State Geological Survey of Kansas, Bulletin 86
1950 Reports of Studies, Part 5, Pages 105-140, Figures 1-3, Plate 1
October 31, 1950

ORIGIN AND ENVIRONMENT OF THE TONGANOXIE SANDSTONE IN NORTHEASTERN KANSAS

By

Thomas W. Lins

CONTENTS

ILLUSTRATIONS

TABLES

ABSTRACT

Study of lowermost deposits of the Virgilian Series (upper Pennsylvanian) in Leavenworth, Wyandotte, and Douglas Counties, northeastern Kansas, indicates localized development of sediment classed as belonging to the Tonganoxie sandstone member of the Stranger formation, which is the lowermost subdivision of the Douglas group in this region. The Tonganoxie rests disconformably on eroded upper Missourian strata consisting of evenly bedded shales and limestones.

The Tonganoxie sandstone mainly occupies and fills a wide, shallow, southwest-trending valley carved in the pre-Virgilian rocks. This valley, named Tonganoxie Valley, has a maximum width of nearly 20 miles and depth of 90 to 100 feet.

Four types of deposits are recognized in the Tonganoxie sandstone: (a) basal conglomerate, (b) sandstone, (c) shale, and (d) coal. The lithologic characters are stratigraphic relations of each of these types are described and interpreted. The filling of the Tonganoxie Valley is judged to have been accomplished by a southwest-flowing low-gradient river, named Tonganoxie River. In part, erosion and deposition in this area are concluded to have been contemporaneous.

INTRODUCTION

The purpose of this report is to show the origin, environment of deposition, and stratigraphic relations of the Tonganoxie sandstone in northeastern Kansas. The results of detailed sedimental and stratigraphic studies bearing on these problems are presented.

The Tonganoxie sandstone is the basal unit of the Upper Pennsylvanian Virgilian Series in parts of eastern Kansas. In the area studied, it consists mainly of a basal sandstone, overlain by shale and a thin coal bed. Evidence of several sorts, outlined in this paper, indicates that in country adjacent to the Missouri River, this sandstone was deposited in a broad river valley, some 14 to 20 miles wide, which extended southwestward from northwestern Missouri across northeastern Kansas. The sandstone is nonmarine and of fluviatile origin. Also, it is judged that the river which deposited the sand and associated finer sediments was very nearly at grade. The name Tonganoxie River is proposed for this Pennsylvanian river and the name Tonganoxie Valley is assigned to the valley in which sediment belonging to the Tonganoxie sandstone of this area was deposited. These names are used in the report.

A regional disconformity occurs at the base of the Virgilian Series throughout Kansas. The Tonganoxie Valley, 80 to 95 feet deep, was formed by erosion of the underlying Pedee and Lansing groups of late Missourian age. North and south of Tonganoxie Valley, the disconformity intersects formations of the Pedee group, whereas in the Tonganoxie Valley, it cuts deeply into units of the Lansing group.

Location of the Area

Strata assigned to the Tonganoxie sandstone member of the Stranger formation, Douglas group, crop out in northeastern Kansas in a belt 0.25 to 14 miles wide, extending from northeastern Leavenworth County to southern Douglas County (Pl. 1). This area lies within Ts. 8 to 14 S. and Rs. 19 to 23 E. The towns of Leavenworth and Vinland approximately define the northern and southern limits of the area included in this study. Other towns in the area are Basehor, Hodge, and Tonganoxie.

Method of Study

The months of June and July 1949 and various subsequent week-ends up to May 1950 were spent in Douglas, Leavenworth, and Wyandotte Counties examining available outcrops of the Tonganoxie sandstone. Topographic maps and aerial photographs were used for mapping. Collected samples were analyzed in the laboratory, using size analysis, heavy mineral separation, thin sections, and insoluble residues. Studies with binocular and petrographic microscopes were made where necessary. Well logs and other subsurface data were examined in an attempt to extend this study beyond the area of outcrop.

Topography of the Area

The bedrocks of northeastern Kansas, including the Tonganoxie sandstone area, comprise alternating sandstone, shale, and limestone of Pennsylvanian age. These beds dip slightly north of west, approximately 25 feet to the mile. Elevations above sea level range from 750 feet along Missouri River, at the east margin of the area studied, to 1,100 feet on the upland at the west margin of the area. Erosion has produced a series of cuestas whose east-facing fronts trend northeastward. The outcrop area is bounded at the west by a conspicuous escarpment capped by the Oread limestone. This formation rises 75 to 150 feet above the lowland east of it, which is underlain by rocks of the Douglas group. Erosion of the Oread escarpment has produced outliers which make prominent hills in the area. Blue Mound, in Douglas County, and Jarbalo Mound, in Leavenworth County, are excellent examples (Pl. 1). Throughout the area, the Haskell limestone member of the Stranger formation forms local low escarpments and outliers. These rise 10 to 30 feet above adjacent areas which are underlain by the shales and sandstones of the Stranger formation. Along Missouri River, various members of the Stanton limestone form small low east-facing escarpments. On the dip-slope plains between the Oread and Haskell escarpments and between the Haskell and Stanton escarpments, the Ireland and Tonganxoie sandstones have been eroded into low moundlike hills. Where pre-Ireland erosion has cut into the Tonganoxie sandstone and the Ireland sandstone is in contact with sandstone beds of the Tonganoxie, larger hills occur, reflecting increased thickness of sandstone. This condition exists south and west of Lansing in Leavenworth County. Glacial till has somewhat masked the escarpments in the northern part of the area.

Missouri River on the north and east and Kansas River on the south control drainage of the area. In the past, critical relief has been such that stream drainage reached grade and flood plains developed, while interfluve areas remained broad, flat, and relatively undissected. Rejuvenation has brought about minor intrenchment of all drainage. Missouri and Kansas Rivers and their main tributaries now seem to have adjusted themselves and are near or at grade, but minor tributaries still are undergoing adjustments.

Acknowledgments

Writing and field work were done under the direction of Professor H. A. Ireland, at the University of Kansas. Much assistance was given by Dr. R. C. Moore and Dr. J. M. Jewett, members of the Kansas Geological Survey, and by various staff members of the Department of Geology at the University of Kansas. Field studies were facilitated by the cooperation of various citizens of Douglas, Leavenworth, and Wyandotte Counties, who permitted gathering of data from water wells, coal mines, and outcrops. I express thanks to all of these persons.

The State Geological Survey of Kansas supplied available maps and permitted use of stratigraphic sections, well logs, aerial photographs, and unpublished field notes. Transportation and field expenses which were furnished by the Survey made this work possible.

The geologic map was compiled from unpublished geologic maps of the State Geological Survey of Kansas and by J. M. Patterson (1933), and from field work by me.

STRATIGRAPHY

Pennsylvanian strata in the northeastern Kansas area studied consist of upper Missourian rocks belonging to the Lansing and Pedee groups and lower Virgilian units assigned to the Douglas group (Table 1). The Douglas group is separated from beds of the underlying Missourian Series by a widespread disconformity. Detailed studies were confined to the Tonganoxie sandstone, the basal member of the Stranger formation of the Douglas group. Except for

Table 1. *Sequence of upper Pennsylvanian rocks in eastern Kansas*

- Pennsylvanian System
  - Virgilian Series
    - Wabaunsee group
    - Shawnee group
    - Douglas group
      - Lawrence shale
        - Amazonia limestone
        - Ireland sandstone

——————Local disconformity——————

      - Stranger formation
        - Robbins shale
        - Haskell limestone
        - Vinland shale
        - Westphalia limestone
        - Tonganoxie sandstone

——————Regional disconformity——————

  - Missourian Series
    - Pedee group
      - Iatan limestone[1]
      - Weston shale[1]
    - Lansing group
      - Stanton limestone
        - South Bend limestone[1]
        - Rock Lake shale[1]
        - Stoner limestone[1]
        - Eudora shale[1]
        - Captain Creek limestone

[1] Locally absent as result of post-Missourian pre-Virgilian erosion.

the Tonganoxie sandstone, the following summary is compiled from Moore (1949). Minor changes which apply to the area under discussion have been made.

Missourian Series

Various strata of the Lansing and Pedee groups of the Missourian Series underlie the Tonganoxie sandstone throughout the area. Knowledge of these strata is necessary in order to understand their relationship to Tonganoxie deposition. The stratigrpahic units are discussed in ascending order.

