and variable thicknesses. These sediments were derived from the west

FIGURE 1. Typical exposure of alluvial chert gravel, about 1 m (3 ft) thick, resting on weathered sandstone, on uplands north of Neosho River valley, east of Emporia, Kansas.

and deposited on a wide alluvial plain. The upper surface of the lowland is little modified by subsequent erosion. However, its eastern and northern margins are locally truncated by headward erosion of tributaries within the Walnut, Cottonwood, and Smoky Hill drainage systems.

The Osage Cuestas and Chautuaqua Hills are generally lower in elevation and relief compared to the Flint Hills. Elevations are mostly in the 250 m to 350 m (820–1,150 ft) range. Upper Pennsylvanian shale and poorly consolidated sandstone underlie most of these regions. Thick limestone units are more resistant to erosion and support conspicuous escarpments, where local relief may reach 50 m (160 ft). Elevations exceeding 360 m (1,180 ft) are found on the Missouri-Arkansas drainage divide in central Anderson County. Chert is relatively scarce within upper Pennsylvanian bedrock throughout eastern Kansas.

Previous Investigations

Deposits of chert gravel in uplands of eastern Kansas were recognized in the late 1800's and early 1900's and investigated in different locations. Early ideas for the genesis of upland chert gravel included outwash drift of glacial origin and residual accumulations on a peneplain (Aber, 1985, 1988). Studies since the 1950's have emphasized the alluvial genesis of chert gravel that was transported from the Flint Hills and deposited in ancient stream channels (O'Conner, 1953). Subsequent valley entrenchment and drainage diversions have left the old alluvial gravels situated on high terraces and hilltops.

Eastward from the Flint Hills, chert gravel deposits attain higher relative positions in the local topography. This trend culminates in Anderson County, where chert gravel is preserved on the Missouri-Arkansas drainage divide, up to 75 m (250 ft) above adjacent floodplains. Frye (1955) concluded that these highest gravels mark an early river system that crossed in an easterly direction what is now a major drainage divide and joined with streams in the Ozark region of Missouri. In an earlier paper, I used the name Old Osage River to refer to this supposed through-drainage route to the east (Aber, 1985).

The ages of the chert gravel deposits can be estimated only on the basis of topographic positions above modern floodplains and degree of soil development. The deposits consist of insoluble siliceous minerals; all soluble components have been removed by prolonged weathering. Thus, appropriate fossils or materials suitable for dating are not preserved. Most geologists have agreed upon Neogene (Miocene or Pliocene) age for upland chert gravels, and these gravels are classified as Tertiary on state and county geologic maps (Aber, 1993). Frye (1955) considered that the oldest chert gravels date from the early Tertiary (Paleogene). I previously designated upland chert gravels within the Walnut drainage basin as the Leon Gravel, a lithostratigraphic unit of formation rank (Aber, 1992). However, similar chert gravel deposits in other basins have not received any formal stratigraphic recognition.

Exotic pebbles of quartzite were noted in upland chert gravels by some early investigators (see Mudge, 1875; Wooster, 1934), who thought the exotics had been washed into the region by glacial meltwater. Some later geologists, however, overlooked the existence of exotic pebbles or discounted their importance. Frye and Leonard (1952, p. 181–184), for example, stated that ". . . the late Tertiary sediments in the eastern one-fourth of Kansas are entirely attributable to the Permian and Pennsylvanian rocks

