THE CODELL SANDSTONE (UPPER CRETACEOUS) OF KANSAS

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ABSTRACT

The Codell Sandstone Member of the Carlile Shale is confined to the northwest one-quarter of Kansas, and is composed of fine to very fine grained, noncalcareous, argillaceous, sandstone and dark gray shale containing thin (about 2 mm) streaks and plano-convex lenses of siltstone. The lower contact of the Codell Sandstone with the Blue Hill Shale is gradational and not well defined. The upper contact of the Codell Sandstone with the Ft. Hays Limestone Member of the Niobrara Chalk is sharp and parallel to the bedding of the two units, but an unconformity apparently exists between the two units. In the subsurface of Rawlins County and southern Wichita County, the Codell has its maximum thickness of approximately 80 feet. The Codell is absent in the vicinity of southern Sherman County, apparently because of nondeposition and in the northeastern part of the area of study because of a lateral gradation into shale. Fossils are present in the Codell, but are not diagnostic. Those fossils that are present, however, and the fine grain-size of the clastics suggest that the Codell was probably deposited in a fairly stable shelf-type marine environment, possibly in response to a gradual lowering of sea level.

INTRODUCTION

PURPOSE AND SCOPE OF STUDY

The Upper Cretaceous (Colorado Group) Carlile Shale has one of the larger outcrop areas of any single formation in the state of Kansas. In the upper part of this unit, there are sandy strata which have been assigned the name Codell Sandstone. It is the purpose of this paper to discuss the areal distribution, lithology and changes in facies of the Codell Sandstone in Kansas. One objective of this study is to furnish data that might help to clarify the stratigraphic relationship of the Codell to the Carlile as a whole, and to the overlying Ft. Hays Limestone Member of the Niobrara Chalk. In Kansas, the Codell is contained within an area of approximately 19,600 square miles in the northwest one-quarter of the state (fig. 1), and it is this area wherein data for this study was collected.

METHODS OF INVESTIGATION

Outcrops of the Codell Sandstone were measured, sampled, and described during the summer of 1959. Laboratory investigation of field samples collected at that time was confined to a general lithologic examination. The distribution and lithologic variations of the Codell Sandstone in the subsurface were determined through the use of electrical and radioactivity well logs. The information from these logs was supplemented by examining subsurface samples of the Codell obtained from the Kansas Sample Log Service, Kansas Geological Survey, Lawrence, Kansas.

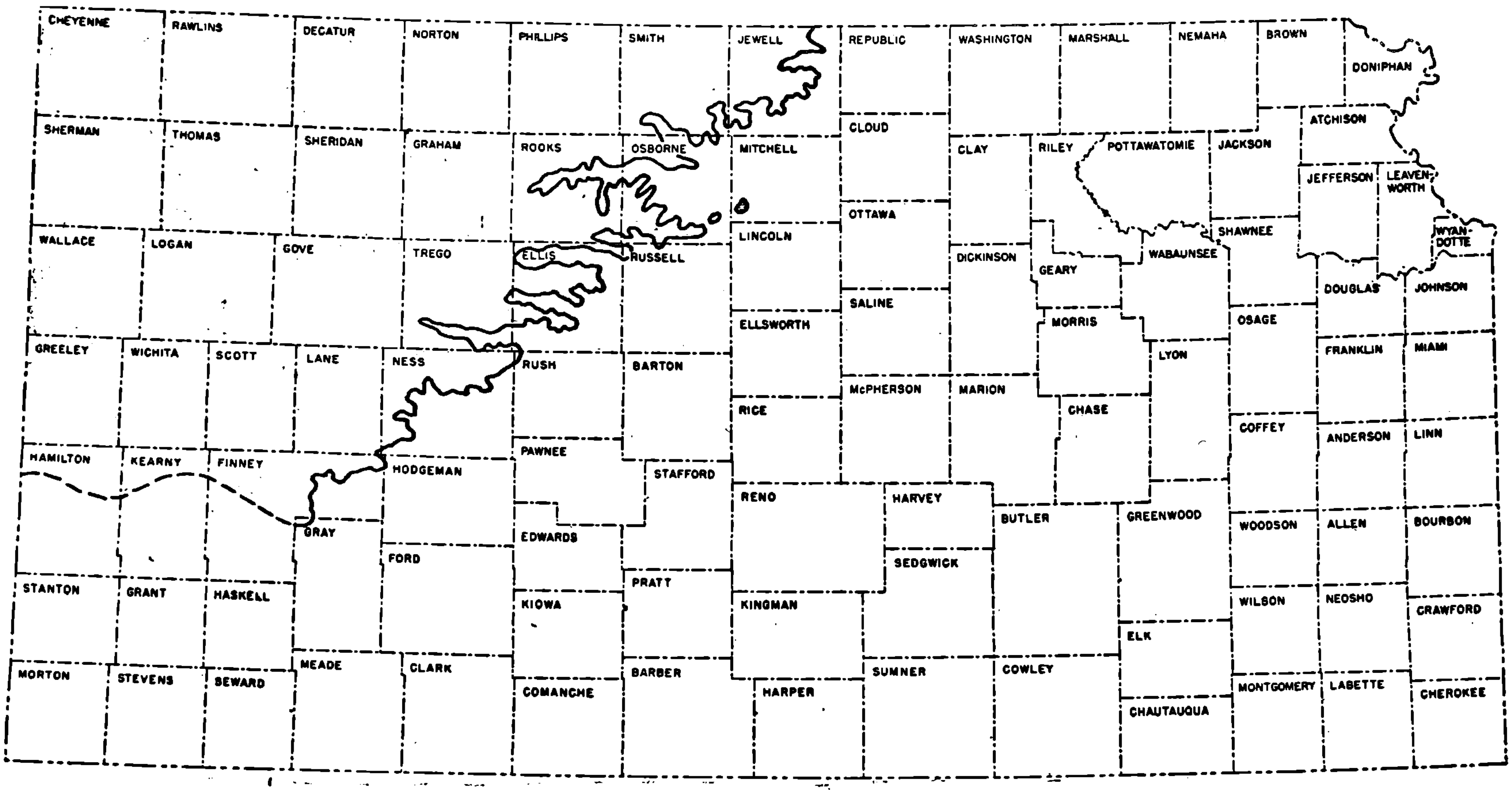


Figure 1. Index map showing the subsurface distribution (shaded) and outcrop belt (solid line) of the Codell Sandstone in northwestern Kansas (Adapted from Moore, et. al., 1937).

PREVIOUS WORK

Since the later part of the Nineteenth Century, considerable attention has been devoted to the Cretaceous deposits of the Western Interior of the United States. Numerous people working in widely separated areas have devoted all or a part of their efforts to some aspect of Cretaceous rocks.

With reference to the Codell specifically, Dane, Pierce and Reeside (1937) have presented some interesting and significant facts on the Codell Sandstone in eastern Colorado. Bourne (1952), Chamney (1954) and Regout (1951) have made a fairly detailed surface and subsurface study of the Colorado Group in the central Great Plains area. Morrow (1941), Dubins (1947) and Hattin (1952) have made pertinent studies of the Colorado Group in Kansas. In addition, several publications by the State Geological Survey of Kansas contain discussions on the Codell Sandstone, and these publications are referred to in the text of this paper and listed in the bibliography.

HISTORY OF NOMENCLATURE

In 1896, G. K. Gilbert (1896, p. 565) proposed the name Carlile Shale for 170 to 180 feet of rock strata cropping out at Carlile Springs in south-central Colorado. Subsequently, the name Carlile Shale was adopted in Kansas, for rocks of similar lithology and stratigraphic position. Later, the Carlile of Kansas was divided into three members. A columnar section of the Carlile Shale and adjacent stratigraphic units is shown in Figure 2.

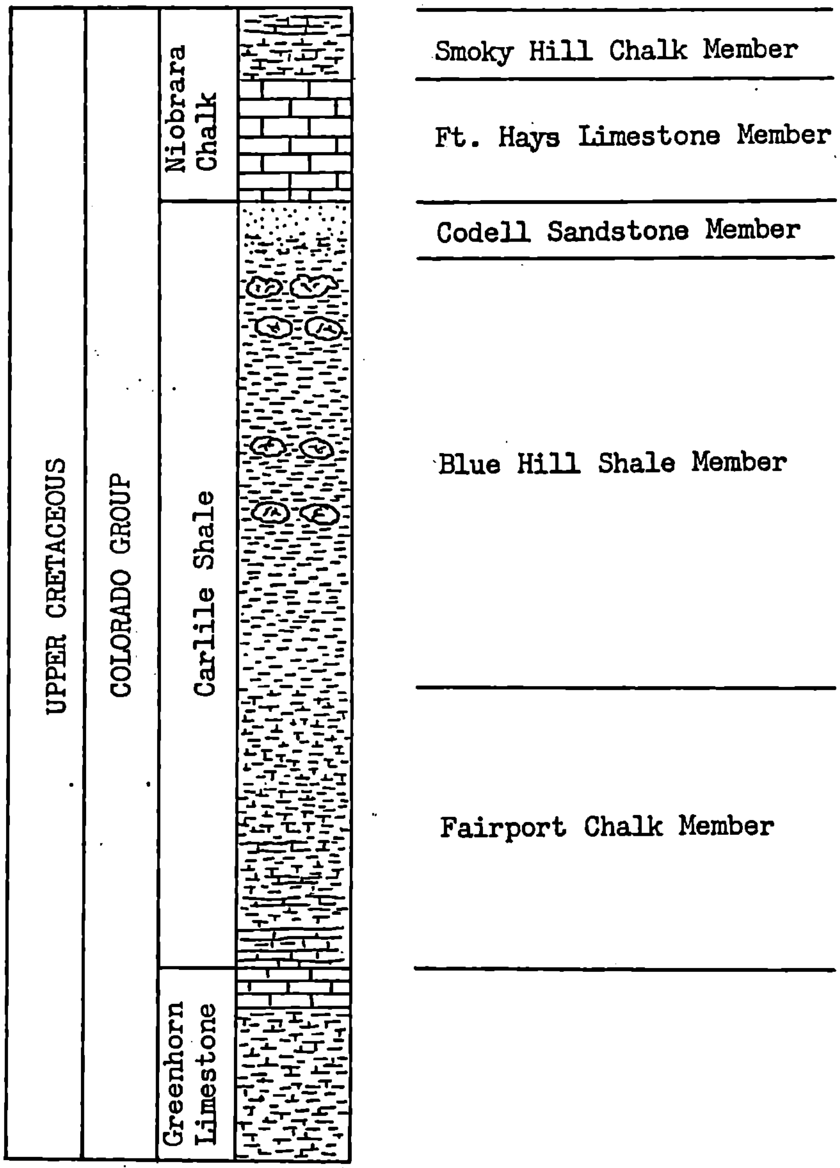


Figure 2. Columnar section showing part of the Colorado Group of Kansas. The classification shown above is currently used by the Kansas Geological Survey (Jewett, 1959).

The Blue Hill Shale was the first of the present members of the Carlile Shale to be named in Kansas. W. N. Logan (1897, p. 218) proposed the name Blue Hill Shale for a sequence of dark shales and large calcareous concretions occurring in the Blue Hills of Mitchell County, Kansas. Logan placed the lower limit of the Blue Hill Shale at the top of a fossiliferous limestone and calcareous shale (Fairport Chalk) while the upper limit was placed at a prominent concretion zone occurring several feet below the base of the Ft. Hays Limestone. In the following year, however, Logan (1898, p. 434) revised the upper limit so as to include all rock up to the base of the Ft. Hays Limestone.

Rubey and Bass proposed the name Fairport Chalky Shale Member in 1925 for "85 feet of chalky marl and thin chalk beds" from "exposures a few miles south and west of Fairport, Russell County," Kansas. (Rubey and Bass, 1925, p. 40, p. 44). The Fairport is overlain by the Blue Hill Shale Member of the Carlile and underlain by the Greenhorn Limestone formation.