LANSING GROUP

Stanton limestone

Captain Creek limestone member.—The Captain Creek limestone is the oldest unit cut by the erosion surface on which the Tonganoxie sandstone rests. The Captain Creek limestone is composed of gray to dark-gray massive and evenly bedded limestone. The individual beds are more than 8 inches thick. In most exposures, the limestone has prominent vertical joints. *Enteletes pugnoides* Newell is abundant in northeastern Kansas and a robust fusulinid, *Triticites neglectus* Newell, occurs commonly on the bedding planes. Along Kansas River, the member ranges from 4.5 to 5.5 feet in thickness.

Eudora shale member.—The Captain Creek limestone is overlain by the Eudora shale. The lower part is black and fissile, but the upper part is light gray or greenish gray in most places. This black shale is an excellent stratigraphic marker. Megascopic fossils are rare in the Eudora shale of northeastern Kansas. The Eudora shale averages 6 feet in thickness.

Stoner limestone member.—This limestone overlies the Eudora shale and is light bluish gray to nearly white; it weathers very light gray or creamy white. Beds of the Stoner limestone weather into thin wavy layers with thin shale partings, although on freshly quarried surfaces it has an appearance somewhat like that of the Captain Creek limestone. To the north it contains abundant *Triticites* of the *T. irregularis* type. In uneroded sections this member is 11 to 15 feet thick.

Rock Lake shale member.—This shale overlies the Stoner limestone. The lower part is gray to greenish-gray clay shale, but in places it contains very thin silty calcareous partings. Some beds display prominent ripple marks. The upper Rock Lake shale is very sandy in places and locally grades into cross-bedded siltstone or sandstone. Marine fossils distinguish this sandy phase from the Tonganoxie sandstone in places where pre-Tonganoxie erosion has removed the South Bend limestone. Locally, this member contains remains of land plants, reptile bones, fish, and marine invertebrates. The thickness ranges from 5 to 10 feet.

South Bend limestone member.—The South Bend limestone is the uppermost member of the Stanton limestone. It lies conformably upon the Rock Lake shale and conformably beneath the Weston shale. It is a dark-gray to blue fine-grained limestone which occurs in beds more than 3 inches thick. The brachiopod *Meekella striatocostata* (Cox) and a fusulinid similar to *Triticites moorei* Dunbar and Condra are the most common fossils. The thickness is 2 to 3 feet.

PEDEE GROUP

The Pedee group consists of the Weston shale, below, and the Iatan limestone, above. This group conformably overlies the upper beds of the Lansing group and disconformably underlies beds of the Douglas group. Throughout much of Platte County, Missouri, and in the Kansas River Valley, the disconformity cuts out the Pedee group and extends downward into the Stanton limestone. Iatan limestone is present only locally to the north and south of these areas. Lower Douglas beds occupy the stratigraphic position of the Weston shale and Iatan limestone where the latter are missing.

Weston shale

The Weston shale includes strata between the top of the Stanton limestone and base of the Iatan limestone. Where the Iatan is missing, the top of the Weston shale is in contact with lower beds of the Douglas group.

The Weston deposits consist mostly of rather uniform dark-blue to bluish-gray marine shale containing several zones of subcylindrical ironstone concretions which lie parallel to the bedding planes. The thickness of the Weston shale is about 55 feet at Beverly Junction, Missouri, and about 70 feet at Vinland, Kansas. Post-Missourian erosion has removed most of the Weston shale in the intervening area.

Iatan limestone

The Iatan limestone overlies the Weston shale conformably and is overlain disconformably by basal deposits of the Douglas group. In the vicinity of Leavenworth, the limestone is light bluish gray to white, both on fresh and weathered surfaces. The bedding is somewhat uneven and indistinct, imparting a massive appearance.

Brachiopods, bryozoans, and crinoid fragments are the most common fossils.

Northeast of Vinland, in Douglas County, it seems that prolonged exposure during early Virgilian time greatly altered the appearance of the Iatan limestone. Here the Iatan is 0.5 to 3 feet thick and is weathered blue gray, light brown, or brown to reddish brown. Incrustations, dense nodules, and thin platy beds, separated by what seems to be residual material, are evidence of solution and downward movement of calcium carbonate which has been redeposited at lower levels. The appearance of the Iatan points to development of a soil during part of early Virgilian time, prior to deposition of the overlying beds.

Virgilian Series

DOUGLAS GROUP

The rocks of the Douglas group are divided into two formations: the Stranger (lower) and the Lawrence (upper).

Stranger formation

The Stranger formation consists of nonmarine and marine beds of the lower part of the Douglas group, extending upward to the disconformity at the base of the Lawrence formation. In northeastern Kansas, the top of the Haskell is defined as the upper boundary of the Stranger formation, because the Robbins shale member (uppermost Stranger of some areas) commonly is absent or cannot be identified there.

Tonganoxie sandstone member.—The Tonganoxie sandstone includes all strata from the disconformity at the base of the Stranger formation upward to the top of the Upper Sibley coal or the base of the Westphalia limestone member. It consists of a thin basal conglomerate, a sandstone, a shale, and at the top, a coal (Upper Sibley coal). Since the character and origin of the Tonganoxie member are the subject of this paper, this part of the Stranger formation will be discussed in detail subsequently. The Tonganoxie member ranges in thickness from 4 to 100 feet in the northeastern Kansas area.

Westphalia limestone member.—In northeastern Kansas, a carbonaceous laminated dark-blue limestone has been identified tentatively as equivalent to the Westphalia limestone of southern Kansas. This dark-blue limestone is widespread throughout the area, occurring 3 to 4 inches above the top of the Upper Sibley coal. A calcareous zone marks its position where the limestone is not well developed. The limestone contains abundant small gastropods and ostracodes in northern Leavenworth County. Ostracodes are the only invertebrate fossils found in this bed in Douglas County, but plant remains are common almost everywhere.

The Westphalia limestone of southern Kansas is characterized by the presence of abundant fusulinids. Faunally and lithologically, the dark-blue limestone occurring persistently next above the Tonganoxie sandstone in northeastern Kansas seems to be a brackish water deposit. Because it occupies the same stratigraphic position as the type Westphalia limestone, the dark-blue limestone is reasonably interpreted as the near-shore equivalent of the off-shore fusulinid-bearing Westphalia limestone of southern areas. The gastropods found in the presumed Westphalia of Leavenworth and adjacent counties may be fresh-water forms. In the areas where the Upper Sibley coal is poorly developed, the bed identified as Westphalia limestone makes an excellent stratigraphic marker for defining the top of the Tonganoxie sandstone member. The Westphalia in northeastern Kansas ranges from 0.3 to 1 foot in thickness.

Vinland shale member.—This shale conformably, and in some places disconformably, overlies the Upper Sibley coal and the Westphalia limestone. It contains variable thicknesses of clayey to sandy shale and sandstone. Except locally, the Vinland deposits are entirely marine. The shale is blue gray and light brown. The sandstone and siltstone beds are light brown to brown. Near the town of Tonganoxie, along U. S. Highway 40 (SE cor. sec. 2, T. 11 S., R. 21 E.), and 2.5 miles south of Lawrence (Cen. E. line sec. 25, T. 13 S., R. 19 E.), the Vinland contains silty and massive sandstones up to 12 feet thick, which occur in the top part of the member. In other places where these silts and sandstones occur at the base of the Vinland shale, the underlying Upper Sibley coal and Westphalia limestone commonly are missing. Excellent plant fossils, but no invertebrates, were found in the lower sandstone zones. The upper sandstone and shale grade into the overlying marine Haskell limestone. The thickness of the Vinland shale in northeastern Kansas ranges from 7 to 25 feet.

Haskell limestone member.—The Haskell member is a very persistent limestone which lies conformably on the Vinland shale member. The lower beds of the Haskell are sandy and contain abundant pelecypods. In northeastern Kansas, there are local thin coquinoidal beds composed of fragments of brachiopods, pelecypods, and crinoids. At some places fusulinids are abundant. The main part of the Haskell is a bluish-gray blocky fine-grained limestone. The Haskell is 2 to 4 feet thick at most outcrops.

Robbins shale member.—Throughout most of Leavenworth and Douglas Counties, the Ireland sandstone rests directly on the Haskell limestone or on older strata, but south of Lawrence, near Baldwin, the Ireland sandstone rests on the Robbins shale. Here, the Robbins shale is a gray argillaceous silty shale which contains a zone of ellipsoidal phosphatic concretions at the base. These concretions contain ammonoid cephalopods and fish brain casts. Near Baldwin, the Robbins shale is 1 to 5 feet thick, but southward it thickens to 100 feet.

Lawrence formation

The Lawrence formation includes strata from the top of the Haskell limestone to the base of the Oread formation. The disconformity at the base of the Ireland sandstone member marks the lower boundary of the Lawrence formation. Where the Robbins shale is absent or not recognized, and the Ireland seemingly rests conformably upon the Haskell limestone, the top of the Haskell limestone is designated as the base of the Lawrence formation.