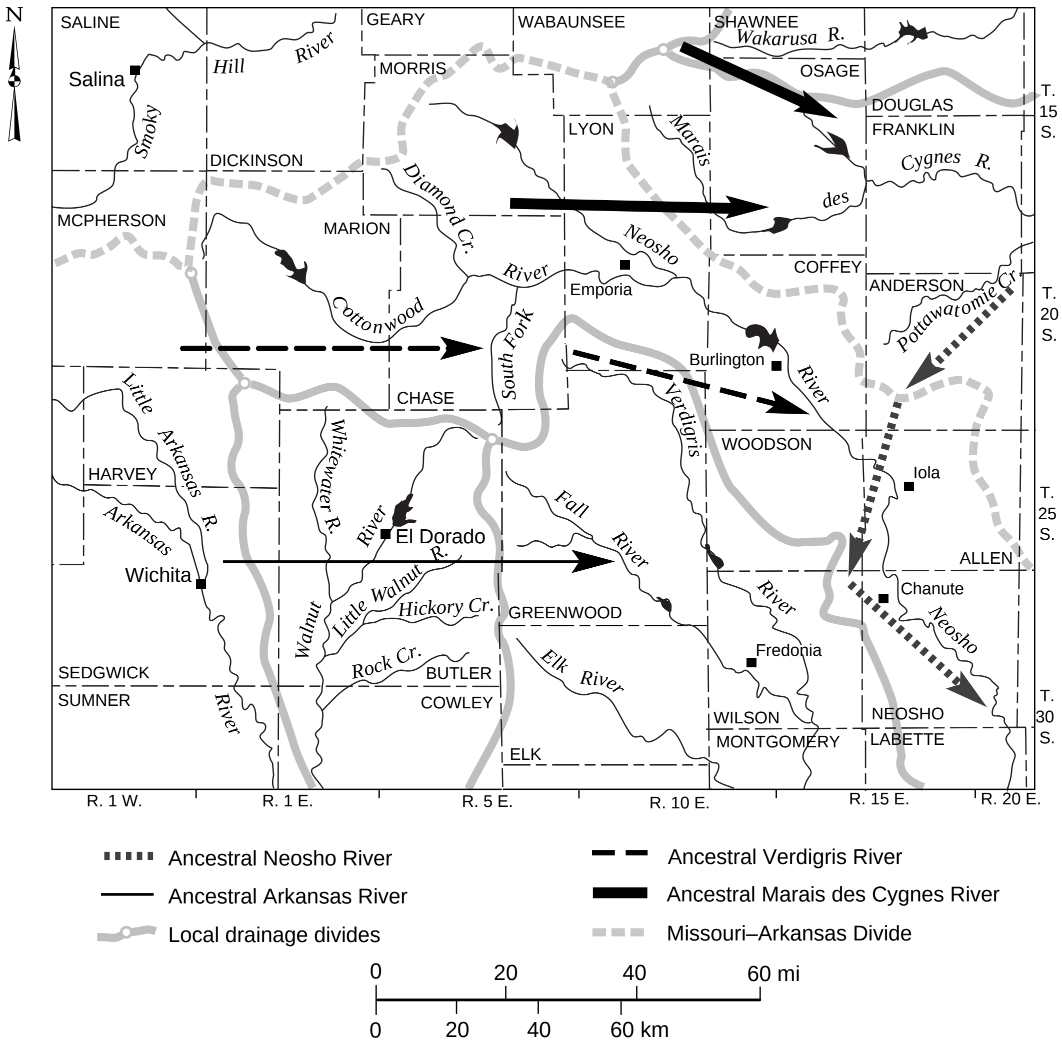

FIGURE 2. Study area showing rivers, drainage divides, and ancestral drainage routes.

eastward from and including the Herington Limestone." They concluded that "some time during the Tertiary the Flint Hills became a major drainage divide separating two strongly contrasting depositional provinces" (Frye and Leonard, 1952, p. 184). This interpretation was repeated in other reconstructions of Kansas drainage development. Seevers and Jungmann (1963) suggested, in contrast, that Neogene drainage from central Kansas did cross the Flint Hills and transported quartzose materials derived from Cretaceous source strata into eastern Kansas.

Methods of Investigation

Field and Laboratory

Various techniques were used to document and analyze the distribution and composition of upland chert gravel deposits in the region of study. Detailed mapping of surficial geology was carried out in Butler County (Aber, 1991), and reconnaissance observations were made throughout the study region (Aber, 1988). Gravel riffles were examined in modern stream channels (Byerley, 1995). Conventional field observations were supplemented by laboratory analysis of chert gravel characteristics. Several hundred pebbles of quartzite, quartzose sandstone, and other exotics have been collected, and these were classified according to rock type and color. Thin sections of representative specimens were cut and examined with a petrographic microscope.

Soil series, as depicted in county soil survey reports, proved to be excellent indicators for both residual and alluvial chert gravel deposits (e.g., Penner et al., 1975; Swanson and Googins, 1977; Neill, 1981). The Florence series is developed in residual chert weathered from limestones on Flint Hills uplands (fig. 5). Chert in these soils has not been transported by streams, although some mass movement may have taken place on slopes. The Olpe series is formed on alluvial chert gravel on hilltops and high terraces (fig. 6). Chert in these soils was transported by streams and deposited in channels as various kinds of

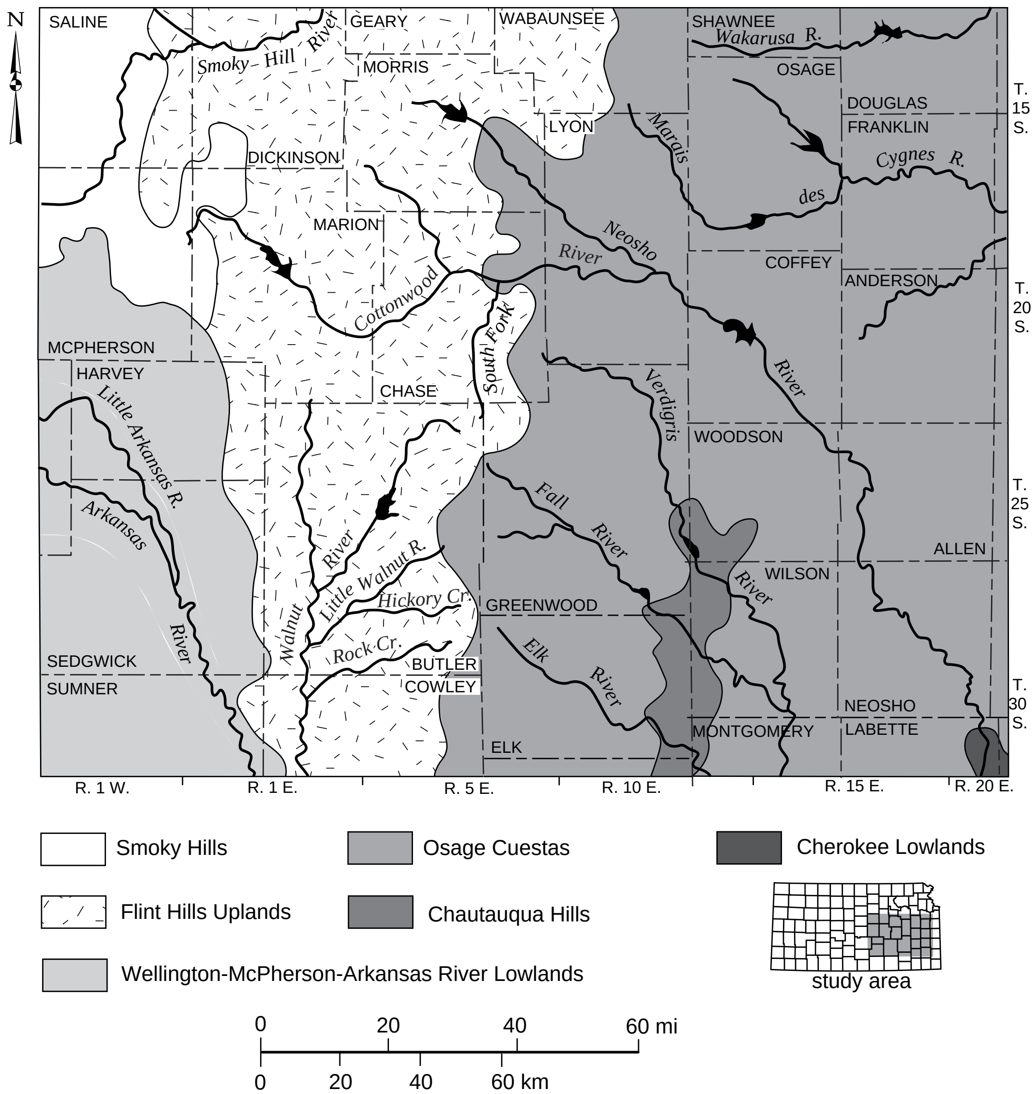

FIGURE 3. Study area showing rivers and principle physiographic regions. In this study, the Arkansas River Lowlands and the Wellington-McPherson Lowlands are treated as one region.