In 1926, N. W. Bass (1926, p. 28) named a sandstone unit occurring in the upper part of the Blue Hill Shale the "Codell Sandstone Bed." The type area is located in the extreme northern part of Ellis County, approximately five miles south of Codell (Rooks County), Kansas. Though a type section was not given specifically, Bass (1926, p. 28) stated that the Codell "is well exposed in a roadcut near the northern boundary of Ellis County in the NE¼, Sec. 3, T. 11 S., R. 17 W., where it is 22 feet thick." For practical purposes, this locality as given by Bass can serve as the type section for the Codell.

The original stratigraphic rank of the Codell, as defined by Bass, was a bed within the Blue Hill Shale. This was subsequently changed in 1933, when Dane and Pierce raised the stratigraphic rank of the Codell to that of a member. Later, it was assigned the rank of member in Kansas (Moore, Frye, and Jewett, 1944, p. 152). However, in 1951, a publication of the State Geological Survey of Kansas (Moore, et. al., 1951, p. 24) listed the Codell as a zone within the Blue Hill Shale. In 1952, the Committee on Stratigraphy of the National Research Council published in a Bulletin of the Geological Society of America (V. 63), a chart entitled "Correlation of the Cretaceous Formations of the Western Interior of the United States." In this chart, the Codell is assigned the rank of member. A more recent publication of the State Geological Survey of Kansas (Jewett, 1959) also lists the Codell as a member of the Carlile, and it is in this sense that the name Codell is used in this paper.

ACKNOWLEDGMENTS

I should like to acknowledge the guidance of my faculty advisor, Dr. K. W. Hamblin, during the course of the study and in the critical reading of this manuscript. Dr. E. Gillerman and Dr. J. M. Jewett have also critically read this manuscript and they have made many helpful suggestions. Also to be thanked are Dr. D. F. Merriam and the Kansas Geological Survey. Dr. Merriam made available the necessary subsurface data from the files of the Kansas Geological Survey, and a number of county maps and base maps of Kansas were provided by the Kansas Geological

Survey. Dr. D. E. Hattin provided several locations for outcropping Codell Sandstone which expedited the field study.

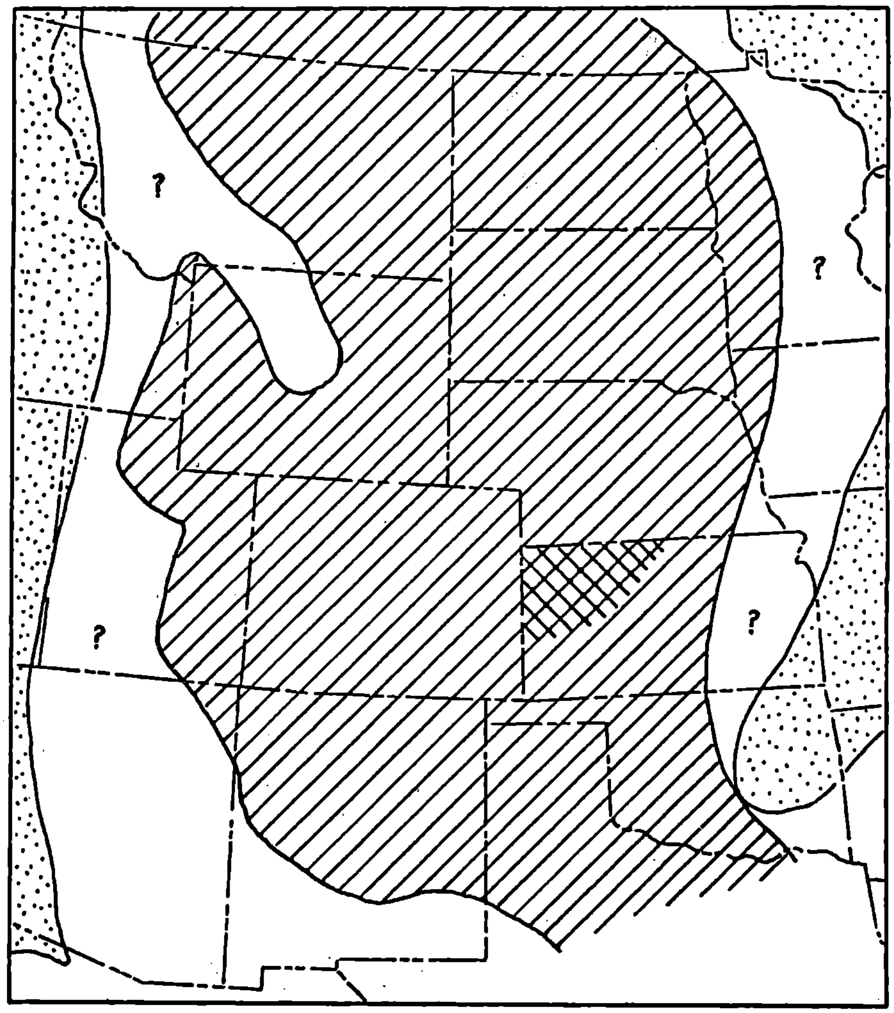
AREAL EXTENT OF CODELL

WESTERN INTERIOR OF THE UNITED STATES

Over much of the Western Interior of the United States, a sandstone occurs at or near the top of the Carlile Shale or its equivalents. This sandstone, the western edge of which crops out along the east side of the Rocky Mountains, is probably the most widespread of the Late Cretaceous Sandstones in the interior region (Reeside, 1957, p. 524). Along its eastern margin, which extends southward from the Dakotas, through Nebraska, Kansas and Colorado, this sandstone has been assigned several names. In Colorado, Kansas and Nebraska, it is called the Codell Sandstone. Between the margins mentioned above, the Codell (or an equivalent stratigraphic unit) is generally present in the subsurface.

Figure 3 shows what Reeside (1957, p. 529) has interpreted to be the original extent of the Codell and equivalent stratigraphic units in the Western Interior. The position and presence of the land areas shown in Figure 3, especially on the eastern side, are based on general data and as such are hypothetical.

A correlation chart is not included in this paper since the names of the stratigraphic units concerned do not change within the general area of this study. However, if details on the correlation of the Codell Sandstone in the interior of the United States are desired, the reader is referred to Cobban and Reeside (1952).



Ancient land area

Inferred original extent of the Codell Sandstone and equivalent stratigraphic units.

Area of study

Figure 3. Map showing the original distribution of the Codell Sandstone and equivalent rock units in the interior of the United States (Adapted from Reeside, 1957).

CODELL IN KANSAS

Outcrop Distribution

In Kansas, the intersection of the Codell with the land surface forms an irregular narrow line extending across Kansas, in a general northeast to southwest direction (fig. 1) from northern Jewell County to northern Finney County. In much of Finney County, and westward through Kearney and Hamilton Counties, the Codell is covered with younger rocks of Tertiary and Quaternary age. However, in the central part of Hamilton County, a few scattered outcrops of the Codell are present. South of Hamilton, Kearney, and Finney Counties, and east of outcrop belt, the Codell has been eroded away except for a few scattered isolated erosional remnants. Outcrops of Codell strata which were measured as a part of this study are described in the Appendix.

Outcropping Codell Sandstone usually does not noticeably influence the physiography of the area of study. This is true partly because of the Codell's argillaceous lithology, but mostly because the relatively thick overlying Ft. Hays Limestone, which is fairly resistant in the dry climate of western Kansas, tends to dominate the topography. The resistant nature of this limestone is expressed as a southeast facing escarpment called the Ft. Hays Escarpment. Usually, the Ft. Hays Limestone is present only as a cap rock on the escarpment with the southeast facing slope developed on the upper part of the Carlile. These slopes tend to be smooth, grass covered and concave upwards (fig. 4) with large to small spheroidal and ellipsoidal concretions from the Carlile and slump blocks of Ft. Hays Limestone strewn over the surface.

Figure 4. Profile of hill slope developed on upper Carlile strata in the NE cor., sec. 3, T. 11 S., R. 17 W., Ellis County, Kansas. The small irregularity in the slope results from an indurated concretion zone that occurs about 40 feet below the base of the Ft. Hays.

Subsurface Distribution

General Statement.

The Codell is generally present under most of the northwest one-quarter of Kansas. Consequently, the Codell that crops out constitutes only a very small portion of the total Codell in Kansas. Thus, in order to better interpret the data obtained from outcropping Codell strata, a subsurface study of the Codell was also made. This subsurface study was of necessity concerned primarily with the thickness variations of the Codell, but also included a broad qualitative interpretation of lithology. For comparative and interpretive reasons, thickness data were also obtained for the underlying Blue Hill Shale and Fairport Chalk Members of the Carlile, and for the overlying Ft. Hays Limestone Member of the Niobrara Chalk. The thickness data were used to construct isopachous maps.

Source of Data.

Electrical and radioactivity well logs were the primary sources utilized to obtain subsurface thicknesses for the members of the Carlile Shale and the Ft. Hays Limestone Member of the Niobrara Chalk. Figures 5 and 6 indicate respectively the general character of the electrical and radioactivity well logs for the stratigraphic interval between the top of the Greenhorn Limestone (or base of the Fairport Chalk Member of the Carlile) and the top of the Ft. Hays Limestone Member of the Niobrara Chalk. Figure 5A shows a typical configuration for the self-potential curve and resistivity curve of electrical logs for the pertinent stratigraphic interval. Figure 5B shows the configuration of the self-potential and resistivity curves for the same stratigraphic interval, but as recorded at lesser depths. It should be noted that the self-potential curve (SP) in Figure 5B is inverted, or reversed, from that found in Figure 5A. This reversal of the self-potential curve, which was noted on many of the logs used in this study, is attributed to the influx of fresh water into the strata of the recorded stratigraphic interval. In fact, only a relatively small number of electrical logs from wells in the northwest corner of Kansas (fig. 8) have normal self-potential curves (i.e., like those found in Figure 5A) for the Carlile and Niobrara formations.