Ireland sandstone member.—The disconformity at the base of the Ireland sandstone locally cuts through the Robbins shale, Haskell limestone, and Vinland shale into the Tonganoxie sandstone. Where the latter is thin, the disconformity at the base of the Ireland may cut through the Tonganoxie into the Weston shale or the Stanton limestone. The Ireland sandstone is light to reddish brown, typically containing disseminated iron compounds, which impart a speckled appearance upon weathering. The sandstones are thin-bedded to massive and in places cross-bedded. Where the Ireland rests on deeply eroded Haskell limestone, the sand is cemented by calcium carbonate. Heavy minerals are common throughout the Ireland sandstone. The thickness of the Ireland sandstone ranges from 3 to 80 feet in northeastern Kansas.

Amazonia limestone member.—This limestone, which is found elsewhere in the upper part of the Lawrence formation, is not recognized in the Leavenworth and Douglas County area.

STUDY OF THE TONGANOXIE SANDSTONE

Previous Work

Early workers (Bennett, 1896; Hall, 1896; Haworth, 1896), in their sections across Kansas, described the basal sandstone of the Lawrence shale as resting upon strata now classified as beds of the Pedee group. Hinds and Greene (1915) described the basal sandstone as a wide channel fill, unconformably overlying various formations now classed as parts of the Lansing and Pedee groups. A study of the physical characteristics of the sandstone by Moore (1931) indicated a flood-plain type of deposit. Patterson (1933) compiled much information on the lithology and stratigraphic relations of the sandstone, known then as the Stranger sandstone and as the basal member of the Stranger formation. The sandstone was named Tonganoxie sandstone in 1934 (Moore, Elias, and Newell). Moore (1936) summarized all information available in 1936 and described lithology, stratigraphic relations, the pre-Tonganoxie erosion surface, and a possible origin and environment of deposition of the Tonganoxie sandstone. Bowsher and Jewett (1943) published results of studies on coal beds of the Stranger formation and described many characteristics of the Tonganoxie sandstone.

General Statement

The Tonganoxie sandstone represents the filling of a large southwest-trending valley, here termed the Tonganoxie Valley, a major feature of the regional disconformity which separates the Pedee group or older beds (Missourian) from the overlying Douglas group (Virgilian). A generalized paleogeologic map of the floor and sides of this Pennsylvanian valley is shown in Figure 1, and a cross section of the valley is given in Figure 3. Both of these illustrations indicate the presence of late Missourian strata extending along the floor and sides of the valley. This is determined from observations of the rocks which occur next below the Tonganoxie sandstone in various places. The pattern shown by the strata was formed by the cutting of the Tonganoxie Valley into the relatively

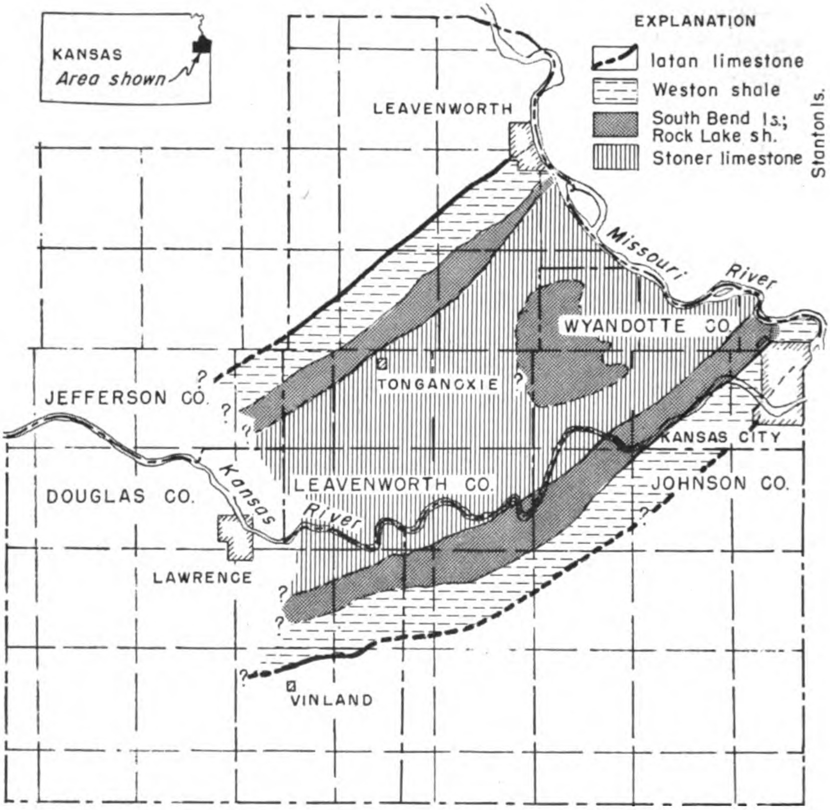


Fig. 1.—Generalized geologic map of the disconformity at the base of the Tonganoxie sandstone.

flat-lying Stanton limestone and formations of the Pedee group. The valley floor in various places is directly underlain by the Stoner limestone, Rock Lake shale, or South Bend limestone (the three upper members of the Stanton limestone). The sides of the valley are formed by the Weston shale and the divides are held up by the Iatan limestone (formations of the Pedee group). Unreliable subsurface data prevented tracing of the valley beyond the Tonganoxie sandstone outcrop area.

Present outcrops closely parallel the old Tonganoxie Valley (Pl. 1), because the north-northeast regional strike nearly coincides with the trend of the valley and because post-Pennsylvanian erosion has stripped away Virgilian (and possibly Permian and

Cretaceous) deposits which covered this region before development of the present land surface. In the past, knowledge of the stratigraphy and sedimentation of the Tonganoxie sandstone has been retarded by the failure to recognize that the present outcrop is approximately parallel to the old Tonganoxie Valley and is not at right angles to the direction of the source of sediment.

The depth of erosion of the Tonganoxie Valley can be ascertained in two ways; by compiling thicknesses of eroded formations from measured sections in near-by areas, and by measuring the maximum thickness of the Tonganoxie valley fill (Tonganoxie sandstone).

The thickness of stratigraphic units which were removed during erosion of the Tonganoxie Valley are: Stoner limestone, 4 feet; Rock Lake shale, 8 feet; South Bend limestone, 10 feet; Weston shale, 60 feet; and Iatan limestone, 2 feet. Only in a few places has erosion cut to the top of the Captain Creek limestone. These are average thicknesses which add up to 84 feet; 90 feet is an approximate figure for the maximum depth of valley erosion.

No complete sections of the Tonganoxie sandstone are exposed and the thickness, therefore, is determined from composite sections. Thicknesses of 85 feet for the sandstone unit and 20 feet for the shale unit indicate 85 feet of valley fill. Due to numerous variations in the thickness of the conglomerate and the coal units and variations in the depth of valley erosion, a maximum thickness of 80 to 100 feet of valley fill is a better estimate. On divides adjacent to the valley, the Upper Sibley coal is found 3 to 10 feet above the Iatan limestone. This indicates that the Tonganoxie sandstone filled the entire valley and overlapped the divides slightly. The figures of 80 to 100 feet of maximum valley fill and 80 to 95 feet of maximum valley erosion are comparable.

Lithology of the Tonganoxie Sandstone

The Tonganoxie sandstone contains four distinct lithologic units, which (in ascending order) include conglomerate, sandstone, shale, and coal.

CONGLOMERATE UNIT

The constituents of the conglomerate unit are: (1) pebbles of limestone, siltstone, and claystone; (2) reworked invertebrate fossils; (3) plant fragments; (4) quartz sand and silt; and (5) limonite, clay calcite, and siderite cement.

Spaces around the pebbles are filled in by quartz sand and silt, plant material, and shale. A few shale and sandstone partings occur locally. Limonite, clay, calcite, and traces of siderite cement the conglomerate into a hard mass.

The limestone, siltstone, and claystone pebbles range in diameter from 5 to 50 mm, 20 mm being average. The limestone and siltstone pebbles are well rounded and the claystone pebbles are compressed. They are poorly sorted and show no clearly marked orientation denoting currents which distributed them. Limestone pebbles are light brown, gray, blue gray, dense, and fine-grained. On weathered surfaces, iron oxides give a reddish color to the pebbles. The siltstone pebbles, although well rounded, are slightly elongated. This is due in part to derivation from thin-bedded siltstone layers and in part to a small amount of compaction. The siltstone pebbles show various shades of brown and red, due to staining by limonite and hematite.