bars, dunes, and riffles. Chert gravel may be interbedded with finer alluvial sediments.

In nearly all cases, field observation verified that alluvial chert gravel is present as depicted on soil survey reports. Very few instances were found in which Olpe soil proved to be residual chert, rather than alluvial deposits. In a few cases, thin deposits of alluvial chert were discovered that are not identified as Olpe soil on the county reports. Other than these few exceptions, the Olpe soil is a regionally reliable indicator for alluvial chert gravel deposits in the uplands of eastern Kansas.

GIS and Remote Sensing

Current investigations have emphasized applications of geographic information systems (GIS) and remote sensing for depicting and analyzing the spatial distribution of chert gravel in the landscape. GIS and image processing were carried out using IDRISI software.

Two kinds of GIS databases were compiled. The first of these was a general raster grid that covers most of the study area, T. 16 S. to T. 30 S. and R. 3 E. to R. 21 E. (fig. 2). This grid is based on the township-and-range system divided into quarter-section (1/2 mile by 1/2 mile) cells and covers about 26,000 km^2 (10,000 mi^2). The second GIS database was a detailed vector database for Allen, Anderson, Coffey, Neosho, Wilson, and Woodson counties, referenced to the UTM coordinate system (fig. 2).

The raster database for Olpe and Olpe-complex soils was created with gravel elevation as the value for each cell. Although this grid system has many shortcomings for accurate cartographic work, it is convenient to use, and for the purpose of this database, small locational anomalies are of little significance. The key attribute for this database is actual elevation of chert gravel, not accurate areal limits. County metric topographic maps (1:100,000) were used

FIGURE 4. Close-up view of angular chert blocks in gravel pit. Compass for scale.

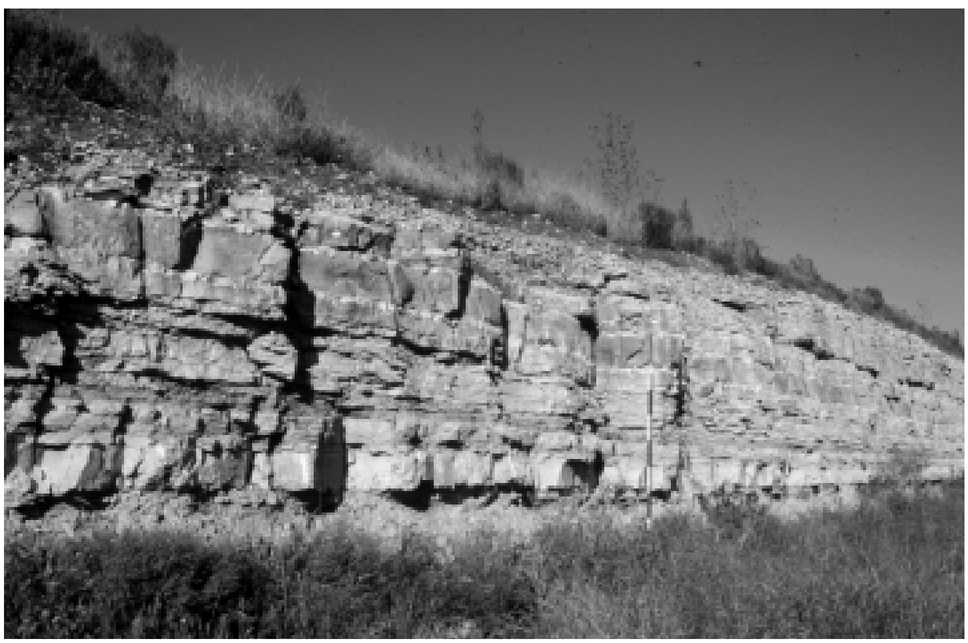

FIGURE 5. Exposure of Florence Limestone in eastern Butler County. Light gray beds and nodules of chert weather out at the surface and accumulate as a residual lag deposit on Flint Hills uplands. Scale pole marked in feet.

for determining the grid and transfering data from soil survey reports. Elevation data for Olpe cells were entered into the database if the Olpe soil covered at least 10 acres (4 hectares) or 1/16th of the quarter section, as estimated from the soil maps. The elevation of the soil was given as the highest elevation contour (nearest 5 m).

The detailed vector database was created for a six-county area in the middle and lower Neosho basin (Byerley, 1995). Geographic data were entered by manual digitizing in vector format from 7.5-minute topographic quadrangle maps. The vector database contains all main rivers and their principal tributaries, reservoirs, county boundaries, and selected cities, as well as geomorphic distribution of alluvial soils and chert gravel. Other kinds of GIS databases were utilized, including various digital elevation models (DEM) and Landsat multispectral scanner (MSS) images from the 1988 growing season (Aber et al., 1997).

FIGURE 6. Profile in Olpe soil in hilltop position on drainage divide between the Little Walnut River and Walnut River valleys, southern Butler County. Scale pole marked in feet.