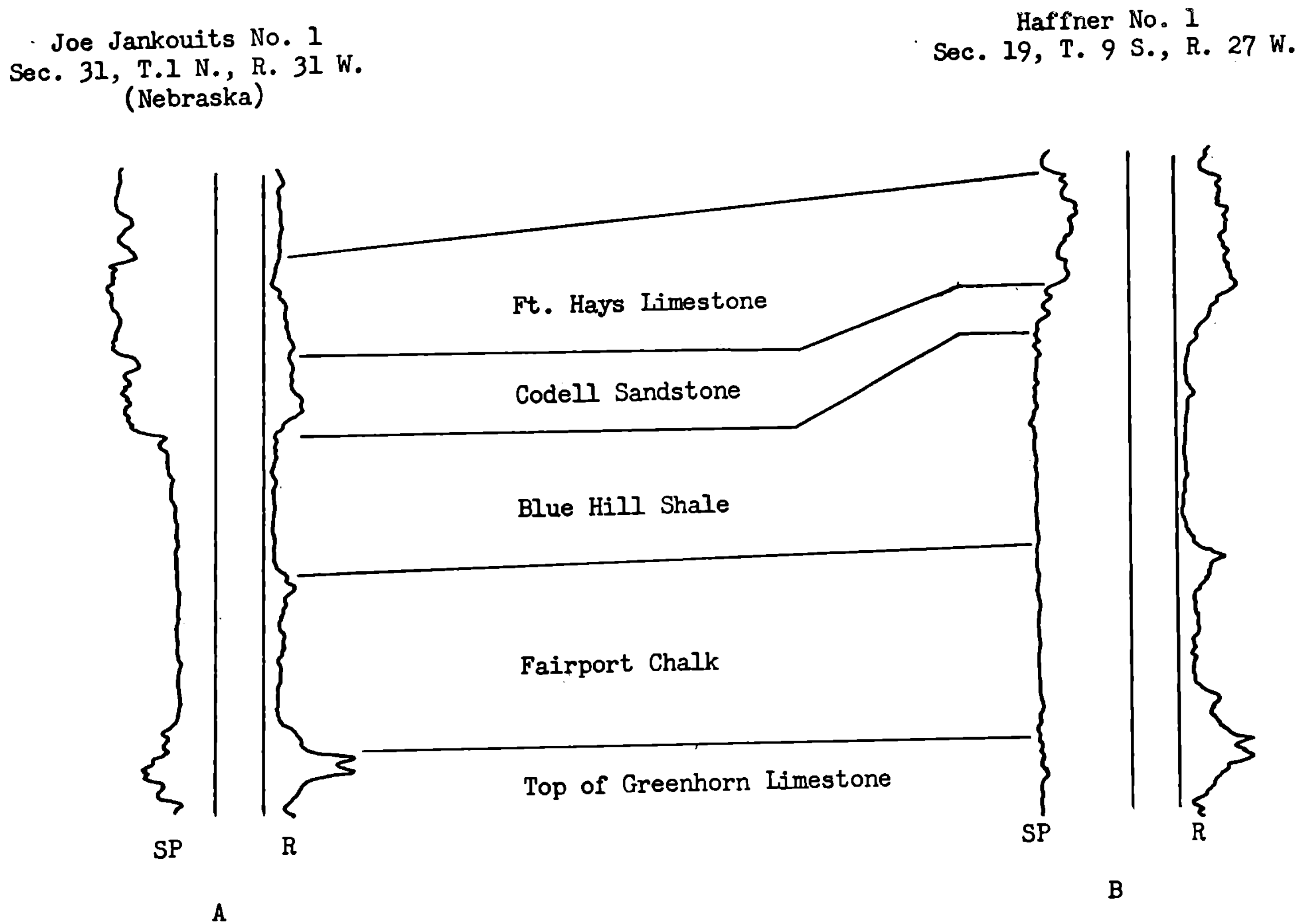


Figure 5. Self-potential (SP) and resistivity (R) curves in northwestern Kansas. A. Log not influenced by fresh water in the strata. B. Self-potential curve on the upper part of log inverted due to fresh water being present in the strata.

In addition to the electrical logs just mentioned, radioactivity logs were also used. Specifically, the type of log utilized in this study was the gamma ray-laterolog log. Figure 6 shows a gamma ray-laterolog well log of the Carlile Shale and Ft. Hays Limestone.

Problems Encountered in Well Log Interpretation.

Generally speaking, on both electrical and radioactivity well logs, the Codell Member of the Carlile Shale is fairly well defined. Numerous problems are encountered, however, in obtaining thickness data on the Codell from electrical logs. The gradational nature of the change in lithology from the Blue Hill Shale to that of the Codell Sandstone makes it particularly difficult to consistently establish a lower contact for the Codell. Because of this, it was decided to arbitrarily place the lower boundary of the Codell at the base of the lowermost prominent sandstone, siltstone or silty shale deflection on a given electrical log. But in doing this, one or more less prominent sandy or silty horizons are sometimes excluded from the Codell and subsequently included in the Blue Hill. It is thought, however, that the resulting isopachous map of the Codell reliably shows the broad variations in thickness of the unit. In this respect, determining what were the most prominent sandstone or siltstone deflections presented another problem in consistency of interpretation. However, through the construction, extention and correlation of subsurface cross sections over the area of study, it is thought that errors having to do with consistency of interpretation were minimized.

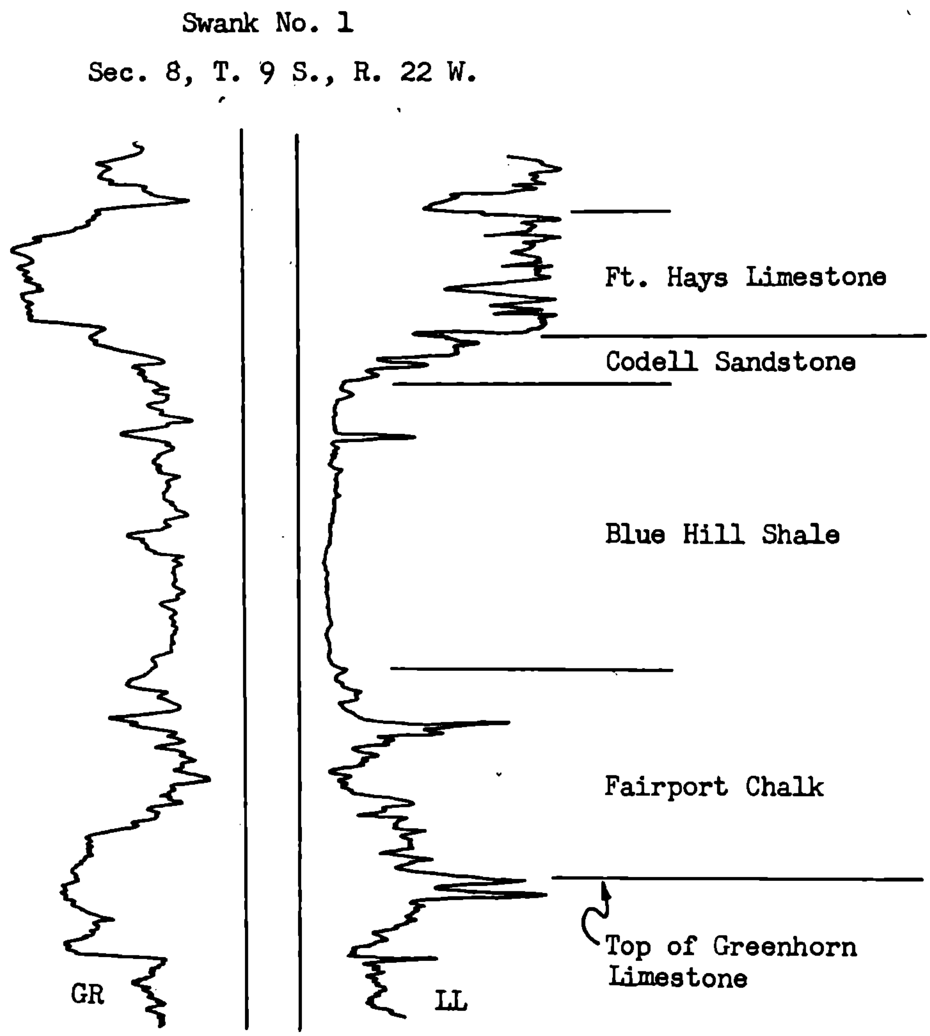


Figure 6. Gamma ray (GR)-laterolog (LL) well log in northwestern Kansas.

In the northwestern part of the state, another problem associated with electrical log interpretation of the Codell is encountered. In northwestern Kansas, the values expressed by the self-potential and resistivity curves of the Codell are very nearly the same as those of the overlying Ft. Hays Limestone. So much so, in fact, that the Codell has often been logged with the Niobrara Chalk as a single unit. Figure 7 is taken from a fairly recent log which combines measurements of the self-potential, gamma ray intensity, resistivity and conductivity all on one log. On the basis of the self-potential (SP), resistivity (R) and conductivity (C) measurements, it would be difficult to determine the position of the contact between the Ft. Hays and the Codell with much confidence (Also see Figure 5A). The measurement and recording of the gamma ray (GR) intensity on this same log, however, serves to rather accurately define the contact between the Ft. Hays Limestone and the Codell Sandstone. It was in this way that the gamma ray log was of most value to this study. In most cases though, gamma ray measurements are not combined with self-potential measurements in the stratigraphic interval concerned in this report. But, after examining many logs, it was found that the general character of the self-potential curve is usually definitive enough to allow one to differentiate the Codell from the Ft. Hays. Points "a" and "b" on the self-potential curve in Figure 7 are generally persistent and diagnostic enough to define the stratigraphic limits of the Ft. Hays.

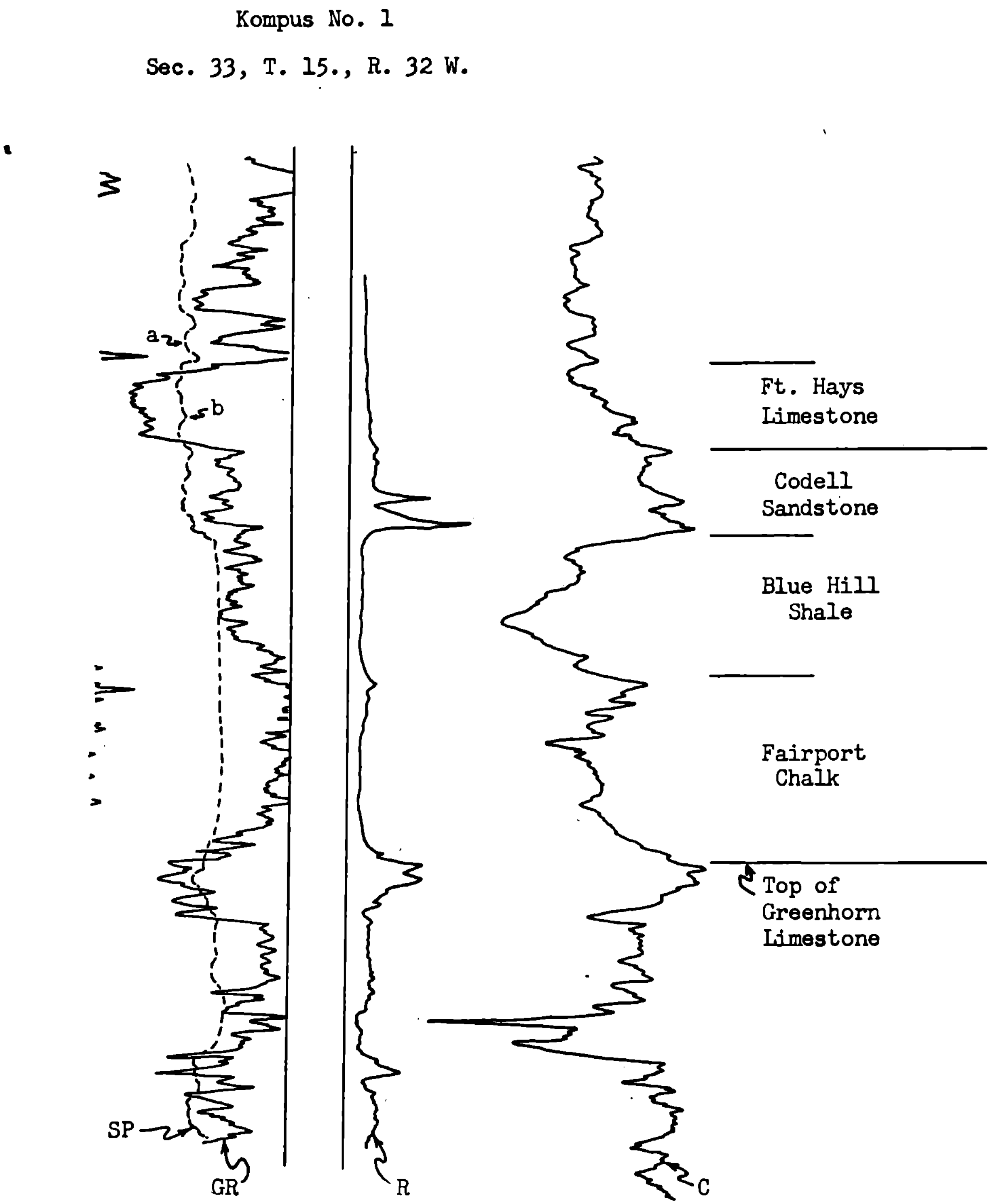


Figure 7. Electrical-radioactivity well log in northwestern Kansas (Key to symbols: C, conductivity curve; R, resistivity curve; GR, gamma ray curve; SP, self-potential curve).