The siltstone pebbles, together with the compressed claystone pebbles, are identical in color and lithology to the associated siltstone and shale of the Tonganoxie sandstone. Their origin can be attributed to reworking of beds of the Tonganoxie member, as discussed later.

Abundant plant fossils occur throughout the conglomerate, seemingly at random, either as carbonized material, molds, or im-

TABLE 2.—*Representative analyses of the Tonganoxie sandstone*

Size	Percent sand by weight	Percent mica by volume
	Festooned cross-bedded sandstone	
0.50 - 0.25 mm		Trace large flakes
0.25 - 0.125 mm	44.40	1.0
0.125 - 0.0625 mm	42.20	0.3
Below 0.0625 mm	13.40	Trace
	Very fine silty sandstone (thin-bedded)	
0.50 - 0.25 mm	0.87	90.0
0.25 - 0.125 mm	33.00	25.0
0.125 - 0.0625 mm	22.60	20.0
Below 0.0625 mm	43.53	20.0

prints. Some plant fragments are 4 feet long and have compressed diameters of 5 inches.

The conglomerate unit occurs widely at the base of the Tonganoxie sandstone, where it rests on various members of the Stanton limestone and locally on the Weston shale. The thickest, best-developed conglomerate occurs in the northeastern part of the Tonganoxie Valley. A good outcrop can be seen along U.S. Highway 73, 0.5 mile north of Victory Junction, in southern Leavenworth County. In many small areas, the conglomerate is missing, as might be expected in a valley-fill type of deposit. Where the conglomerate is absent, the sandstone unit of the Tonganoxie member rests directly on Missourian rocks.

SANDSTONE UNIT

Texture.—The sandstone unit comprises almost three-quarters of the sediment of the Tonganoxie member. Colors generally range from light to dark brown. Iron oxide occurs throughout as a stain and as cementing material, imparting a variety of colors to the sandstone. Mechanical analyses of two representative samples are given in Table 2. The sand is composed largely of quartz grains ranging in size from one-sixteenth to one-fourth mm. Grains more than one-fourth mm in diameter are scarce and consist mostly of mica flakes. From 10 to 40 percent of the sandstone consists of quartz silt. The proportions of silt, very fine sand, and fine sand vary both laterally and vertically. Muscovite is present throughout. Results of sieve analyses, shown in Table 2, bear out the field observation that as the proportion of larger size sand grains increases, the amount of muscovite decreases; and, conversely, as the proportion of larger size sand grains decreases, the amount of muscovite increases. Although not shown in Table 2, the muscovite flakes having largest diameter occur among the coarser sands. This relationship of amount and size of mica flakes to coarseness of the sand reflects the competency of currents which transported the material, and is therefore a significant feature of the sandstone. A considerable amount of muscovite is present on the bedding planes of the siltstones and imparts a lamellar appearance; carbonaceous material produces the same effect in other siltstone beds.

Composition.—Quartz constitutes more than 95 percent of the sand grains, which are angular to subangular. Binocular examination and petrographic study of thin sections reveal that on many grains angularity has been accentuated by secondary quartz growth. Many such grains, exhibiting small crystal faces, have uniform extinction under crossed nicols.

Muscovite, clay, limonite, and a few grains of tourmaline comprise most of the remaining 5 percent of the detrital material. Small amounts of chlorite occur, which probably represent minor amounts of original biotite (Lee and Payne, 1944, p. 90). Muscovite in sufficient quantity to form 25 percent of the detrital material occurs in some beds. Argillaceous layers and the valley shale remnants within the sandstone unit are composed largely of clay minerals. Light-brown interstitial clay is universally present, and serves as a weak cement. Limonite occurs in small grains and as cementing material. Tourmaline is rare; grains of this mineral were found only after large quantities of Tonganoxie sediment had been separated in bromoform. Plant material and ironstone concretions occur in zones indiscriminantly distributed through the sandstone unit. Where the basal conglomerate is absent and the sandstone unit rests on limestones of the Stanton formation, the sandstone is cemented by calcite and is gray rather than brown.

Stratification.—Deposition of the sandstone unit produced three types of stratification: (1) festooned cross-bedded siltstone and sandstone; (2) massive-bedded siltstone and sandstone; and (3) thin-bedded argillaceous siltstone, sandstone, and silty shale. The composition of these types is essentially identical, except for the greater amount of fine material in the thin-bedded type.

Festooned cross-bedding was first described by Knight (1929) in the Fountain and Casper formations of Wyoming. It consists of numerous cut and fill structures, each cut being an elongate trough which is closed at the upstream end and open at the downstream end. The fill consists of oblique crescentic laminae which occupy the trough from its head to downstream end, thus forming a narrow elongate cross-laminated lens. In the Casper formation and also in the Tonganoxie sandstone, such cross-bedded lenses occur in nested groups, each lens truncating the subjacent and adjacent lenses, and in turn truncated by the superjacent lenses. The overall appearance is that of a nested group of cut and fill structures. The Tonganoxie beds exhibiting festooned stratification rest on eroded members of the Stanton limestone. The festooned cross-bedding of the Tonganoxie sandstone is not as well developed and is on a smaller scale than that described by Knight. The oblique laminae are shorter, and presumably owing to weaker current action during Tonganoxie sedimentation, large cut and fill structures, which Knight interpreted as marine cross-bedding, did not develop.

The trough-shaped channels containing the oblique laminae are as much as 20 feet long and are 6 to 8 feet wide. The laminae, which are 0.5 to 3 inches thick, have dip angles of as much as 30 degrees. Generally these laminae are 2 to 6 feet in length. All oblique laminae are concave upward, truncated at the top, and tangent to the base of the lens which they form. Many of the oblique laminae of sandstone and siltstone alternate with thin micaceous and carbonaceous silty to shaly laminae.

Directions of dip of the cross-bedded oblique laminae range from north through west to south. Since cross beds produced by river currents generally dip downstream, the most common direction of dip indicates the down-valley trend. This most common dip direction of the Tonganoxie oblique laminae is west-southwest to southwest. Therefore, the axis of the Tonganoxie Valley is judged to have extended in this direction.

The massive-bedded type of stratification consists of siltstones and sandstones which contain excellent examples of the sedimentary phases described by Gilbert (1914). These are (1) thin beds of the first phase of smooth traction, (2) cross beds of the first dune-rippled phase, and (3) thin beds representing a return to first phase smooth traction.

The massive-bedded stratification grades downward and laterally into festooned stratification and upward and laterally into the thin-bedded type. An excellent example of massive bedding can be seen along a creek in Douglas County, just north of the Cen. E. line sec. 26, T. 13 S., R. 21 E.

The thin-bedded type of stratification is best developed along margins of the Tonganoxie Valley. Throughout the area, this type occurs at the top of the sandstone unit and grades into the overlying shale unit. This stratification is characterized by thinness of the beds and their high content of mica and carbonaceous material.

Abnormally thick sections of shale, to 60 feet thick, occur locally in the Tonganoxie member. (Fig. 3, sec. C-C′, column 2). The lower part of these shales grades laterally into the sandstone unit of the Tonganoxie, but the upper part of the shales belongs to the shale unit. Since the lower shales are stratigraphic equivalents of

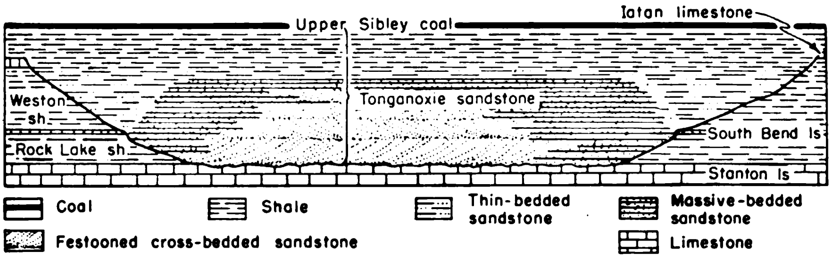


FIG. 2.—Diagrammatic cross section showing relation of Tonganoxie sandstone to Tonganoxie Valley.

the sandstone unit and seem to have been deposited contemporaneously with the sands of the sandstone unit, they are here termed "valley shales." These valley shales occur as isolated remnants in the Tonganoxie Valley.

The valley shales are even-bedded, blue gray to dark blue, and contain zones of ironstone concretions. Interbedded with the shales are numerous thin siltstone and sandstone beds with well-developed ripple marks. Some thin coals (Lower Sibley) are contained in the valley shale.