Gravel Composition

High-terrace and hilltop gravel deposits are composed almost entirely of crudely bedded chert derived from lower Permian bedrock of the Flint Hills. Milky quartz and siliceous fossils, also derived from the same bedrock sources as chert, are another component of these gravels. These components typically make up 98% to more than 99% of the small-pebble (4–8 mm, 0.16–0.31 in) fraction of high-terrace and hilltop gravels in eastern Kansas. Other locally derived components include sandstone, shale, petrified wood, and iron concretions, which may make up 2% of the gravel deposits, especially in vicinity of the Chautauqua Hills.

Exotic pebbles are present in trace amounts (less than 1%) in most gravel deposits (fig. 7). The exotics include, in relative order of abundance, quartzite, quartzose sandstone, dark flint, and a single piece of weathered granite. Some petrified wood may also be exotic. Most exotics are pebbles, but a very few are cobbles, up to 9 cm long. They are usually well rounded and polished. Quartzite pebbles display typical metamorphic features: schistose or gneissic fabrics, undulatory extinction of quartz grains, corroded or sutured grain boundaries, and veins of biotite or epidote. These pebbles fall into three general color groups: about 60% are yellow, orange, and light brown (5Y, 5YR, 10YR); about 30% are pink, red, and red-purple (5R, 10R, 5RP); and 10% are purple, dark brown, and gray (5P, 5Y, 5YR, N) (Aber, 1985).

The lithology of exotics closely matches that of the arkosic alluvium of the Wellington-McPherson-Arkansas River Lowlands and the basal Cretaceous conglomerate of the Smoky Hills region (Aber, 1985). Exotic pebbles are trace constituents of upland gravel deposits in most portions of the study region. However, exotics have not been discovered along the Marais des Cygnes valley in southern Osage and northeastern Lyon counties. Nor have exotics been found along the South Fork of the Cottonwood River valley in central Chase County. Exotic pebbles are seemingly most abundant in gravels of the lower Walnut basin and on the Missouri-Arkansas divide in Anderson County. In many cases, exotic pebbles tend to be locally more abundant in higher (that is, older) gravel deposits.

Regional Distribution of Upland Chert Gravel

Regional distribution of high-terrace and hilltop gravel deposits is depicted according to actual elevation on the raster database (fig. 8). This database overestimates the actual area of upland gravels, as individual gravel cells may represent full coverage to as little as 10 acres (4 hectares) of Olpe soil. Nonetheless, the database provides for a regional overview of gravel distribution and elevation. The highest gravel deposits are located in headwaters of the Walnut, Verdigris, Fall, and Cottonwood drainage basins at elevations greater than 400 m (1,310 ft). These gravels are preserved near the crest of the Flint Hills escarpment. The lowest gravels are found near the eastern and southeastern margins of the study region at elevations less than 300 m (980 ft).

Walnut Drainage Basin

Chert gravel deposits are abundant on high terraces and hilltops in southern Butler and northernmost Cowley counties (fig. 2). Gravel deposits are associated with the Little Walnut River, Hickory Creek, and Rock Creek valleys, as well as the lower Walnut River valley. These streams have entrenched their headwaters into or below the Florence Limestone Member, which is the primary source of residual chert. Streams in western and northern Butler County either have not yet entrenched or are just beginning to erode into the Florence Limestone Member. This explains the general lack of older chert alluvium in northern and western portions of the Walnut drainage basin.

FIGURE 7. Selection of exotic pebbles from upland chert gravel in the lower Walnut basin in southern Butler County. Pebbles are quartzite and quartzose sandstone. Swiss knife for scale.

Upland chert gravel deposits are formally named the Leon Gravel after the city of Leon (Aber, 1992). A stratotype is designated in NE sec. 35, T. 27 S., R. 5 E. As defined, the Leon Gravel is equivalent to the Olpe or Olpe-Norge soil map units within the Walnut drainage basin of Butler and Cowley counties. The Leon Gravel is usually 1–2 m (3.3–6.6 ft) thick and rests on Permian bedrock. It can be informally separated in some places into upper and lower members on the basis of topographic position in relation to adjacent modern valleys. The upper member occupies hilltop or drainage-divide positions, about 18–30 m (60–100 ft) above modern floodplains. The Olpe soil B2 unit color is typically moderate to dark reddish brown (10 R 4/6 to 3/4). The lower member occupies high-terrace positions, roughly 6–12 m (20–40 ft) above modern floodplains. The Olpe soil B2 unit color is typically moderate brown (5 YR 4/4).

Upland chert gravels in the Walnut drainage basin are preserved almost exclusively on the northern sides of eastern tributaries—Little Walnut, Hickory, and Rock valleys—and on the eastern side of the lower Walnut valley. The same pattern holds true for lower (that is, younger) terraces within these valleys, and rivers are cutting bedrock bluffs in many places on valley sides opposite the terraces. Exotic pebbles are found within chert gravel deposits in all portions of the Walnut basin and are especially abundant along the lower Walnut valley.

Cottonwood Drainage Basin

Chert gravels are abundant along the main valley and most tributary valleys of the Cottonwood system in Chase and Lyon counties (figs. 2, 8). However, chert gravel is not found farther upstream in Marion County for the same reason that chert gravels are not present in western Butler County, i.e., lack of cherty limestone source outcrops. Gravel elevations are highest in southern Chase County at 420 m (1,380 ft). In the headwater source region, chert gravels are relatively low in the present landscape, but the gravels rise relative to the local topography downstream. Chert gravel caps the drainage divide, near the junction of the Neosho and Cottonwood rivers in Lyon County at an elevation of 350 m (1,150 ft) (fig. 9).

Chert gravel is nearly continuous along the northern side of the main Cottonwood River valley, and gravel is also abundant along the western side of the north-trending South Fork of the Cottonwood River valley. Similar patterns are seen for smaller tributary valleys; gravel is preserved north of west-east valleys and west of north-south valleys.