COMPOSITION OF THE CODELL SANDSTONE

MINERALOGY

The Codell Sandstone is composed primarily of very fine grains of quartz plus a considerable but variable amount of clay material. While a detailed petrographic analysis of the Codell was not undertaken as a part of this study, some data are available. Rubey and Bass (1925, p. 34) give the following description of the Codell in Russell County:

> Most of the grains are quartz, chiefly colorless, a few of which show shadowy extinction under crossed nicols, but some are smoky gray and translucent and a few are pink and transparent. Dark gray chert, somewhat kaolinized orthoclase, and some black opaque fragments are rather common and grains of clear orthoclase and some plagioclase (more calcic than An 30), faintly pinkish microcline and perfect crystals of zircon showing no effects of abrasion are present. Much of the quartz shows abundant inclusions that are in part at least acicular cristals of brown tourmaline and apatite.

The clay minerals of the Codell were not determined specifically as a part of this study. Occasionally, however, there were noted thin seams of clay material that tended to swell considerably after they were moistened, suggesting a clay mineral of the montmorillonite group. One x-ray diffraction analysis made of a shale in the upper part of the Codell at one locality in Rooks County (LoC) (RoA) suggests that the most common clay mineral in clay material of unweathered Codell is probably illite.

A study of the heavy minerals of the Codell was made by Moss (1932, p. 22-23) with the following results:

> Zircon 68 per cent, tourmaline 12 per cent, garnet (grossularite) 12 per cent, rutile 5 per cent, staurolite 1 per cent and traces of anatase, chlorite, muscovite, corundum and topaz. All of the zircon and the majority of the other minerals are in euhedral crystals or angular fragments. The zircon percentage rises from 58 percent in Mitchell County to 87 percent in Ness County.

Subsurface samples of Codell Sandstone in northwestern Kansas seem to be of the same mineralogical composition as that of outcropping Codell except for the lack of weathering. One notable exception is the occurrence of very small greenish colored grains in many of the subsurface samples of Codell. These greenish grains seem to be concentrated in, if not confined to, the extreme upper part of the Codell. The exact mineralogical composition of the greenish grains was not determined, but their appearance excepting maybe grain size, fits the general field definition of glauconite. In the limy sandstones at the top of the Codell in southern Ellis County (Locality ElK), some greenish colored grains are present. These grains, however, seem to have a micaceous structure and may be chlorite rather than glauconite. The absence, or apparent absence, of the greenish grains at most outcrops of the Codell is possibly a result of weathering.

Thin bands and nodules of calcite occur in some outcropping Codell strata. Some calcite is also present in subsurface samples of the Codell, especially in the extreme northwestern corner of Kansas. In the northwestern corner of Kansas, the Codell is weakly cemented with calcite. It was also noted that as the location of the subsurface samples approaches the outcrop belt, there seems to be a corresponding decrease in calcite as a cementing agent in the Codell. In connection with this, inversions of the self-potential curve of electrical well logs (Fig. 5B) made it possible to roughly outline an area in the northwest part of Kansas, wherein surface or fresh water has not yet entered the Codell strata (Hatchured area shown in Figure 8). Throughout the remaining area of subsurface Codell, surface water has entered the strata

(Shaded area in Figure 8). Calcite in the Codell seems to be more abundant where fresh water has not yet entered Codell strata. This suggests that the lack of calcareous material in outcropping Codell strata is possibly a result of solution.

Pyrite is present in outcropping Codell and it is also fairly common in subsurface samples. Also affecting the gross mineralogical composition of the Codell are bone fragments and teeth. These, however, seem to concentrated in the upper part of the unit and in most places are scarce.

TEXTURE

Grain sizes in the Codell range downward from nearly one-half millimeter to that of clay sized particles. In the better developed sandstones of the Codell, the sand grains are mostly fine to very fine in size (Wentworth size classification). It might be added that a general microscopic examination suggested that the quartz grains range down to clay sized particles, and may constitute a sizable fraction of the interstitual clay material of the Codell and perhaps an appreciable fraction of the clay material in the shale beds of the Codell and the underlying Blue Hill Shale.

Individual quartz grains are for the most part angular and equant. Subangular grains are also common and the shape of the quartz grains does vary slightly. Rubey and Bass (1925, p. 34) noted that in Russell County, the larger grains of the Codell are commonly more angular than those of intermediate size.

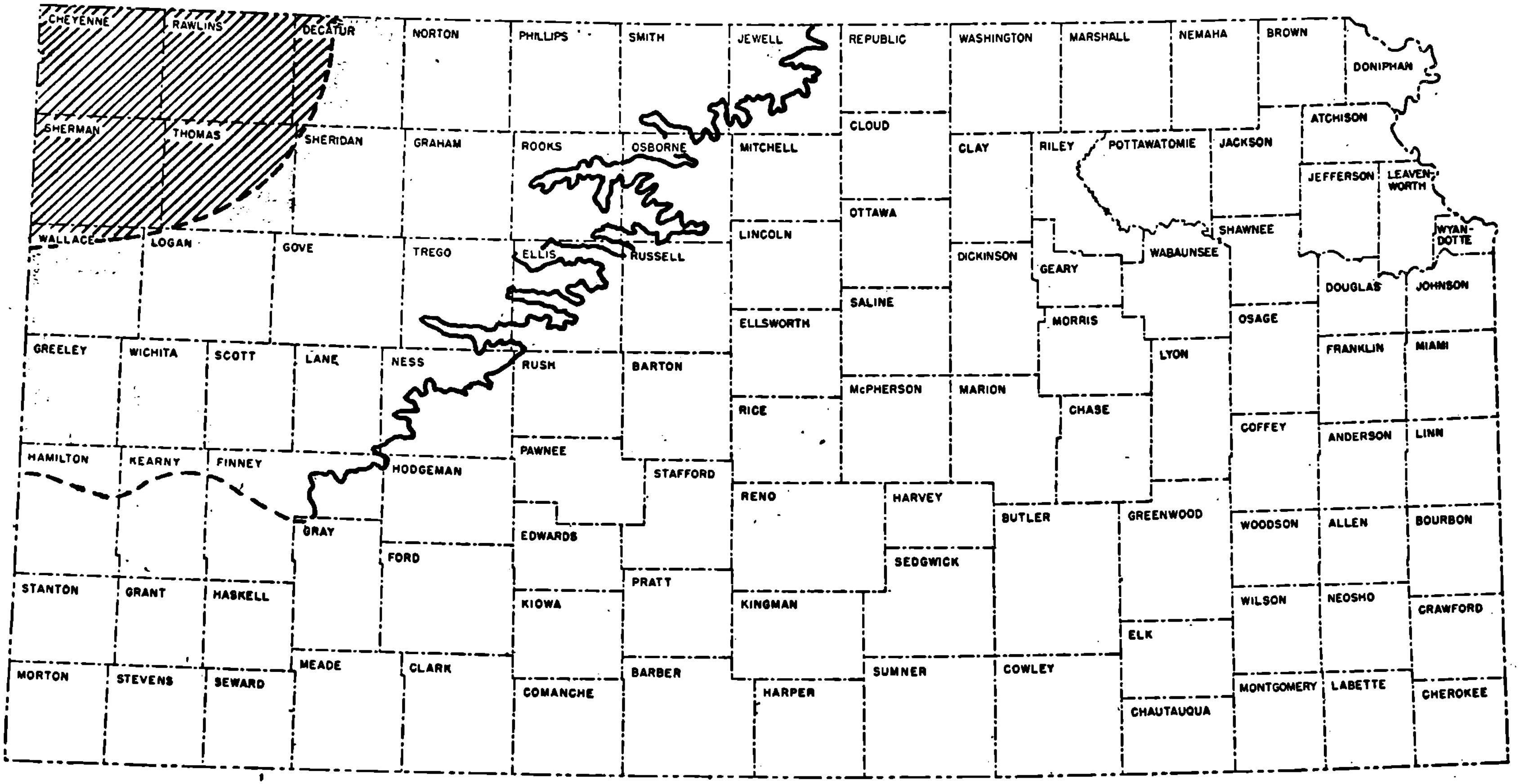


Figure 8. Map illustrating the presence of fresh water in Codell strata. The hatchure lines define that area where fresh water is not present in the Codell. The shaded portion of the map represents that area of the Codell where the strata does contain variable amounts of fresh water.

Another noticeable feature shown by most of the quartz grains in the Codell is their slightly frosted and pitted appearance. The frosted surface of these grains is quite fine, even on the smaller grains. The origin of the frosted surface is usually attributed to eolian action. However, it has been pointed out by Pettijohn (1957, p. 70) that quartz grains, in the presence of a carbonate, may develop frosted and pitted surfaces. Because of the proximity of the Codell to the Ft. Hays Limestone and the possibility that the Codell originally contained some intergranular calcium carbonate, it may be that some of the frosted surfaces on grains in the Codell developed in a similar manner.

LITHOLOGY

Outcropping Codell in Kansas is characteristically composed of fine grained clastic particles. More specifically, it can usually be divided into two somewhat similar though distinctive lithologic units. These are:

1. A massive to thin bedded, very fine grained, light gray, noncalcareous, argillaceous sandstone or sandy siltstone that weathers to a light yellowish-brown or dark yellowish-brown color.
2. Fissile, dark gray to gray, noncalcareous, sandy and/or very silty shale containing small light gray streaks or lenses of siltstone.

In general, outcropping Codell is not well indurated, being held together chiefly by clay material. But, because of the clay material, the Codell may be quite hard when dry, even though samples generally become soft and disintegrate rather quickly after immersion in water. Locally, cementing agents are present in outcropping Codell mostly in the form of thin bands and nodules of iron oxide or calcium carbonate.

SEDIMENTARY STRUCTURES

CROSS-BEDDING

In general, cross-bedding is not common in the Codell Sandstone cropping out in Kansas. In northern Ellis County, some faintly defined cross-bedding is present at the top of the Codell. Near the Cedar Bluff Reservoir, in Trego County, a block of slumped Codell Sandstone shows well developed cross-bedding. At another locality in Mitchell County (Locality McA), some cross-bedding is present in a sandy siltstone bed occurring approximately 20 feet below the base of the Ft. Hays Limestone. At most outcrops, though, the cross-bedding, if present, is usually found in the sandstone at or near the top of the Codell. Also, the cross-bedding in the upper few feet of the Codell Sandstone seems to be better developed than that seen at lower stratigraphic intervals in the Codell. Most of the cross-bedding seems to be of the medium to large scale shallow trough type (McKee and Wier, 1953). Very small scale cross-bedding and cross-laminae (McKee and Wier, 1953) are also present and seem to be fairly common.

LENSES

Throughout most of the Codell, especially where the Codell is composed of sandy and silty shale, there are numerous streaks, small lenses, and thin bands of sandstone or siltstone. In many places, these are irregular in shape and disposition (fig. 9); many, however, have a plano-convex lens-like vertical cross section (fig. 10). The plano-convex lens type seems to be more abundant in the lower portion of the

Figure 9. Sketch showing irregular streaks of siltstone in shale in the upper part of the Carlile Shale in northwestern Kansas.

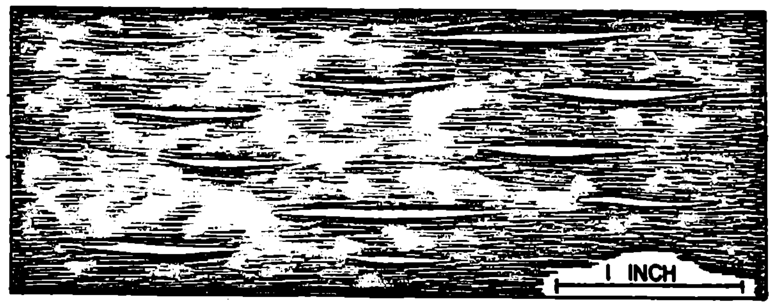


Figure 10. Sketch showing plano-convex lenses of siltstone in shale in the upper part of the Carlile Shale in northwestern Kansas.

Codell where they occur as small (0.15 foot $\pm$) siltstone lenses in shale. Many of these small lenses of siltstone are laminated with paper-thin layers of shale.