The sandstone unit of the Tonganoxie thins from 65 feet in the main channel area to 5 feet along the margin of the Tonganoxie Valley. As shown in Figure 2, the festooned cross-bedded and massive-bedded siltstones and sandstones occur in the lower and central parts of the valley where the sandstone unit is thickest and grade laterally and upward into the thin-bedded sandstone type which characterizes the margins of the valley (Fig. 3, sec. C-C′).

SHALE UNIT

The shale unit of the Tonganoxie grades upward from and overlies sediments of the thin-bedded type throughout the Tonganoxie Valley. It consists of two distinct phases, silty shale and clay shale. The silty shale is highly micaceous and ranges in color from light brown to dark red or brown. Fine carbonaceous material and fossilized plant fragments are abundant throughout. No marine fossils have been observed.

The clay shale is light bluish gray to dark blue and contains minor amounts of mica. The shale is sticky to firm, and in many zones fracture surfaces exhibit slickensides. The shale is even-bedded, individual layers reaching an inch in thickness. Bands of hollow and solid ironstone concretions are common. Plant fragments are especially abundant in shale beneath the thin coal beds and in equivalent intervals where accumulation of plant material was insufficient to form a coal bed.

The shale unit is commonly silty where it overlies the festooned cross-bedded sandstone of the valley and where the lower part of the overlying Vinland shale is sandy. The thickness of the shale unit ranges from 10 to 25 feet.

COAL UNIT

The Upper Sibley coal is designated as the coal unit of the Tonganoxie member. This coal bed is the uppermost stratum of the Tonganoxie and can be correlated throughout the Tonganoxie Valley. The Upper Sibley coal maintains a fairly constant stratigraphic position across the valley from north of Leavenworth to Vinland, in Douglas County (Pl. 1). Identification of the lateral continuity is strengthened by the presence of the overlying dark-blue limestone, which is correlated with the Westphalia limestone.

The Upper Sibley coal varies in thickness. At some places the coal is represented by a thin shale containing plant fossils. Elsewhere, the coal is a fairly pure bed which increases in thickness to an observed maximum of 20 inches near the town of Tonganoxie. The average thickness is about 8 inches. Stems, leaves, and trunks are preserved either as molds or as carbonized material; limbs and trunks exhibit leaf scars and limb attachment marks. The plant molds are found at the basal contact of the coal. Upper and lower parts of the coal have shale partings but the central part is generally a well-developed coal, free from clay. No underclay has been observed and roots or trunks were not observed in place. Ironstone and rare calcareous and pyrite concretions occur widely under the coal zone. The percolation of ground water through the coal has somewhat altered the subjacent shale.

The upper part of the Upper Sibley coal grades through 3 to 4 inches of calcareous carbonaceous shale into a carbonaceous argillaceous laminated limestone which has been correlated with the Westphalia limestone of southern Kansas (Moore, 1949). In northern Leavenworth County, abundant small high-spired gastropods occur in the gradational beds and in the lower part of the West-

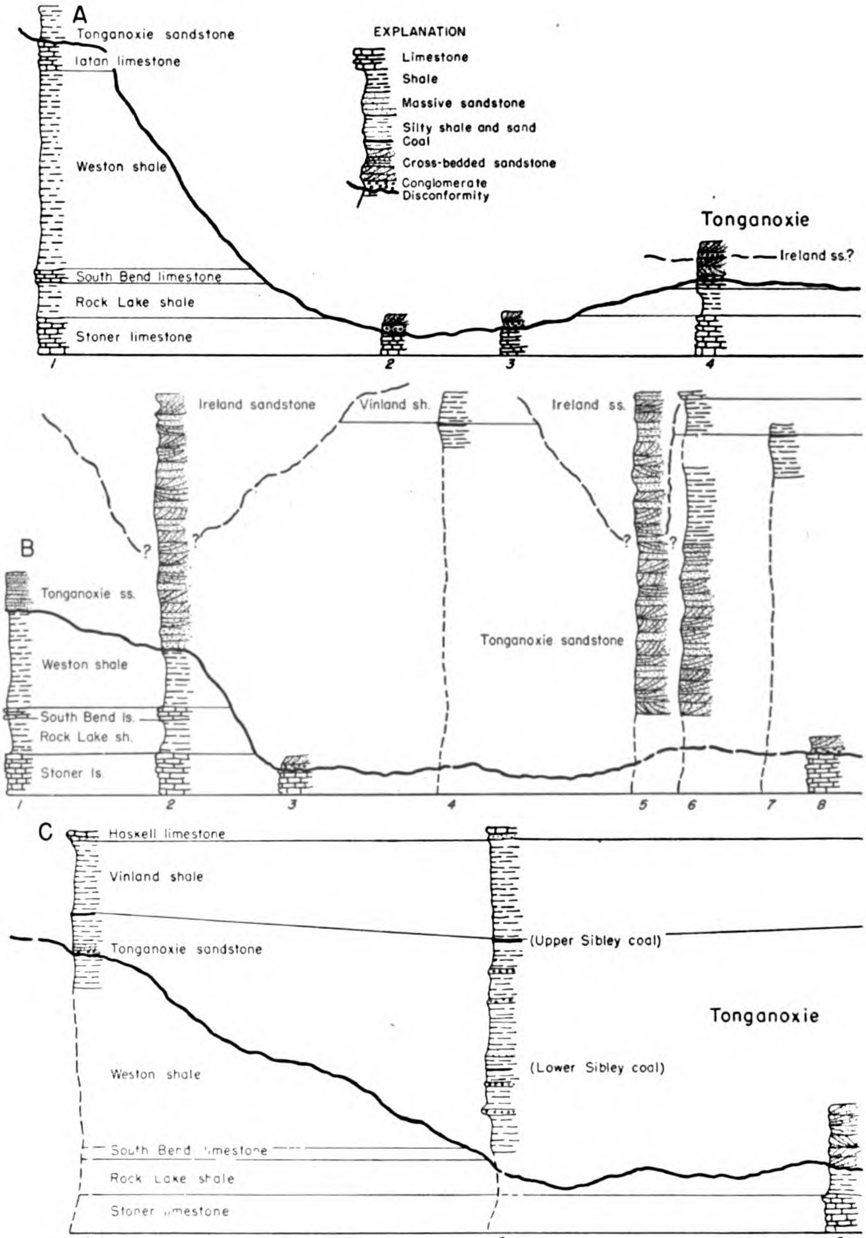
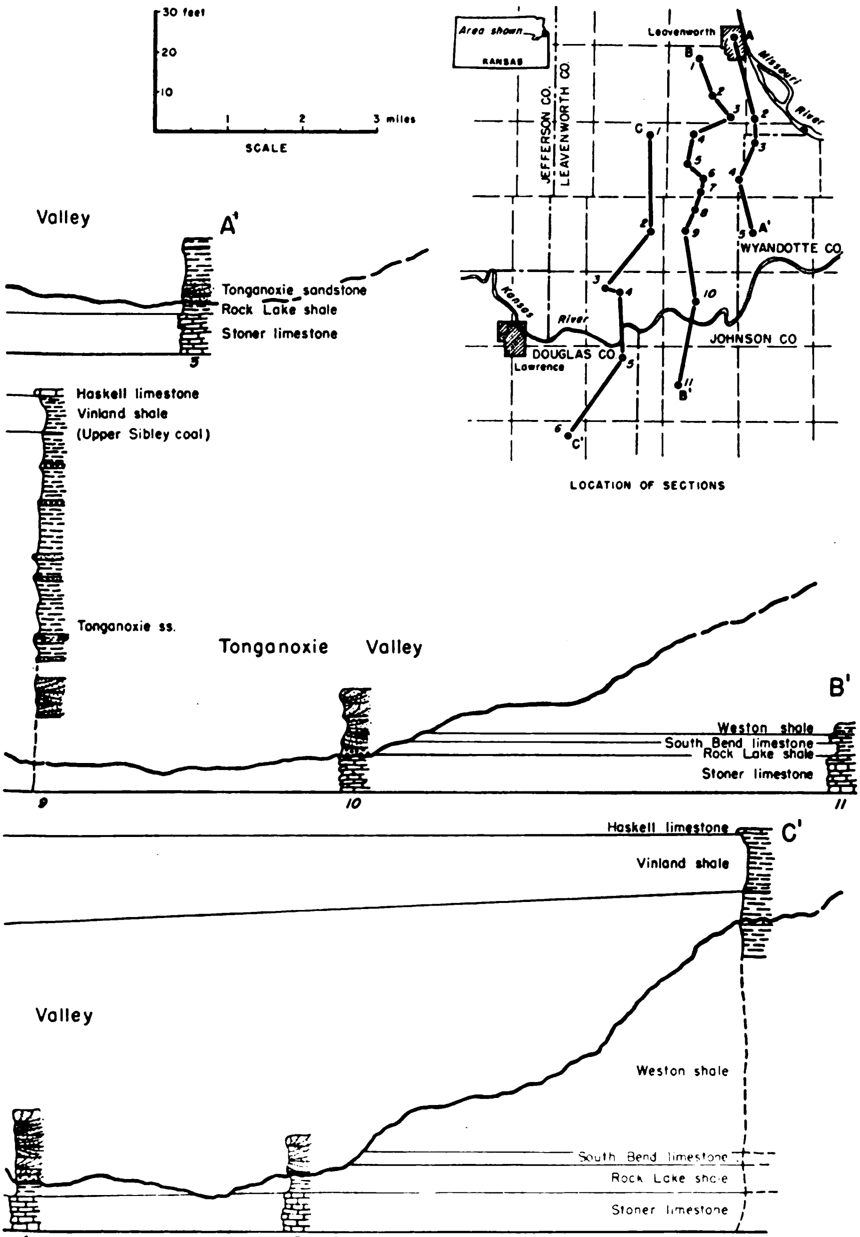