Exotic pebbles are relatively common in gravels associated with the main Cottonwood River valley, but exotics have not been found in gravels along the South Fork of the Cottonwood River valley. Exotics are scattered in thin (non-cherty) soils on limestone hilltops in eastern Marion County. These exotic pebbles match in type and color those found in chert gravels to the east, but many of the Marion exotics bear glossy polish and facets typical of ventifacts. They appear to represent a residue of formerly extensive, non-cherty gravel deposits (Aber, 1988).

Neosho Drainage Basin

Chert gravels occur in several portions and topographic positions within the Neosho River basin (figs. 2, 8). These are described beginning with upstream portions.

Kahola Creek valley. High-terrace gravels are preserved along the northern side of a small east-flowing tributary of the Neosho in the southeastern corner of Morris County. These gravels contain no exotic pebbles, and the creek is cutting bedrock bluffs on the southern valley side.

Middle Neosho River valley. Nearly continuous trend of chert gravel is present on high terraces and hilltops along the northeastern side of the valley in Lyon and Coffey counties. Gravel elevations range from 10 m to 50 m (33–160 ft) above the adjacent floodplain. These gravels contain occasional sandstone and petrified wood along with relatively common exotic pebbles.

Southwestern Coffey County. Broad upland distribution of chert gravel is found on high terraces and local divides west of the Neosho valley. Exotic pebbles are common.

Anderson and northwestern Allen counties. Chert gravel is preserved in the vicinity of the Missouri-Arkansas drainage divide in central Anderson County at elevations of 350–360 m (1,150–1,180 ft) (fig. 10). These gravels are remarkable for the high degree of chert-pebble roundness and for the abundance of exotic pebbles. The chert gravels extend on hilltops as a broad belt from the divide downward to the southwest. This gravel belt merges with the high-terrace trend along the northeastern side of the Neosho valley at an elevation of about 310–320 m (1,020–1,050 ft).

Lower Neosho River valley. Chert gravels occur along the western side of the valley in Woodson, Allen, and Neosho counties. High terraces are adjacent to and 10–20 m (33–66 ft) above the modern floodplain, whereas hilltop gravels form a discontinuous belt 30–40 m (100–130 ft) above and 6–8 km (3.7–5 mi) west of the valley. Exotic pebbles are found in both high-terrace and hilltop deposits.

Marais des Cygnes Drainage Basin

Well-defined belts of high-terrace and hilltop gravels are found along the northern margins of Marais des Cygnes River valley and tributaries in Osage and northeastern Lyon counties (figs. 2, 8). Gravel elevations range from 10 m to 40 m (33–130 ft) above adjacent floodplains. Exotic pebbles are not present in any gravels along the main Marais des Cygnes trend; however, a few exotics have been found in chert gravels on the Wakarusa-Marais des Cygnes divide in northwestern Osage County.

Verdigris Drainage Basin

Upland chert gravel is abundant in upper portions of the basin in southern Lyon and northeastern Greenwood counties (figs. 2, 8). Gravels are found north of the Verdigris valley and on the divide between the Verdigris and the Neosho and Cottonwood basins. Drainage-divide sites are as much as 80 m (260 ft) above and 6 km (3.7 mi) away from the Verdigris floodplain in northeastern Greenwood County. Exotic pebbles are common in these gravels.

In northeastern Greenwood County, the Verdigris River turns toward the south-southeast. Along most of this stretch, chert gravels bearing exotics are found west of the valley, and gravel occurs east of the valley in a few places. Near the junction with the Fall River, chert gravel caps the drainage divide between the two basins. Exotics are also found as isolated pebbles resting on bedrock terrain across north-central Greenwood County.

Fall Drainage Basin

Chert gravel deposits are preserved along much of the Fall River system (figs. 2, 8). Gravel elevations are highest in the headwaters of the Flint Hills at 440 m (1,440 ft), and lowest elevations are 250 m (820 ft) near the junction with the Verdigris River. For the most part, chert gravel is preserved on northern sides of the Fall River valley and its tributaries in Greenwood County. Downstream from Fall River Reservoir, gravel is found on both sides of the valley, and gravel is preserved south of the Fall River valley in southern Wilson County.

Interpretation of Ancient Drainages

Reconstruction of Ancestral Drainages

The ancestral drainage routes are represented by gravels that are highest in the local landscape and are unrelated to modern river systems (figs. 2, 8). Distribution of exotic pebbles is another important factor for reconstructing ancient west-to-east through-drainage routes. Four ancestral drainage routes may be recognized on these bases, from south to north (Aber et al., 1995) (fig. 2).

The ancestral Arkansas River flowed from the Wichita vicinity eastward across Butler and Greenwood counties into what is now the Fall River drainage basin (fig. 2). The exact position of the ancestral Arkansas is problematic. However, such a dispersal route is necessary to explain the presence of exotic pebbles in chert gravels in the headwaters of the Walnut River basin near the crest of the Flint Hills (fig. 11).

The ancestral Verdigris River flowed eastward across the central portion of the study region—Marion, Chase, Lyon, and Coffey counties (fig. 2). This through drainage is demonstrated by the belts of exotic-bearing gravels on the Verdigris-Cottonwood and Verdigris-Neosho drainage divides and across southern Coffey County, as well as by isolated exotic pebbles on hilltops of the Flint Hills.

The ancestral Neosho River came from the northeast, as evidenced by the broad belt of exotic-bearing gravel that slopes toward the southwest from the Missouri-Arkansas drainage divide in Anderson County (figs. 2, 12). Presumably, the ancestral Verdigris and Neosho rivers joined in the vicinity of southeastern Coffey or northwestern Allen counties, from whence the ancestral Neosho followed a path similar to, but west of, the modern Neosho River.