A few relatively large lenses of sandstone, siltstone or shale are also present in the upper few feet of the Codell. Lenses observed by the author measured about 15 feet across the face of the outcrop and had a thickness of one foot or less. Figure 11 shows one-half of an argillaceous sandstone lens at Locality RoA in Rooks County. This lens occurs approximately 12 feet below the base of the Ft. Hays Limestone. It will be noted that a band of wavy shale is present midway between the upper and lower surface of the sandstone lens. Slickensides present on the shale at the base of the sandstone lens suggest, though, that the irregularities in the bedding are a result of fairly recent movements, probably associated with slumping. At Locality ElC, a relatively thin (0.5 foot) plano-convex sandy shale lens having a width of about 15 feet is present in a massive sandstone unit. These larger lenses seem to occur only in the upper part of the Codell. This indicates that currents, though relatively weak, were active at the time the clastics in the upper part of the Codell were deposited.

TUBULAR STRUCTURES

Throughout most of its outcrop belt in Kansas, the Codell contains in its extreme upper part numerous light gray calcareous tubular structures (fig. 12).

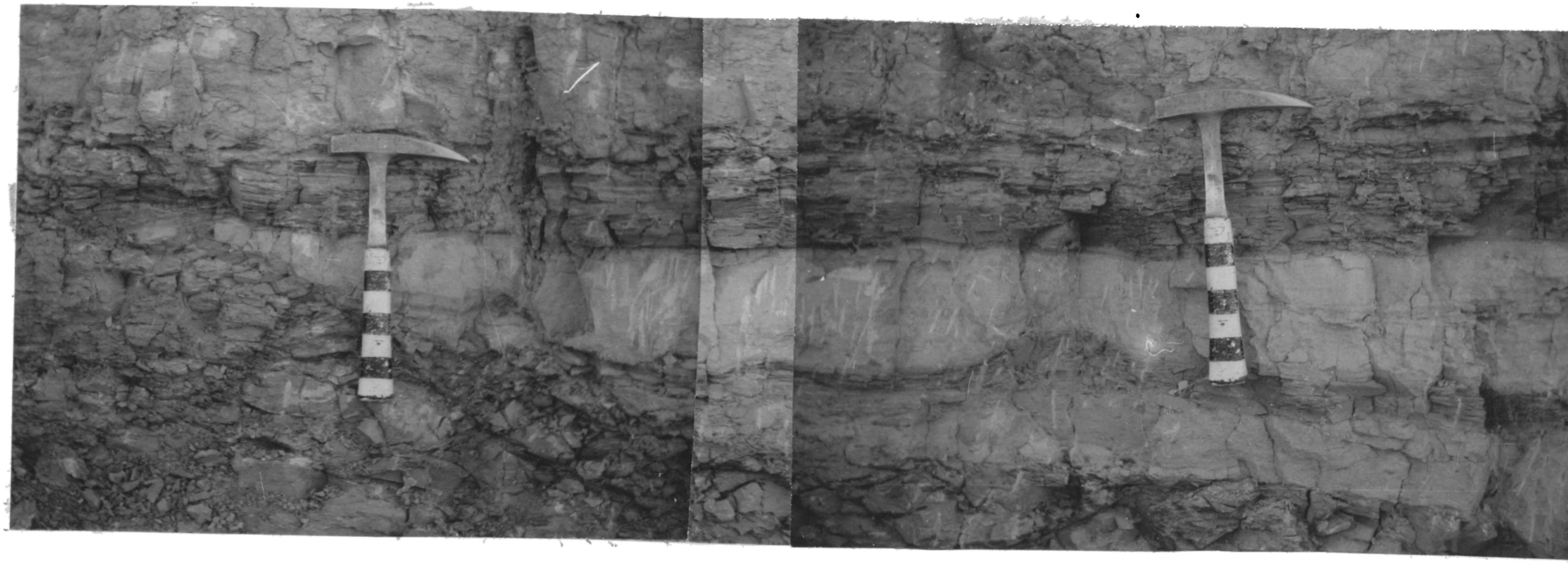


Figure 11. One half of a very fine grained sandstone lens in the upper part of the Carlile Shale. SW¼, Sec. 33, T. 7 S., R. 16 S., Rooks County, Kansas (Locality RoA).

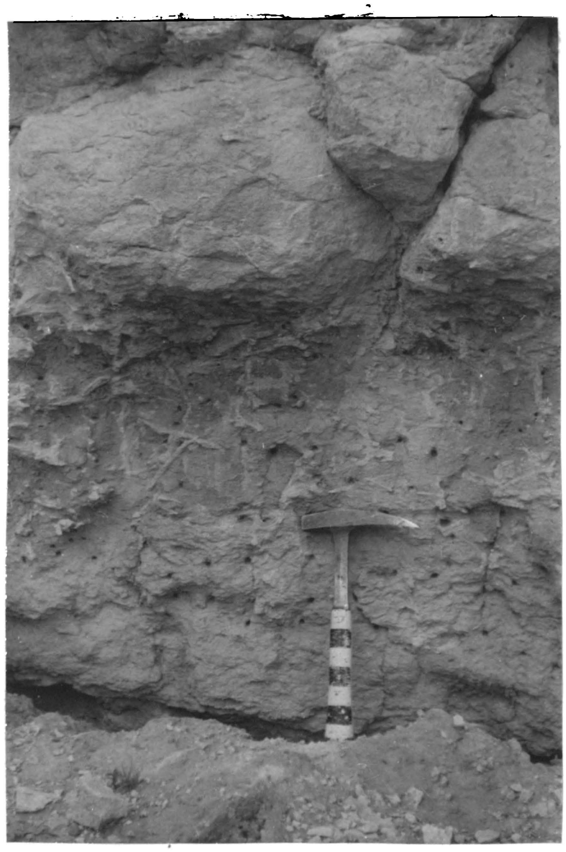


Figure 12. Grayish white, calcareous tubular structures occurring in the Codell Sandstone just below the base of the Ft. Hays Limestone. The holes in the sandstone are a product of recent burrowing organisms. NW cor., SW¼, Sec. 5, T. 10 S., R. 13 W. (Locality ObE).

These tubular structures are usually anastomosing, but have a dominantly vertical orientation. Their diameter is usually about 0.02 to 0.05 foot though one having a diameter of about 0.1 foot was noted. For the most part, they do not seem to extend much lower than three feet below the base of the Ft. Hays Limestone, and usually are most abundant in the upper one foot. An exception occurs at Locality ElC where the tubular structures are present approximately seven feet below the base of the Ft. Hays Limestone, as well as near the base of the limestone. However, the tubular structures occurring seven feet below the Ft. Hays at Locality ElC, are predominantly horizontal (fig. 18). In many places, they are sparce or possibly absent but locally, they may be so abundant as to be almost sheet-like (fig. 13). Although it is not readily apparent at most outcrops, the tubular structures often seem to extend up into the Ft. Hays Limestone. They occur mostly in sandstone or siltstone but are also present in shale, especially in the southern part of the area of study.

The origin of the calcareous tubular structures is questionable, although it is probable that they are organic, originating from a burrowing organism of one type or another. However, because there seems to be no real proof of this, they are included in this section dealing with sedimentary structures.

SEPTARIAN CONCRETIONS

In southern Osborne County, large calcareous concretions ranging up to eight feet in diameter occur in the Codell Sandstone. This is the only area wherein large concretions were observed in sandstone proper. At numerous other localities, though, large concretions are present in the shale underlying the Codell.

All of the large concretions seem to be septarian (fig. 14), containing numerous veins of either brown (color due to hydrocarbons, Swinford, 1953) or white calcite. They are ellipsoidal to spheroidal in shape and seem to be syngenetic in as much as thin siltstone beds pass through them undisturbed (fig. 15). Fossils and pyrite nodules are often found associated with the concretions.

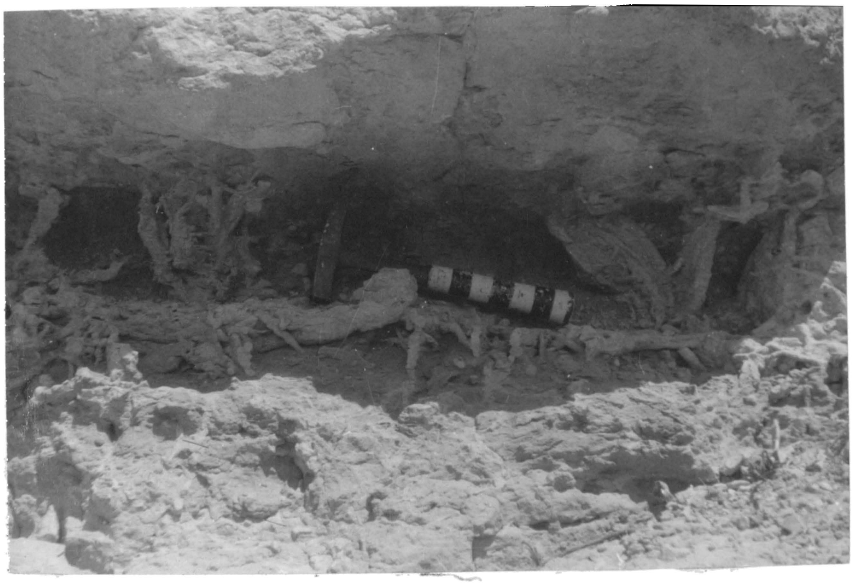


Figure 13. Calcareous structures in the upper part of the Codell Sandstone just below the Ft. Hays Limestone. NW cor., SW¼, Sec. 22, T. 12 S., R. 16 W. (Locality ElF).

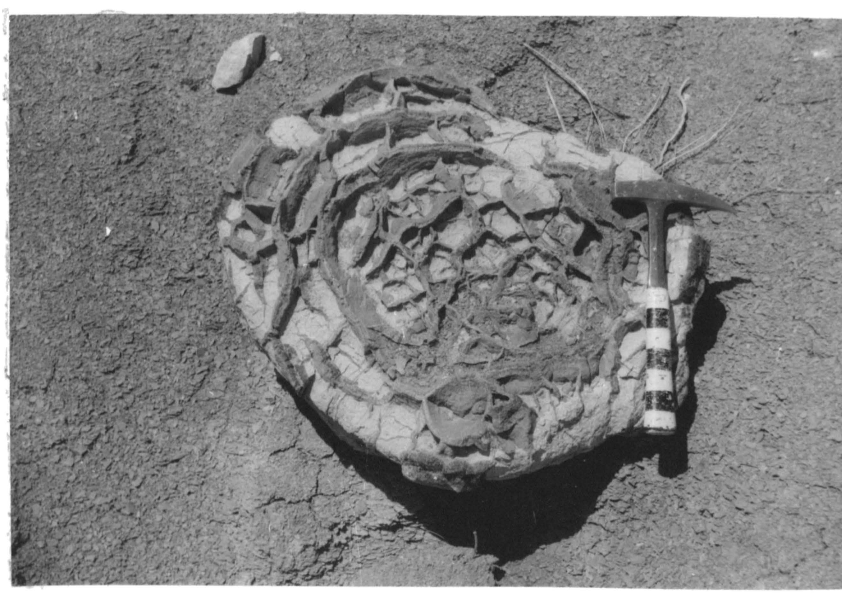


Figure 14. Septarian concretion found 45 feet below the base of the Ft. Hays Limestone in the upper part of the Carlile Shale. NE cor., NW¼, Sec. 12, T. 11 S., R. 16 W., Ellis County (Locality ElE).