FIG. 3.—North-south cross



sections across Tonganoxie Valley.

phalia limestone. Excellent impressions of tree trunks, limbs, and leaves are preserved throughout the limestone. Where the Upper Sibley coal is not identifiable or is absent, the base of the Westphalia limestone can be used as the upper stratigraphic boundary of the Tonganoxie sandstone.

Other bituminous coal beds occur below the Upper Sibley in the shale and sandstone units of the Tonganoxie sandstone. In general, these beds are thin and laterally not extensive. Except for the Lower Sibley coal, correlation from area to area is difficult.

The Lower Sibley coal is contained in valley shales which are lateral equivalents of the sandstone unit. Since these valley shales are isolated remnants surrounded by sandstones of the sandstone unit, correlation of the Lower Sibley coal is based on stratigraphic position. Valley shales containing the Lower Sibley coal are exposed on the Sumner farm in the NW cor. sec. 24, T. 11 S., R. 21 E. and at Blue Mound (Douglas County) on the S. line sec. 21, T. 13 S., R. 20 E.

Within the sandstone unit, the thin coal beds are preserved mostly in local lenticular remnants of valley shale, but such occurrences are not common. A thin local bed occurs north of Bonner Springs at the Cen. S. line sec. 17, T. 11 S., R. 23 E. The stratigraphic relationship is shown on Figure 3 (column 5, sec. A-A').

Relations of the Tonganoxie Sandstone to Overlying Beds

Normally in northeastern Kansas, the Upper Sibley coal is stratigraphically overlain by the Westphalia limestone, Vinland shale, Haskell limestone, and Ireland sandstone. However, the Ireland sandstone in most localities rests disconformably on the Haskell limestone and older strata. Locally throughout the area, erosion which is recorded by the disconformity reached the sandstone unit of the Tonganoxie member; subsequent deposition of the Ireland resulted in a very thick section of sandstone. Therefore, an understanding of the relation of the Ireland and Tonganoxie sandstones is important to study of geology in the area.

Haworth (1894, p. 122), in naming the Lawrence shale, miscorrelated the limestone now called Haskell with the Iatan limestone. Hall (1896), Haworth (1896), and Hinds and Greene (1915) recognized only one sandstone body in the section. Hall and Haworth recognized the shallow-water characteristics of the basal sandstone member of this sequence but did not observe the large stratigraphic erosional surface on which the sandstone was deposited. Later detailed stratigraphic work by members of the State Geological Survey of Kansas revealed upper and lower sandstone bodies, resting unconformably on older formations and in places one on the other. The upper sandstone (above the Haskell limestone) was named Ireland (Moore, 1932) and was classified as the basal member of the Lawrence shale. The lower sandstone (below the Haskell limestone and above the true Iatan), locally in contact with various members of the Stanton limestone, was named Tonganoxie sandstone (Moore, Elias and Newell, 1934) and was regarded as the basal member of the Stranger formation.

The Ireland sandstone rests disconformably upon the Stranger formation in most localities. Lithologically, the Ireland sandstone is indistinguishable from the basal member of the Stranger formation, the Tonganoxie sandstone. The Ireland generally is more reddish, owing to its higher iron oxide content, but this distinction cannot be used over wide areas. In places, the pre-Ireland erosion and the deposition of the Ireland sandstone directly on the sandstone unit of the Tonganoxie resulted in thick sections of sandstone which have been mapped previously as Tonganoxie sandstone. Examples are in the vicinity of Hodge, Leavenworth County. Combined sections of Ireland and Tonganoxie sandstone 100 to 150 feet thick occur locally throughout the area. A few of these thick sandstone sections contain a conglomerate of siltstone and mud balls cemented by clay and calcium carbonate. The conglomerate probably marks the contact between the two sandstone bodies. An excellent example of such a conglomerate is seen in an outcrop west of the railroad track along the N. line sec. 36, T. 10 S., R. 22 E. Well-defined Ireland sandstone is found to the west of this outcrop, the Haskell limestone is absent, and the obviously greater abundance of disseminated iron in the sandstone above the conglomerate indicates that the conglomerate probably marks the contact between the Ireland and Tonganoxie sandstones.

Laterally, the lower part of the Ireland sandstone may be found at the same stratigraphic level as shales of the Tonganoxie sandstone member and seems to grade into them. Failure to recognize the upper sandstone as Ireland and the shales as Tonganoxie has retarded understanding of the origin and environment of both the Tonganoxie and Ireland sandstones.

Field work has shown that in practically all sections where the Haskell limestone is present, the Upper Sibley coal occurs 7 to 18 feet below its base. Where sandstone occupies this interval the Haskell limestone is absent. Absence of the Haskell limestone and the Upper Sibley coal in near-by areas and the presence of sandstone at the same stratigraphic horizon definitely identify the sandstone as Ireland. This points to deep post-Haskell erosion prior to deposition of Ireland sandstone.

Sedimentary Origin and Environment of the Tonganoxie Sandstone

GENERAL STATEMENT

As shown in Figures 1 and 3, the Tonganoxie sandstone occupies a southwest-trending valley, 14 to 20 miles wide and 80 to 100 feet deep. The prevalent southwesterly dip of laminae in the festooned cross-bedded sandstone indicates that the Tonganoxie River flowed from northeast to southwest.

DISCONFORMITY

The regional disconformity at the base of the Virgilian Series, of which the disconformity at the base of the Tonganoxie sandstone is a part, denotes a time of widespread retreat of the Pennsylvanian sea in the midcontinent region. Post-Missourian folding in the southwestern part of the midcontinent suggests that the regional disconformity was not due entirely to a eustatic change of sea level. With retreat of the sea, erosion cut the Tonganoxie Valley and produced the disconformity which coincides with the floor of the valley.

Reconnaissance work north and south of the Tonganoxie Valley has revealed no similar erosional valley. In these areas, the disconformity seemingly occurs in the midst of a shale sequence which overlies the Iatan limestone and underlies or is part of the Vinland shale. In localities where the Iatan limestone is absent, the disconformity is between the Weston shale and the overlying Vinland shale.

While erosion, unaccompanied by local sedimentation, proceeded north and south of the Tonganoxie Valley, erosion and concurrent deposition took place in the valley. As thickness of sediment in the Tonganoxie Valley increased and as the sea encroached, erosion of the valley ceased, but north and south of the valley it continued. Accordingly, the part of the disconformity which is marked by the base of the Tonganoxie sandstone is not precisely equivalent in time value to the disconformity elsewhere. Also, the sediment which ultimately came to be deposited over the divide areas north and south of the valley was laid down after the Tonganoxie Valley had been filled. This indicates that in regional correlation, the Tonganoxie sandstone is a little older than sediments overlying the disconformity in areas outside the valley.

TONGANOXIE VALLEY

The Tonganoxie Valley is interpreted as having been cut by a basinward-flowing river which, owing to retreat of the sea, was forced to cross an emerged sea bottom. Faunal and sedimental evidence indicates that the Pennsylvanian seas were shallow. Consequently, the initial dip of the sediments (dip of the profile of equilibrium) was very gentle and small vertical changes in sea level uncovered or submerged large areas. The gradients of rivers flowing over such emerged sea bottoms evidently were low, but sufficient to permit excavation of shallow valleys.

The ratio of 14 to 20 miles of valley width to 80 to 100 feet of valley depth indicates that the Tonganoxie River was near grade and that minor fluctuations in current velocity could result in either erosion or deposition.