The ancestral Marais des Cygnes River originated in the Flint Hills region and flowed eastward across northern

Lyon and southern Osage counties (fig. 2). This local drainage is suggested by hilltop gravels north of the Marais des Cygnes valley, which do not contain exotic pebbles derived from west of the Flint Hills. A northern branch of the ancestral Marais des Cygnes is indicated by exotic-bearing chert gravels on the Wakarusa-Marais des Cygnes divide in northern Osage County. These rivers may have connected with the ancestral Neosho somewhere to the east.

These ancestral drainages bear no relation to many of the modern rivers, in particular the Walnut, Cottonwood, and upper Neosho. The prominent northwest-trending valley orientation of modern rivers is also not evident in the ancestral drainage pattern.

Geomorphic Implications of Ancestral Drainages

These ancestral drainage routes shed light on the geomorphic evolution of eastern Kansas south of the glaciated region. The fact that through drainages crossed the highest parts of the Flint Hills from west to east implies that alluvium of the Wellington-McPherson-Arkansas River Lowlands once extended eastward across what is now the Flint Hills (fig. 2).

The eastern edge of the Wellington-McPherson-Arkansas River Lowlands marks the divide between the Neosho-Cottonwood and Walnut basins to the east and the lower Arkansas drainage to the west (fig. 2). This edge has retreated westward, due to steeper gradients and more aggressive erosion in the headwaters of the eastern systems. At one time, the Arkansas alluvial plain must have sloped gently eastward. Isolated exotic pebbles on hilltops demonstrate the former extent of the alluvial plain. In like manner, the terrain east of the Flint Hills must have been considerably higher than today. For example, highest gravels of the ancestral Verdigris are preserved on the drainage divide in northeastern Greenwood County, at an elevation of 390 m (1,280 ft), 80 m (260 ft) above the modern Verdigris floodplain.

In previous studies, gravels on the Missouri-Arkansas divide in Anderson County were interpreted as an eastern extension of gravel trends along the Cottonwood and Neosho valleys (Frye, 1955; Aber, 1985). However, the regional slope of these gravels to the southwest argues strongly against this point of view. These gravels apparently represent a river flowing from the northeast. Origin of the headwaters for this stream is uncertain, as are the sources for exotics. The gravels are situated up to 70 m (230 ft) above regional floodplains.

At the time of deposition, chert gravels occupied the lowest topographic positions—stream channels—in the surrounding landscape. Preservation of exotic-bearing gravels in drainage-divide positions demonstrates a wholesale inversion of topography in eastern Kansas. Considerable erosion has taken place, such that former low points now occupy the highest positions in the local landscape. The minimum magnitude of vertical erosion can be estimated from the elevations of highest chert gravels in relation to present stream-valley floodplains in each drainage basin (table 1).

These figures indicate at least 40 m to 80 m (130–260 ft) of vertical erosion has taken place across eastern Kansas during the Quaternary. The figures are minimum estimates only; they do not take into account deeper valley erosion and aggradation (below floodplain level). River entrenchment has been greatest in the western Flint Hills (Walnut basin), immediately east of the Flint Hills (Verdigris basin), and in the Marais des Cygnes basin, where 70–80 m (230–260 ft) of downcutting is demonstrated. This pattern of erosion suggests that the Flint Hills may have emerged gradually as a bedrock massif, while terrains to the east and west were eroded down.

Drainage Diversions

The ancestral drainage routes were altered through a series of stream captures. The ancestral Arkansas was diverted in two stages, first into the Walnut River, and later to the modern Arkansas River south of Wichita (Aber, 1992). The ancestral Verdigris was likewise captured in at least two locations, and portions were diverted into the modern Verdigris River in northeastern Greenwood County and the South Fork Cottonwood River in southern Chase County (fig. 13). The upper portion of the ancestral Neosho and parts of the upper ancestral Marais des Cygnes were also involved with stream captures and drainage shifts. The ages of these (and other) captures are unknown. Thus, it remains impossible to reconstruct the exact sequence and timing of various drainage diversions in eastern Kansas.

Neotectonic Implications

During valley entrenchment, west-east rivers have migrated southward, and north-south streams have shifted eastward across nearly all parts of eastern Kansas. Valley asymmetry is highly systematic across a broad geographic region. This pattern is manifested both in the distribution of older upland gravel as well as by lower terraces and bedrock bluffs within modern valleys. These valley patterns are true for different hydrologic or geologic factors for individual rivers. Valley asymmetry is consistent regardless of direction or gradient of stream flow, valley width or depth, volume of discharge, channel bed or bank characteristics, or bedrock in the drainage basin. Only a few, local exceptions to the general pattern for valley asymmetry are known, such as the lower Walnut River and parts of the lower Fall and Verdigris rivers in the southernmost part of the study region.

This pattern of valley asymmetry has been noted before and several explanations considered (Aber, 1985), including Coriolis force, unequal input of sediment from tributary streams, and crustal tilting. Of these possibilities, it seems that slow, continuing crustal warping downward