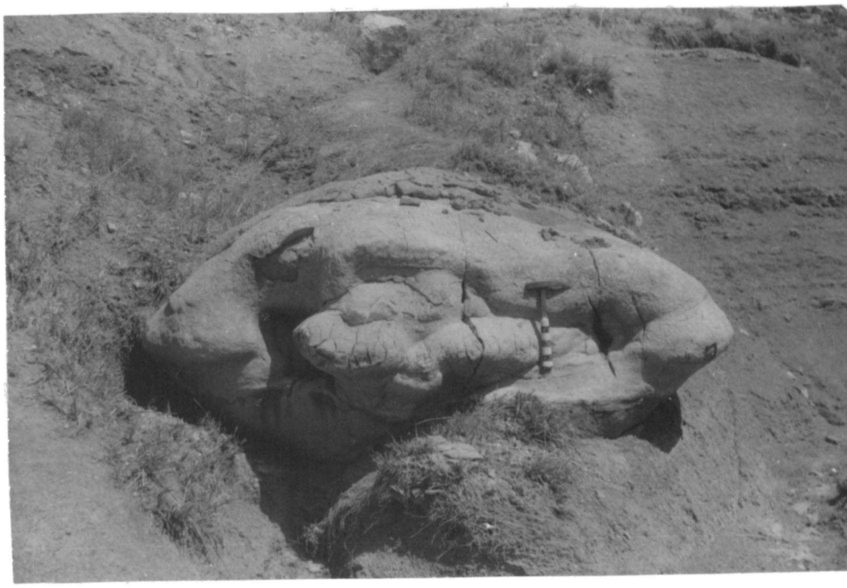


Figure 15. Septarian concretion in the upper part of the Carlile Shale. SW¼, Sec. 26, T. 12 S., R. 16 W., Ellis County, Kansas (Locality E10).

OTHER STRUCTURES

Limonite Nodules.

Scattered sparingly throughout the Codell Sandstone are solid nodules of limonite. These vary in size and shape but are usually 0.1 foot or less in diameter and more or less ellipsoidal. Their outer surface is usually rough or irregular. In as much as some of these nodules have iron sulfide cores, it is likely that the solid limonite nodules in the Codell represent iron sulfide nodules that have been altered by weathering.

Locally, there are also found some usually smaller, smooth, round or elongated, solid limonite nodules. These seem to be most abundant in the sandstone in the extreme upper part of the Codell. These may be coprolites.

Also, at Locality JwC in Jewell County, a number of small hollow limonite nodules, or perhaps concretions, were found. These hollow nodules tend to be elongated and flattened somewhat. In size and shape, they resemble the smooth nodules that may be coprolites; the fact that they are hollow, though, suggests that they may be of secondary origin.

Ripple Marks.

At one locality in Mitchell County (Locality McA), small oscillation-type ripple marks were present in a very fine grained sandstone occurring in a concretion zone approximately 25 feet below the base of the Ft. Hays. Although this was the only occurrence of ripple marks noted in the field, many of the plano-convex lenses and thin disconnected sandstone or siltstone beds that are present in the upper part of the Carlile may be a product of a similar environment.

PALEONTOLOGY

Fossils are fairly common in the Codell, but are not very diagnostic. Most of the fossils found in the Codell consist of shark teeth and bones or fragments of bones. The shark teeth are both of the cutting and pavement types. Bone material is also present as sand-sized particles and probably ranges downward to clay sized particles. The sand-sized particles of bone material are especially common in the calcareous, or limy, sandstones in southern Ellis County.

In Ellis County (Locality ElF), part of an Inoceramus sp. shell and one large vertebrae (0.15 foot) were found in the Codell near the base of the Ft. Hays Limestone. Locally, on the surface of outcropping Codell Sandstone, there are other structures of probable organic origin, but they are not clearly distinguishable as such. Also, some smooth limonite nodules (See page 41 of this draft) found in the Codell may be fossilized fecal pellets, but this is uncertain. One fossil Elopid fish has been found in the Codell and described by Miller (1958, p. 213). Miller points out that Elopid fish living today are both nearshore marine and fresh-water dwelling. Also, Hattin (personal communication, 1960) reports finding both calcareous and arenaceous forms of foraminifera in the Codell.

CONTACTS WITH OTHER UNITS

LOWER CONTACT

The columnar section in Figure 2 points out that sedimentation which produced the strata of the Carlile proceeded from a calcareous mud phase (Fairport Chalk) to a noncalcareous mud phase (Blue Hill Shale) and then finally to a sandy mud phase (Codell Sandstone). Changes in sedimentation between these three phases seem to have been gradual. Because of this, the lower boundary of the Codell with the Blue Hill Shale has be more or less arbitrarily chosen.

On the outcrop, the Codell-Blue Hill contact is commonly placed where there is, in addition to a notable change in color, a distinct increase in the amount of sand-size particles present in the section. The color change is from the dark gray to bluish gray color of the Blue Hill Shale to a light yellowish brown or light gray color of the Codell. The yellowish brown color is dependent on the degree of weathering to which the outcrop has been subjected. At relatively fresh outcrops, the sandstone or siltstone of the Codell is light gray in color. By placing the Codell-Blue Hill contact at the base of a prominent sandstone or siltstone unit, however, the presence of numerous siltstone lenses and/or sandy shale below this point tends to be disregarded. But if the shale containing abundant siltstone lenses is included in the Codell, there is the problem of establishing a lower boundary for the Codell. The gradational character of this change in lithologies makes the task of establishing a lower boundary extremely difficult. It is the opinion of the author, though, that the shale in the extreme upper part of the Carlile which contains notably abundant and conspicuous lenses of siltstone should be regarded as a part of the Codell, in as much as the appearance of these siltstone lenses reflects a small change from the previous environment of sedimentation. In this paper, the shale (in the extreme upper part of the Carlile) containing numerous streaks and plano-convex lenses of siltstone will be included in the Codell Sandstone.

UPPER CONTACT

The upper contact of the Codell does not present the same problems as does the lower contact. The Codell is overlain by the Ft. Hays Limestone Member of the Niobrara Chalk. The contact between these two units is parallel to the bedding in the two units, and is sharply defined as a result of an abrupt change in lithologies. This change in lithologies is from a shale, siltstone or sandstone of the Codell to chalky limestone of the Ft. Hays. (See Figures 19 - 21).

Paleontological evidence (Dane, Pierce, and Reeside, 1937, p. 220) suggests that there is an unconformity between the Carlile Shale and the Niobrara Chalk and it is thought that this unconformity occurs at the base of the Ft. Hays Limestone. The sharp contact between the limestone and the underlying clastics does indeed seem to be a logical place to put the upper contact of the Codell. However, it may be that some of the strata in the upper part of the Codell are composed of reworked material and possibly should not be included in the Carlile. This will be discussed more at the conclusion of this paper.

DESCRIPTION OF THE CODELL IN THE TYPE AREA (NORTHERN ELLIS COUNTY)

The type section of the Codell, Locality E1D, is at a roadcut on the north flank of the Smoky Hill River Valley in the NE cor., Sec. 3, T. 11 S., R. 17 W., Ellis County (fig. 16). The upper portion of the roadcut is composed of light yellowish gray chalky Ft. Hays Limestone. The contact between the Ft. Hays Limestone and the underlying Codell Sandstone is sharp and marked by a thin (ca. 0.15 foot) layer of gray shale and poorly indurated orange-brown sandstone. For the most part, the 24 feet of strata immediately underlying the Ft. Hays consist of light yellowish to brownish gray massive to somewhat nodular, very fine grained, friable, noncalcareous, argillaceous sandstone. This is underlain by about 5.5 feet of soft siltstone and then approximately 16 feet of soft siltstone and then approximately 16 feet of gritty shale containing thin beds and small streaks and plano-convex lenses of siltstone. The lower part of this gritty shale is spotted. The spots are composed of silt sized particles which are enclosed in a gray clayey matrix. A rather conspicuous concretion horizon occurs in this shale about 40 feet below the base of the Ft. Hays. The gritty shale is in turn, underlain by only slightly gritty to non-gritty, dark gray flaky shale which lacks the numerous small lenses and streaks of siltstone. Contacts between the various lithologic units mentioned above, excepting the Codell-Ft. Hays contact, seem to be gradational.

The lower 16 feet of the 24 feet of sandstone at Locality E1D contains several layers that are noticably argillaceous, and which tend to form small indentations in the weathered profile. In general, the sand-

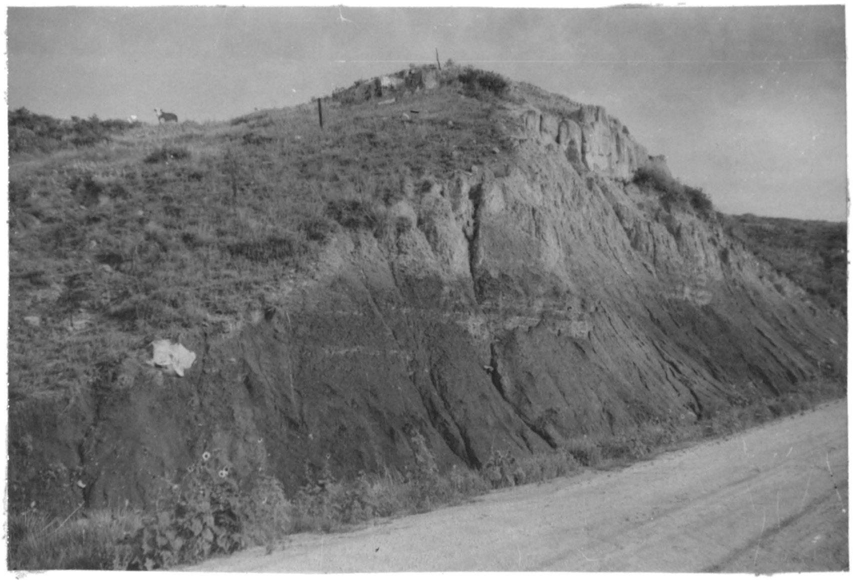


Figure 16. Codell Sandstone capped with Ft. Hays Limestone and underlain by Blue Hill Shale in the NE cor., Sec. 3, T. 11 S., R. 17 W., Ellis County (Locality E1D). Note the concretion (C) and the numerous thin beds of siltstone in the lower part of the Codell.

stone tend to become less argillaceous toward the top of the unit. Small yellowish brown to yellow specks of iron oxide also occur in the 16 feet of the sandstone unit, and thus gives it a somewhat mottled appearance. The upper eight feet of the sandstone is more massive than the underlying 16 feet and stands out more boldly on the outcrop (fig. 16).

Thin horizontal bands of limonite, generally about 0.05 feet thick, and scattered irregularly shaped limonite nodules, about 0.1 foot in diameter, are abundant in the upper eight feet of the sandstone. However, many of the bands of limonite fill what are probably recently formed fractures, and these cut diagonally across the bedding throughout the 24 feet of sandstone. In general, the bedding in the sandstone is very faint and not readily apparent.

Close examination, however, reveals that much of the sandstone does exhibit very small scale irregular bedding. This latter feature is generally more noticeable, however, in the more argillaceous horizons, primarily because of the contrast in texture between the silt and/or sand sized particles and clay sized particles. The upper part of the sandstone, especially the upper one foot, contains a few calcareous tubular structures.

Several miles west of the type section, another outcrop, Locality ElC, which is quite similar lithologically to that of the type section, shows more clearly the disposition of lithologies in the upper portion of the Codell (fig. 17). The upper sandstone unit consists of 7.5 feet of massive very fine grained argillaceous sandstone which exhibits on weathered surfaces faint lines suggestive of medium scale (McKee and Wier, 1953) cross-bedding. This massive sandstone unit is underlain by a sandstone of similar lithology except that it is more argillaceous. Also, in the lower sandstone unit, less argillaceous beds alternate with more argillaceous beds in a somewhat rythmic fashion (This feature is also present in the lower 16 feet of sandstone at Locality ElD). At the top of the massive sandstone unit, and in contact with the base of the Ft. Hays Limestone, there is a very thin layer of soft yellowish brown sandstone.

In the upper massive sandstone unit at Locality ElC, there occurs a relatively thin (maximum thickness about 0.5 foot) sandy, plano-convex shale lens having a width of about 15 feet. This shale is composed of dark gray gritty shale interlayered with light gray bands of siltstone.