EROSION AND DEPOSITION IN THE TONGANOXIE VALLEY

Initial deposition of the Tonganoxie sandstone is judged to have been contemporaneous with erosion in the Tonganoxie Valley. (1) The Tonganoxie Valley is very shallow compared to its width, indicating that the river must have been close to grade and that valley erosion was primarily lateral rather than downward. It is probable that a river carving such a shallow wide valley would be depositing at one place and eroding at another, all at the same time. (2) The basal conglomerate seems to be of local origin (as discussed below). (3) Festooned cross-bedded sandstone occurs in the areas of deepest erosion and inferred strongest currents, and thin-bedded sandstones occur where erosion was least. (4) Valley shale deposits seemingly were contemporaneous with the sandstone unit.

Present large streams, which are near or at grade, are continually reworking their flood-plain and channel deposits. During times of floods, valley widening and deepening take place in the channel and deposition occurs on the flood plain. As the channel shifts, sediment is removed from parts of the flood plain and redeposited elsewhere. Such valley sedimentation is contemporaneous with valley erosion and does not represent deposition subsequent to carving of the entire valley.

SOURCES OF SEDIMENT

The immediate sources of Tonganoxie sediments may be sought in sandy and silty near-shore and alluvial facies of earlier Pennsylvanian sediments to the east and north of the area, or in pre-Pennsylvanian terranes such as occur in the Ozark dome, Wisconsin Highlands, or the Appalachian region.

The sandstones and siltstones of the Tonganoxie are composed largely of angular quartz grains. Other detrital minerals are scarce, except muscovite. No rounded frosted sand grains of the St. Peter type have been observed. It seems probable that the Tonganoxie siltstones and sandstones represent reworked micaceous sediments of Pennsylvanian age which were exposed by the retreat of the sea and were transported westward from the upstream parts of the Tonganoxie River system.

Most of the limestone pebbles are lithologically similar to the Stanton and Iatan limestones. This suggests that the pebbles were derived from these formations, probably at places not far distant from the deposits of conglomerate. The poor sorting of the pebbles and the intermixture of pebbles with water-worn brachiopods, crinoid fragments, and some fusulinids also indicate that the pebbles were of a local detritial origin.

Deposition of the conglomerate unit.—The cutting of the Tonganoxie Valley indicates that during erosive periods the river acquired a load from its channel to supplement the sand, silt, and clay transported from farther east. The Tonganoxie Valley area of northwestern Missouri and northeastern Kansas was underlain by limestones and shales of the Missourian Series. Little sand or silt was available for river load. Consequently, the traction load of the river was augmented by fragments of locally derived limestone and shale. These fragments were seemingly too large for the usual competency of the river; they were shifted from place to place as the valley formed and were concentrated as the basal conglomerate of the Tonganoxie sandstone.

Deposition of the sandstone unit.—The sediment of the Tonganoxie sandstone shows that the Tonganoxie River was transporting fine micaceous sand, silt, and clay which were deposited in the channel and on the flood plain of the Tonganoxie Valley. The main channel area of the Tonganoxie Valley is shown by the location of extensive deposits of festooned cross-bedded and massive-bedded siltstones and sandstones.

To my knowledge, festooned cross-bedding has not been observed in modern sediments or produced in the laboratory. It has not been reported widely from the older sediments. Presumably, it results from alternate cutting and filling of troughlike channels by strong shifting currents.

Clay accumulated in the local lakes and swamps of the flood plain while silt and sand were deposited in the channel areas. The clay material became valley shales. The ripple-marked siltstone and sandstone beds within the valley shales may represent times of minor flooding when current action was strong. Some plant material accumulated in the valley shale material, as is shown by the presence of the Lower Sibley coal. Later channel migration failed to remove the valley shale deposits and they remain as remnants of formerly more extensive deposits surrounded by the festooned cross-bedded and massive-bedded siltstones and sandstones of the sandstone unit.

Deposition of the shale unit.—The gradual change in lithology from the thin-bedded strata of the sandstone unit into the overlying shale unit represents a change in depositional environment. This change seems to reflect reduction of the river gradient and slow encroachment of the sea from the west. Beds tentatively identified as brackish water in origin, overlain by marine strata, occur widely above the Tonganoxie sandstone. This sequence of strata is interpreted to represent progress toward marine conditions and establishment of marine conditions in the area. The initiation of the marine invasion was probably contemporaneous with deposition of the shale and coal units and partly may have been responsible for the reduction of river gradient.

The association and lithology of the shale unit suggest that deposition took place in broad shallow lakes, swamps, and on the partly inundated flood plain of the Tonganoxie Valley. The blue-gray to dark-blue color of the iron-bearing shales indicates that the water table was high and that the environment was primarily one of reduction, rather than oxidation. The high content of carbonaceous material in the shales also suggests that reducing conditions prevented complete oxidation of the organic matter. Iron was precipitated in the swamps and lakes, probably as iron carbonate, forming ironstone concretions. Where colloidal clay was present, clay ironstone beds formed.

No invertebrate fossils have been found in the shale unit. Although the environment seems to denote reducing conditions, there is no evidence of pyrite, marcasite, black shales, and other signs of "foul bottom" conditions. If the shale unit had been deposited in a marine environment, occurrence of marine invertebrates should furnish proof.

Deposition of uppermost beds of the shale unit terminated existence of the Tonganoxie Valley. The shale material filled the valley and overlapped the divides (Fig. 3, sec. C-C′). Deposition of the shale unit was followed by accumulation of the material of the Upper Sibley coal over what had been the Tonganoxie Valley and in small areas north and south of the divides.

Deposition of the coal unit.—Characteristics of the Upper Sibley coal and associated sediments have been studied in order to determine the origin and environment of deposition of the coal. The following are significant features of the Upper Sibley coal.

1. The coal zone can be recognized within the Tonganoxie Valley and on the marginal divide areas, but in many places the coal is absent and a carbonaceous shale represents the zone.

2. Sections of the coal bed show no clay or silt in the middle part.

3. Plant material, consisting of stems, limbs, trunks, and leaves, was the parent material of the coal.

4. Plant remains are well preserved in subjacent and superjacent strata and show no signs of having been transported by currents.

5. Subjacent shales are well bedded but plant material is not parallel to the bedding planes.

6. Subjacent shales are nonmarine.

7. Underclay has not been observed.

8. Fossils, tentatively identified as fresh to brackish-water forms, occur in overlying beds, but no definitely marine fossils have been found.

9. Subjacent and superjacent strata grade into coal.

Bowsher and Jewett (1943, p. 38) suggest that coals of the Stranger formation possibly may have been produced from detrital plant material which accumulated in a marine littoral environment. Coals of such allochthonous origin would have to have been brought into place by currents. Moore (1940) states that at least 15 to 20 feet of vegetable matter is required to furnish material for 8 to 12 inches of coal. If this is true, the average 8-inch thickness of the Upper Sibley coal represents approximately 15 feet of vegetable material. It seems to me that fluctuations in currents during the time required for deposition of the 15 feet of vegetable material at least occasionally would have brought in silts and clays. The lack of interbedded silt or clay in the Upper Sibley coal suggests that the coal is not detrital. The coal does grade upward and downward into plant-bearing clay shale but the central part is free from clay.

The leaves, stems, limbs, and trunks preserved in the Lower and Upper Sibley coals, and in the subjacent and superjacent gradational shales, show no signs of having been transported from their place of growth. Fragile leaves and stems are preserved intact. Bark with leaf and limb attachment scars is preserved on the trunks. There is no abrasion or other evidence indicating their transportation as detritus.

Physical similarities of the Upper Sibley coal to the Lower Sibley coal also indicate a common origin. On the basis of its stratigraphic relations, the Lower Sibley coal seems definitely to be nonmarine. The Lower Sibley coal is preserved in valley shale remnants which grade laterally into definitely nonmarine beds of the sandstone unit, and is overlain by the nonmarine shale unit of the Tonganoxie sandstone.

I am of the opinion that the Lower and Upper Sibley coals are of continental autochthonous origin. There is a possibility that some of the very thin local beds in the sandstone and shale units may have been derived from previously formed peat or coal beds which were reworked and redeposited, but physical charactristics of the coal beds give the impression that original peat and plant material which later formed the coal accumulated *in situ*.

Considering the Tonganoxie sandstone as a depositional unit, the Upper Sibley coal seems an integral nonmarine member of a depositional sequence or cycle. The sequence of nonmarine sandstone, followed by nonmarine shale, and finally by coal, indicates a reduction of current action in the area and the final filling of the Tonganoxie Valley by organic deposits. Marine sediment of the overlying Vinland shale represents completion of marine flooding and beginning of the marine part of a cyclothem.