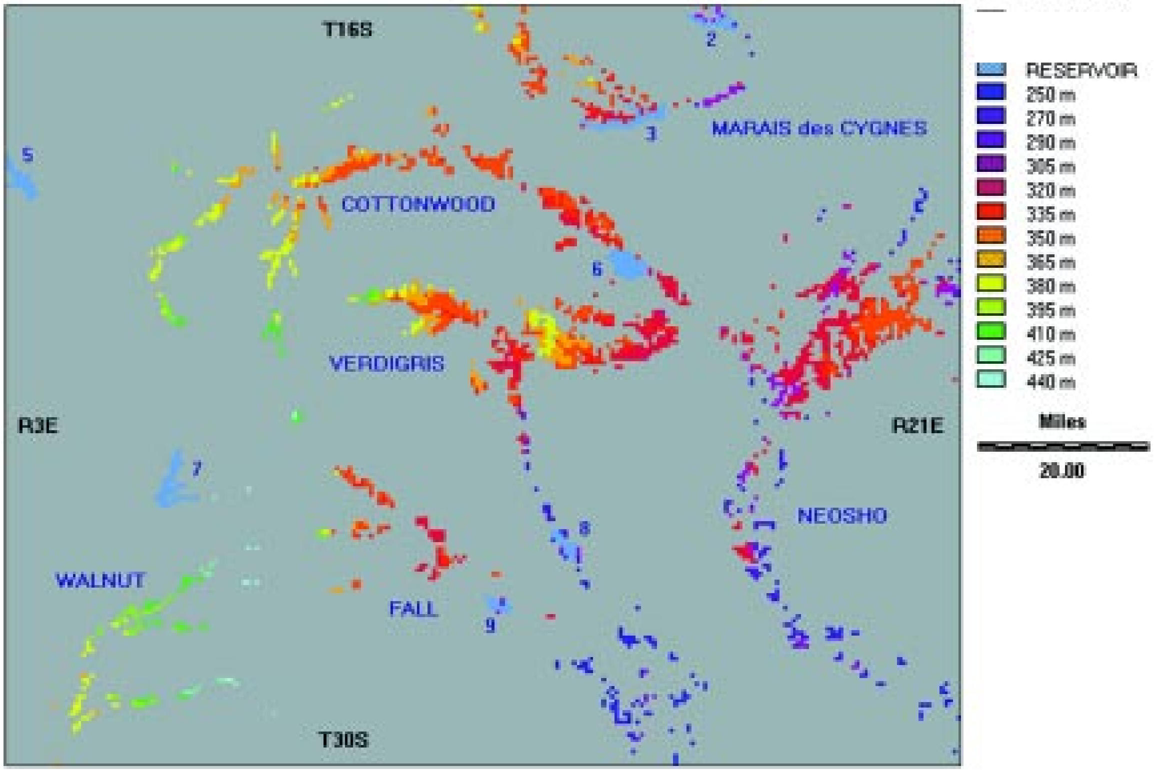

FIGURE 8. Raster grid of upland chert gravel deposits (Olpe soil) in eastern Kansas, according to township-and-range grid. Each pixel represents one quarter section in area (0.25 mile^2, 0.65 km^2); pixels are color coded according to elevation classes. Numbers indicate man-made reservoirs: 2 = Pomona, 3 = Melvern, 5 = Marion, 6 = John Redmond, 7 = El Dorado, 8 = Toronto, and 9 = Fall. See also fig. 2.

FIGURE 9. Exposure of hilltop chert gravel in Emporia, Kansas. The water tanks in background are situated on the drainage divide between the Neosho River and Cottonwood River valleys.

FIGURE 10. Neosho chert gravel deposits. Digital elevation model for parts of Anderson, Coffey, Woodson, and Allen counties. Detailed distribution of upland chert gravel (Olpe soil) outlined in black; elevation classes shown by color coding. Model has 90 m (300 ft) resolution; derived and corrected from DEM-24K; UTM coordinate system. Digital elevation model obtained from the Kansas Geological Survey—DASC. Image processing by R. Byerley and N. Wilkins.

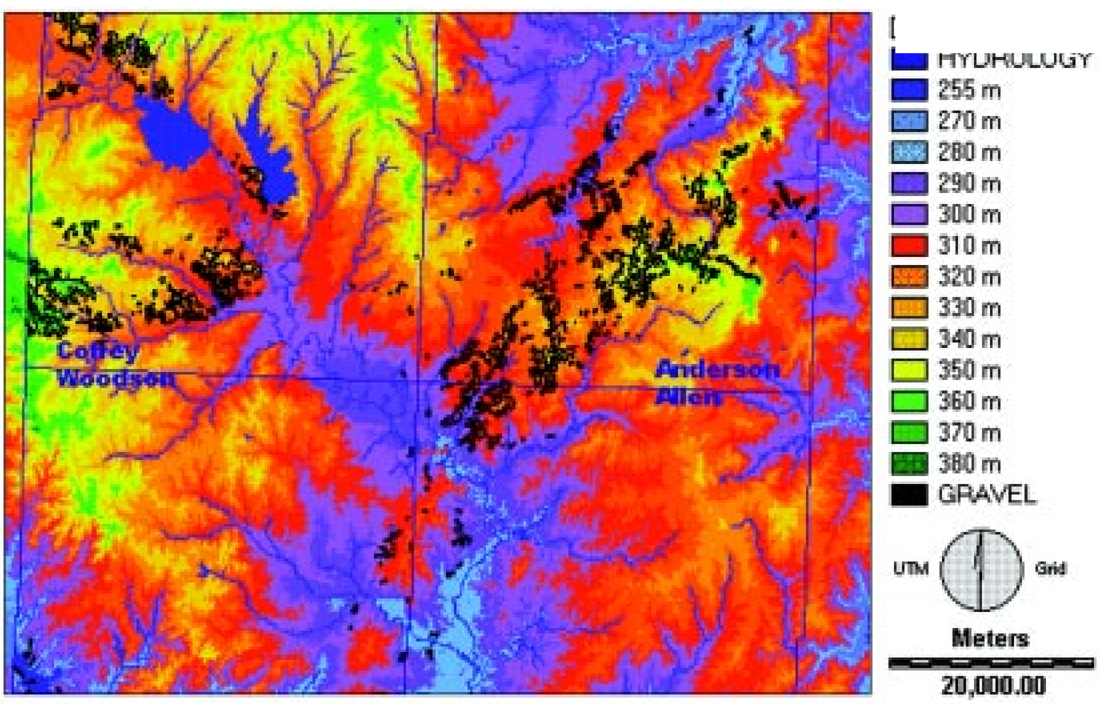

FIGURE 11. High-terrace chert gravel resting on Kinney Limestone, in headwaters of the Little Walnut drainage, near crest of Flint Hills [elevation, 450 m (1,475 ft) or more] in eastern Butler County. This terrace gravel contains exotic quartzite derived from the west. The presence of exotics here implies a reversal in drainage since the Miocene. Scale pole marked in feet.