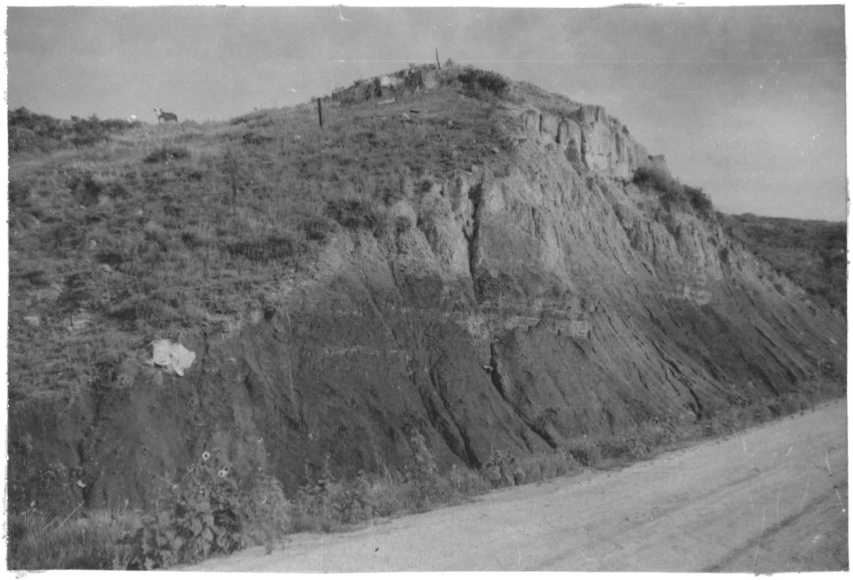


Figure 16. Codell Sandstone capped with Ft. Hays Limestone and underlain by Blue Hill Shale in the NE cor., Sec. 3, T. 11 S., R. 17 W., Ellis County (Locality EIO). Note the concretion (C) and the numerous thin beds of siltstone in the lower part of the Codell.

stone tend to become less argillaceous toward the top of the unit. Small yellowish brown to yellow specks of iron oxide also occur in the 16 feet of the sandstone unit, and thus gives it a somewhat mottled appearance. The upper eight feet of the sandstone is more massive than the underlying 16 feet and stands out more boldly on the outcrop (fig. 16).

Thin horizontal bands of limonite, generally about 0.05 foot thick, and scattered irregularly shaped limonite nodules, about 0.1 foot in diameter, are abundant in the upper eight feet of the sandstone. However, many of the bands of limonite fill what are probably recently formed fractures, and these cut diagonally across the bedding throughout the 24 feet of sandstone. In general, the bedding in the sandstone is very faint and not readily apparent.

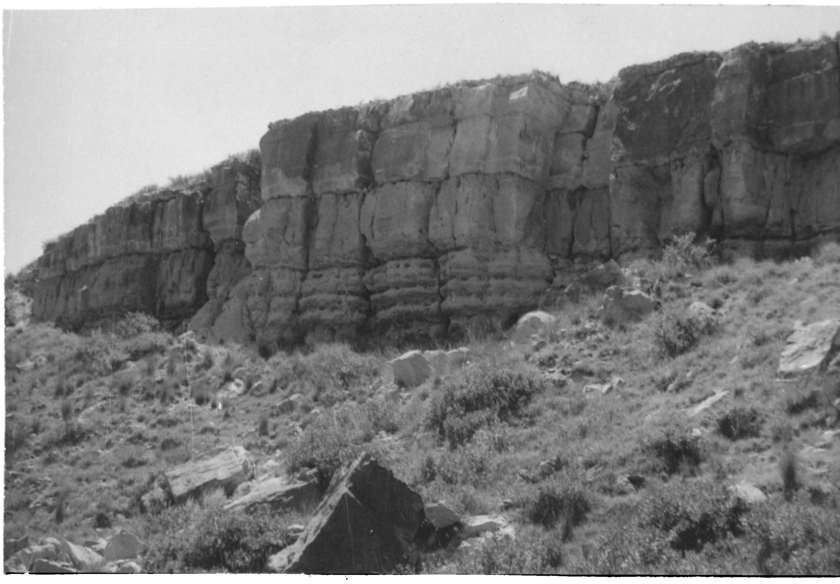


Figure 17. Ft. Hays Limestone in sharp contact with the Codell Sandstone in the SE¼, Sec. 4, T. 11 S., R. 18 W., Ellis County (Locality ElC).

On the top of the sandstone immediately underlying this shale lens, there occurs an interlacing network of horizontally disposed tubular structures (fig. 18). These tubular structures are also present in the lower rythmically bedded sandstone, but seem to be relatively rare. Actually the tubular structures may be more abundant than they first appear to be in both the massive and rythmically bedded sandstone units, but because of the uniform texture and lithology of the sandstone, simply are not visibly expressed on the rock surface. Tubular structures are also found in the sandstone near the base of the Ft. Hays Limestone where they tend to be vertical and composed of a light gray, somewhat chalky, calcareous material, and consequently, they are more apparent on the outcrop.

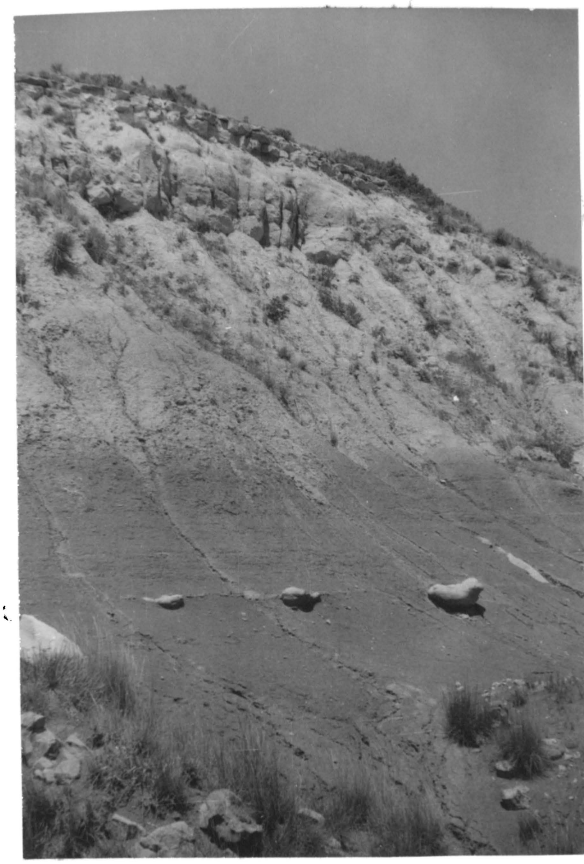


Figure 19. Outcrop of Codell Sandstone situated in the NE cor., NW¼, Sec. 12, T. 11 S., R. 16 W., of Ellis County (Locality E1E).

gritty, dark grey shale. This alternating sequence of siltstone and gritty shale is underlain by approximately 10 feet of dark gray shale containing plano-convex lenses and an occasional thin bed (about 0.1 foot thick) of siltstone. At the top of this gray shale, there occurs a spotted shale similar to that found at Locality E1D. A pronounced septarian concretion zone is present about 45 feet below the base of the Ft. Hays.

LATERAL VARIATIONS OF LITHOLOGY

VARIATIONS ALONG THE OUTCROP

In general, as one goes northeast or southwest from the Codell's type section, the argillaceous sandstone of the Codell grades laterally into siltstone and shale. Northeast of the type section this change is rather abrupt whereas to the southwest the change is more gradual. In order to better demonstrate these variations of the Codell's lithology on the outcrop, a cross section compiled from measured sections has been prepared and is shown on Plate I.

From Plate I, it can be seen that sandstone and siltstone in the upper part of outcropping Carlile Shale are most abundant in northern Ellis County and southern Osborne County. North of southern Osborne County, sandstone and siltstone are practically absent from the upper part of the Carlile. There is, however, a thin sandstone bed occurring at the extreme top of the Carlile Shale, which, north of the type locality, is usually in contact with limestone at the base of the Niobrara. This sandstone is rather wide spread, occurring as far north as the Kansas-Nebraska border. Some characteristic features of this sandstone bed as seen on the outcrop are:

1. Its thickness over the area north of the type section varies from about three feet to a feather edge, with approximately one foot a rather commonly observed thickness;
2. It is fine to very fine grained and very argillaceous;
3. It is noncalcareous;

4. It weathers to a pronounced orange to yellowish brown color; unweathered, it is light gray to gray;
5. It contains small (0.03 foot) shark teeth and bone fragments which are locally rather abundant;
6. It contains light gray to nearly white, calcareous anastomosing tubular structures (not always readily apparent or abundant north of the type section) which locally seem to extend upwards into the overlying Ft. Hays Limestone.
7. It contains widely scattered nodules of limonite having a diameter of approximately 0.1 foot;
8. The upper contact with the Ft. Hays Limestone is sharp and parallel.
9. The lower contact with the underlying shale is sometimes irregular having small indentations or channels into the underlying shale.

Southwest of the type section, a sandstone of similar lithology to that just described is also present in the upper part of the Carlile. It is different, though, in that locally, it may be separated from the Ft. Hays Limestone by shale or siltstone; its thickness is more variable; it is generally more calcareous, and; the anastomosing calcareous tubular structures seem to be more common.

At the type section, Locality E1D, the main body of Codell Sandstone is underlain by siltstone and then shale containing small streaks and plano-convex lenses of siltstone. Northeastward from Locality E1D, the amount of sandstone decreases rapidly. In southern Osborne County, at Locality

ObE, sandstone is interbedded with siltstone and is still fairly abundant. However, in central Osborne County, Locality ObC, the sandstone present is confined practically to the previously discussed thin sandstone at the top of the Carlile, with the bulk of the Codell represented by dark gray shale containing numerous streaks and plano-convex lenses of siltstone. In eastern Rooks County, west of Osborne County, an outcrop at Locality RoA (See Plate II for location) probably represents that area of transition between the sandstones of the Codell and the silty shale in Osborne County. At Locality RoA, the Codell is composed of very sandy and silty shale containing numerous thin beds of sandstone and siltstone, especially in the 40 feet of strata immediately underlying the Ft. Hays Limestone (fig. 20).

In northern Osborne County at Locality ObB, about one foot of sandstone occurs in the uppermost part of the Carlile and is in contact with the Ft. Hays Limestone. This sandstone is underlain by about 14 feet of dark gray noncalcareous shale that lacks the conspicuous plano-convex lenses of siltstone; this shale is underlain by about 26 feet of shale containing plano-convex lenses of stilstone. This sequence of lithologies, i.e. Ft. Hays Limestone underlain in order by a thin sandstone bed, dark gray shale containing plano-convex lenses of siltstone, and then dark gray shale lacking plano-convex lenses, remains a persistent feature of the strata in the upper part of the Carlile northeastward to the Kansas-Nebraska border (See Plate I).