Tonganoxie Sandstone and Cyclic Deposition

The conditions of deposition of the Tonganoxie sandstone may explain the absence of the nonmarine sand, shale, and coal units of certain cyclothems in the Pennsylvanian sections in Kansas.

Upper Pennsylvanian cyclic deposition in Kansas primarily expresses sea level fluctuations. Marine and nonmarine deposition closely followed the shifting shore lines. During most of late Pennsylvanian time in northeastern Kansas, the shore line was farther east. Erosion has removed the eastern, dominantly nonmarine, facies of most of the Pennsylvanian cyclothems. These missing facies contained the nonmarine units of cyclothems which are represented by marine beds in Kansas. Deposition of the Tonganoxie sandstone marked a time when the eastern nonmarine facies extended well into Kansas. Successive stratigraphic sections to the west should reveal that the Tonganoxie sandstone grades into marine sediments. Where the equivalent of the Tonganoxie sandstone is marine, a stratigraphic section would lack the nonmarine sand, shale, and coal units of a cyclothem.

Stratigraphic sections which include sediments of the Tonganoxie Valley and its overlying deposits contain the nonmarine sandstone, shale, coal, and marine units of a cyclothem. Stratigraphic sections outside the valley contain only the marine units of this cyclothem, although uppermost parts of the nonmarine unit may be present. Sections of the latter type may lead one to believe that the nonmarine units should be found only farther east, whereas actually, the nonmarine units are restricted to a near-by valley.

ECONOMIC GEOLOGY

The Tonganoxie sandstone is the most important aquifer in the area under discussion. Nearly all well water for stock and domestic use is obtained from this sandstone. The town of Tonganoxie obtains its water supply from this sandstone in wells east of the town.

The festooned cross-bedded and massive-bedded deposits in the center of the old Tonganoxie Valley have greater porosity and permeability than the thin-bedded sandstone near the old valley margins. Wells drilled at short distances north or south of the old Tonganoxie Valley encounter no Tonganoxie sandstone. In those areas, the Ireland is the most important aquifer near the surface, although locally it is absent also.

Porosity and permeability are best developed in the basal conglomerate, where ground water has dissolved parts of the limestone pebbles and the calcium carbonate matrix. Ground water moves freely along the contact where the conglomerate rests on limestones of the Stanton formation. Poor wells completed above the Upper Sibley coal or in the shale unit of the Tonganoxie sandstone could be improved by deepening to the conglomerate of the Tonganoxie in order to take advantage of the greater porosity of this zone.

Care should be exercised in drilling wells in the upland areas where thick sections of the Ireland and Tonganoxie sandstones occur. In these areas the valley walls of existing streams are steep and thick sections of the sandstones are exposed; ground water drains into the streams through the highly porous sandstone, causing the water table to become appreciably lower during dry weather. Wells in these areas should be deepened to the basal contact of the Tonganoxie sandstone in order to obtain ground water which moves laterally along the surface of the underlying impermeable strata.

The thin coals of the Tonganoxie sandstone have been mined in the past, but such ventures are generally not profitable commercially, except under unusual circumstances such as conditions produced by a war. The coal resources of the Stranger formation (Douglas group) are discussed by Bowsher and Jewett (1943).

The Tonganoxie sandstone is an extensive possible source of fine quartz sand and silt, although the high iron and mica content may limit its use. The poor degree of cementing makes the sandstone very easy to quarry and large deposits with only a thin overburden are present.

SUMMARY

The following is a summary of the major results obtained in this study.

1. The Tonganoxie sandstone consists mainly of nonmarine beds of sandstone, shale, and coal which are considered to be the nonmarine units of a cyclothem. The Tonganoxie sediments are divided into four units: conglomerate, sandstone, shale, and coal. Three types of stratification are observed in the sandstone unit: (a) festooned cross-bedded sandstone and (b) massive-bedded siltstones and sandstones in the center of the old Tonganoxie Valley, and (c) thin-bedded sandstone along the valley margins. The festooned cross-bedded and massive-bedded sandstones grade laterally and upward into the thin-bedded sandstones. The thin-bedded sandstone grades upward into the shale unit, which grades vertically into the coal unit.

2. The Tonganoxie sandstone is confined to a valley extending southwestward across northeastern Kansas. Only slight marginal overlap of the upper part of the shale and coal units occur on adjacent divide areas.

3. The Lower Sibley coal is preserved in valley shale remnants of former extensive flood-plain deposits.

4. Excessive thicknesses of sandstone (more than 65 feet) are due to combined thicknesses of the Ireland and Tonganoxie sandstones.

5. Sediments composing the Tonganoxie sandstone were derived from the east and deposited by a southwest-flowing river.

6. The mica of the Tonganoxie is detrital and not authigenic.

7. The Tonganoxie sandstone may be the time equivalent of sandstones of the same name elsewhere in Kansas, but the immediate source of sediments and the depositing rivers probably were not the same.

8. The disconformity at the base of the Tonganoxie sandstone does not represent precisely the same time interval as the regional disconformity outside the Tonganoxie Valley.

9. The Tonganoxie is older than beds overlying the regional disconformity in most places elsewhere.

10. The stratigraphic relations and conditions of deposition of the Tonganoxie sandstone may explain the absence of certain cyclothem units in Kansas.

11. The alignment of the present outcrop is approximately parallel to the old Tonganoxie Valley and is not at a right angle to the direction of the source of sediment.

12. Greater porosity and permeability for ground water prevails in the basal conglomerate and in the festooned cross-bedded and massive-bedded sandstones than in the thin-bedded sandstones and the shale unit of the Tonganoxie sandstone. The sandstone is not encountered in various wells drilled outside the old Tonganoxie Valley.

REFERENCES

BENNETT, JOHN (1896) A geologic section along the Kansas River from Kansas City to McFarland: Kansas Univ. Geol. Survey, vol. 1, pp. 107-124.

BOWSHER, A. L., AND JEWETT, J. M. (1943) Coal resources of the Douglas group in east-central Kansas: Kansas Geol. Survey, Bull. 46, pp. 1-94, figs. 1-12, pls. 1-6.

GILBERT, G. K. (1914) The transportation of debris by running water: U. S. Geol. Survey, Prof. Paper 86, pp. 1-263, figs. 1-89, pls. 1-3.

HALL, J. G. (1896) A geologic section from state line, opposite Boicourt, to Alma, principally along the Osage River: Kansas Univ. Geol. Survey, vol. 1, pp. 99-106.

HAWORTH, ERASMUS (1894) A geologic section along the A. T. & S. F. R .R. from Cherryvale to Lawrence, and from Ottawa to Holliday: Kansas Univ. Quart., vol. 2, pp. 118-126.

———— (1896) A geologic section from Coffeyville to Lawrence: Kansas Univ. Geol. Survey, vol. 1, pp. 129-139.

HINDS, HENRY, AND GREENE, F. C. (1915) The stratigraphy of the Pennsylvanian Series in Missouri: Missouri Bur. Geology and Mines, vol. 13, pp. 1-255.

KNIGHT, S. H. (1929) The Fountain and the Casper formations of the Laramie basin; a study on genesis of sediments: Wyoming Publ. Sci. and Geology, vol. 1, no. 1, pp. 1-82, figs. 1-41.

LEE, WALLACE, AND PAYNE, T. G. (1944) McLouth gas and oil field, Jefferson and Leavenworth Counties, Kansas: Kansas Geol. Survey, Bull. 53, pp. 1-195, figs. 1-20, pls. 1-10.

MOORE, E. S. (1940) Coal, its properties, analysis, classification, geology, extraction, uses, and distribution: 2d ed., pp. 1-473, John Wiley & Sons, Inc., New York.

MOORE, R. C. (1931) Pennsylvanian cycles in the northern midcontinent region; Illinois Geol. Survey, Bull. 60, pp. 247-257, figs. 53-55.

———— (1932) A reclassification of the Pennsylvanian System in the northern midcontinent region: Kansas Geol. Soc., Guidebook 6th Ann. Field Conf., pp. 79-98, figs. 1-4.

————(1936) Stratigraphic classification of the Pennsylvanian rocks of Kansas: Kansas Geol. Survey, Bull. 22, pp. 1-256, figs. 1-12.

————(1949) Divisions of the Pennsylvanian System in Kansas: Kansas Geol. Survey, Bull. 83, pp. 1-203, figs. 1-37.

Moore, R. C., Elias, M. K., and Newell, N. D. (1934) Pennsylvanian and Permian rocks of Kansas: Kansas Geol. Survey, chart.

Patterson, J. N. (1933) The Douglas group of the Pennsylvanian in Douglas and Leavenworth Counties, Kansas; unpublished manuscript, in Library, University of Kansas, Lawrence.