FIGURE 12. Exposure of exotic-bearing chert gravel near the Missouri-Arkansas drainage divide in central Anderson County. The gravel is about 2 m (6 ft) thick in this section.

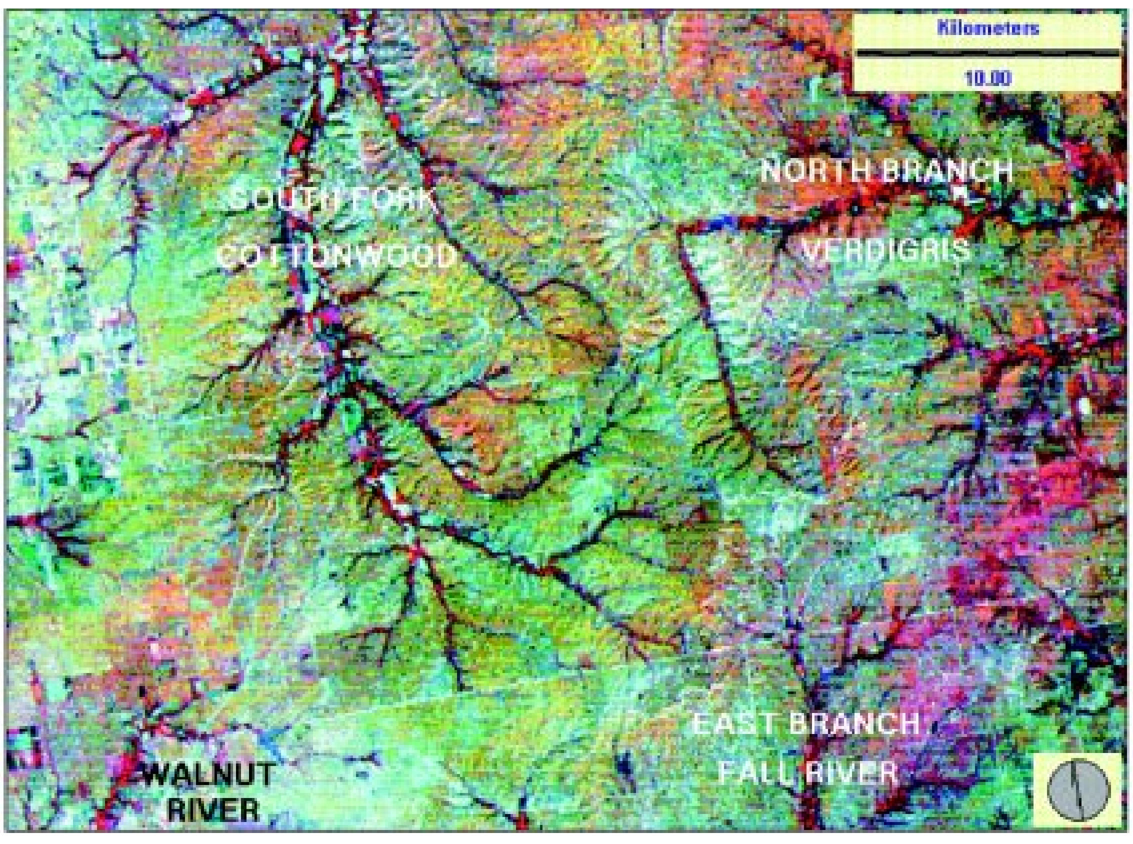

FIGURE 13. Landsat multispectral scanner (MSS) image of central Flint Hills region in southern Chase, northwestern Greenwood, and northeastern Butler counties. Standard false-color composite, in which active vegetation appears pink and red. Vegetation is active within valleys, and Flint Hills uplands appear in green-orange colors in this autumn image from a drought year. The abrupt change in direction of the upper North Branch Verdigris River is one of the most prominent drainage anomalies in Kansas. This anomaly is presumably a result of stream capture by the South Fork Cottonwood of the ancestral Verdigris. Note the alignment of headwaters for the North Branch Verdigris River and East Branch Fall River valleys. These two valleys are part of the Verdigris lineament trend at about 350° (Aber et al., 1997). Digital Landsat MSS data obtained from the EROS Data Center, U.S. Geological Survey.

TABLE 1. Minimum amount of vertical erosion in eastern Kansas drainage basins.

Drainage Basin	**Erosion**
Walnut	80 m (260 ft)
Verdigris	80 m (260 ft)
Marais des Cygnes	70 m (230 ft)
Neosho	50 m (160 ft)
Fall	50 m (160 ft)
Cottonwood	40 m (130 ft)

to the south and east toward the Gulf of Mexico is the only viable explanation on a regional basis (Aber, 1990). Local exceptions may result from differential movements in basement structures. However, crustal tilting and local structural movements remain impossible to verify through independent evidence. If such crustal tilting has occurred, it would have the effect of increasing gradients for streams that drain toward the south or southeast. Those streams, thus, would have an erosive advantage during dissection of the landscape. This may explain the predominance of drainage captures by streams flowing toward the south or southeast. It could also explain why northwest-trending valleys are so prominent in the modern landscape.

Conclusions

Based on this study of chert gravel, the following conclusions can be drawn: (1) The Flint Hills were much less prominent and did not form a major drainage divide during the Neogene. (2) Considerable erosion has occurred across all of eastern Kansas with up to 80 m (260 ft) of dissection during the Quaternary. The Flint Hills emerged at the same time as terrains to the east and west were eroded down. (3) Exotic pebbles in chert gravels of eastern Kansas were derived from Tertiary and Cretaceous sources west of the Flint Hills. (4) Modern rivers within the study region bear little resemblance to the oldest recognizable drainage routes. (5) Regional valley asymmetry may be the result of long-continuing crustal tilting downward to the south and east.

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