Southwest of the type section (Locality ElD), the massive sandstone beds become less abundant in the Codell and are not found outcropping south of central Ellis County. Massive sandstone beds may be present in the

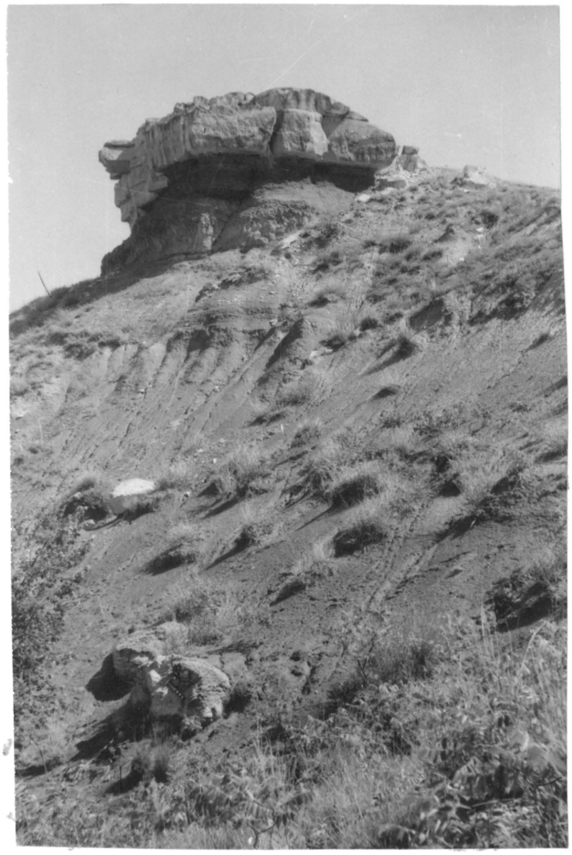


Figure 20. Carlile Shale capped with Ft. Hays Limestone. The 40 feet of strata underlying the base of the Ft. Hays is composed principally of sandy and silty shale with sandstone and siltstone most abundant in the upper 10 feet. The concretion in the foreground lies approximately 60 feet below the base of the Ft. Hays Limestone. SW¼, Sec. 33, T. 7 S., R. 16 W., Rooks County, Kansas (Locality RoA).

vicinity of western Finney County (See Plate II), but are presently covere by younger rocks. South of central Ellis County, the Codell is composed principally of dark gray gritty shale containing thin beds, streaks and small plano-convex lenses of siltstone with locally developed sandstone lithologies. The sandstone and siltstone beds that are present in the Codell south of central Ellis County are usually most abundant and conspicuous in the upper few feet of the Codell, and thus occupy a stratigraphic position similar to that of the thin sandstone bed at the top of the Codell in northern Kansas. Where sandstones are present in the upper part of the Codell, they may be separated from the overlying Ft. Hays Limestone by a shale bed.

At several outcrops south of the type section, the sandstone beds in the upper part of the Codell are calcareous. These calcareous sandstone beds occur principally in the southern part of Ellis County and the northern part of Ness County. In this area, numerous thin, wavy, light gray beds of sandy calcium carbonate occur in the sandstone (fig. 21).

Light gray calcareous tubular structures are also present at most outcrops southwest of the Codell's type section. They occur in the uppermost part of the Codell Sandstone and usually extend upwards into the Ft. Hays Limestone.

The contact between the Codell and the Ft. Hays Limestone southwest of the type section is parallel and sharp. Locally,though, where the sandstone is calcareous, the change in lithologies seems to be somewhat gradual. At some localities, the lower contact of the sandstone beds is wavy or irregular. These irregular contacts indicate that there was some erosion or reworking of previously deposited sediments.

The cross section of outcropping Codell Sandstone (pl. I) extends no farther south than Finney County. Other outcrops of the Codell Sandstone do occur, though, west of Finney County in Hamilton County. In Hamilton County, several southward flowing tributaries of the Arkansas River, have exposed the upper part of the Carlile in a few areas. Tertiary and Quaternary sediments have effectively covered most of the older rocks present in the intervening area. Although the writer of this paper

Figure 21. Codell Sandstone underlying the Ft. Hays Limestone. The yellowish brown sandstone containing numerous thin gray limy layers is separated from the Ft. Hays by about 2.5 feet of shale. SW¼, Sec. 28 T15 S., R. 20 W., Ellis County, Kansas (Locality E1K).

did not see the Codell in Hamilton County, Bass (p. 63, 1926) describes the Codell as being composed of "...25 feet...of gritty shale containing very thin streaks of silty sandstone, and the top two feet is largely sand."

VARIATIONS IN THE SUBSURFACE

Subsurface samples and electrical log data serve to define in the subsurface of northwestern Kansas, two areas wherein the Codell is composed of sandstone similar to that outcropping at the type locality (See Plate II). Both of these areas elongated along a line having a general northwest to southeast trend. One area of relatively well developed sandstone lithology occurs in the central part of extreme western Kansas, in the vicinity of Greeley, Wichita, Kearny and possibly Finney Counties. The other area is found in northwestern Kansas, in the vicinity of Cheyenne County and Rawlins County and extends southeastward until it intersects the surface in northern Ellis County and southern Rooks and Osborne Counties.

In both of the above mentioned areas, there is a considerable amount of interstitial argillaceous material in the sandstone, in addition to locally intercalated beds of shale. The Codell in Greeley, Wichita and Kearny Counties seems to be appreciably more argillaceous than the Codell in northwestern Kansas. Electrical logs and subsurface samples suggest that the Codell in Greeley, Wichita and Kearny Counties is composed primarily of siltstone and sandy shale with only locally developed sandstone lithologies. Fairly well developed sandstone, similar to that found at the type section and in the extreme northwestern Kansas, does seem to be more common, though, in Greeley County and western Wichita County. In northwestern Kansas, the better developed sandstones of the Codell are very similar to the sandstones outcropping at the type locality in northern Ellis County.

The Codell Sandstone is present in the subsurface over a wide area between the two belts of sandstone mentioned above, and it is composed predominantly of siltstone and sandy shale. These sandy shales are probably very much like those occurring in Ness County.

In the northeastern part of the area of study, in the vicinity of Phillips, Smith and Jewell Counties, recognizable Codell Sandstone is not present on electrical logs. Indeed, the electrical logs strongly suggest that the Codell grades laterally northward into shale (fig. 22). This is also suggested by outcrop data (pl. I). The zigzag line on Plate II delineates approximately the line north of which the Codell grades laterally into shale and becomes unrecognizable as a unit.

Another area in which the Codell is absent occurs in the vicinity of Sherman County and Wallace County. In this area, the Codell seems to have been eroded away, or, was never deposited. This will be discussed further in the conclusion of this paper.

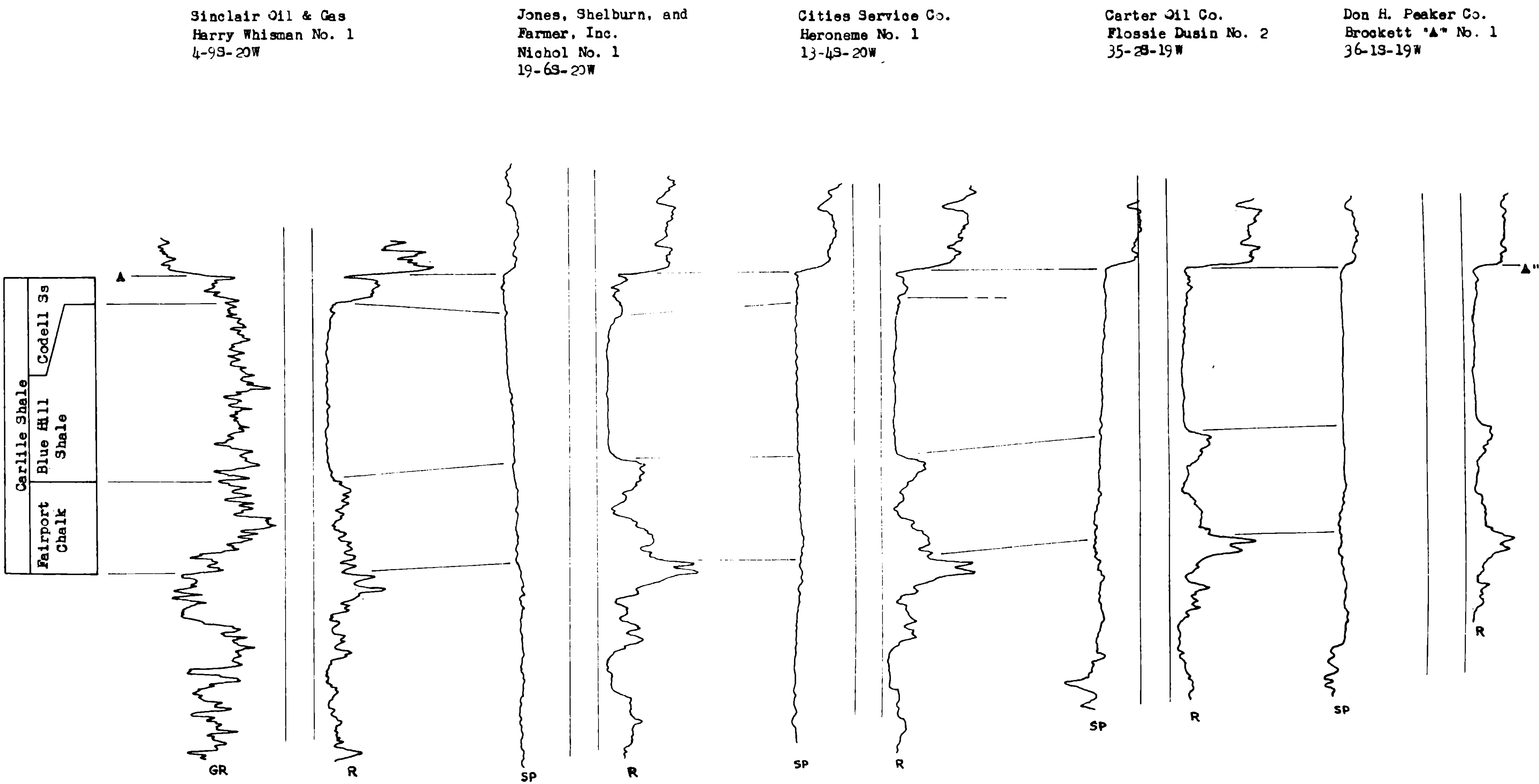


Figure 22. North-south subsurface cross section showing the lateral transition of the Codell Sandstone into Shale. Location of the cross section is shown on Plate II. (GR, Gamma Ray; SP, Self Potential; R, Resistivity)

THICKNESS

THICKNESS VARIATIONS OF THE CODELL SANDSTONE

Two areas of relatively thick Codell Sandstone are shown on Plate II. One of these areas occurs in northwestern Kansas, in Rawlins County and the other is in central western Kansas, in the vicinity of Wichita, Kearny, and Finney Counties. Both of these areas seem to be elongated slightly among a line having a general northwest to southeast trend. They also correspond generally with the same areas in which the relatively better developed sandstones of the Codell occur. The maximum thickness of the Codell in Kansas in the subsurface occurs in central Rawlins County, where it is about 90 feet thick. In central western Kansas, the thickness of the Codell may exceed 80 feet. A good comparison of the two areas of thick Codell is difficult to attain, though, because of the scarcity of electrical logs in the vicinity of southern Wichita, and Scott Counties, and northern Kearny and Finney Counties. Also, the character of the electrical logs in the southern part of the area of study is probably influenced to some degree by fresh water in the Codell.

Between the two areas of relatively thick Codell Sandstone, the unit is usually between 10 and 30 feet thick with 20 feet and approximate average. In southern Sherman and northern Wallace Counties, the Codell is absent. In southeastern Scott County, there is a small area in which the Codell seems to be absent.

In the northeastern part of the area of study, the Codell Sandstone seems to grade laterally into shale, and in so doing creates a zero isopachous line. This zero isopachous line is not sharp and is showing on Plate II by means of a zigzag line. The zero isopachous line does not take into consideration the previously described thin sandstone that occurs at the top of the Carlile in contact with the base of the Ft. Hays Limestone. The reason for not considering this thin sandstone is given in the conclusion of this paper.

THICKNESS VARIATIONS OF STRATIGRAPHIC UNITS ASSOCIATED WITH THE CODELL

Carlile Shale

On comparing the isopachous map of the Carlile Shale (fig. 23) with the isopachous map of the Codell (pl. II), it can be noted that there are several areas of similarity. Near the western border of Kansas, in the northwest corner of Wallace County and in the southwest corner and north central part of Sherman County, the Carlile thins to about 160 feet which is the minimum thickness of the Carlile in Kansas. In this same area, the Codell thins and is absent over part of the area.

From the western border of Kansas, the Carlile increases in thickness to the east. This trend toward increasing thickness to the east, however, is not uniform. Indeed, there are two rather conspicuous westward extending salients of thicker Carlile strata. One of these salients is located in northern Kansas, and runs east to west across Cheyenne, Rawlins and Decatur Counties. The other salient, which is situated in the central part of extreme western Kansas, near the border of Wichita, and Kearny Counties, seems to be more abruptly terminated than the salient in northern Kansas, and has a northwest by southeast orientation. These

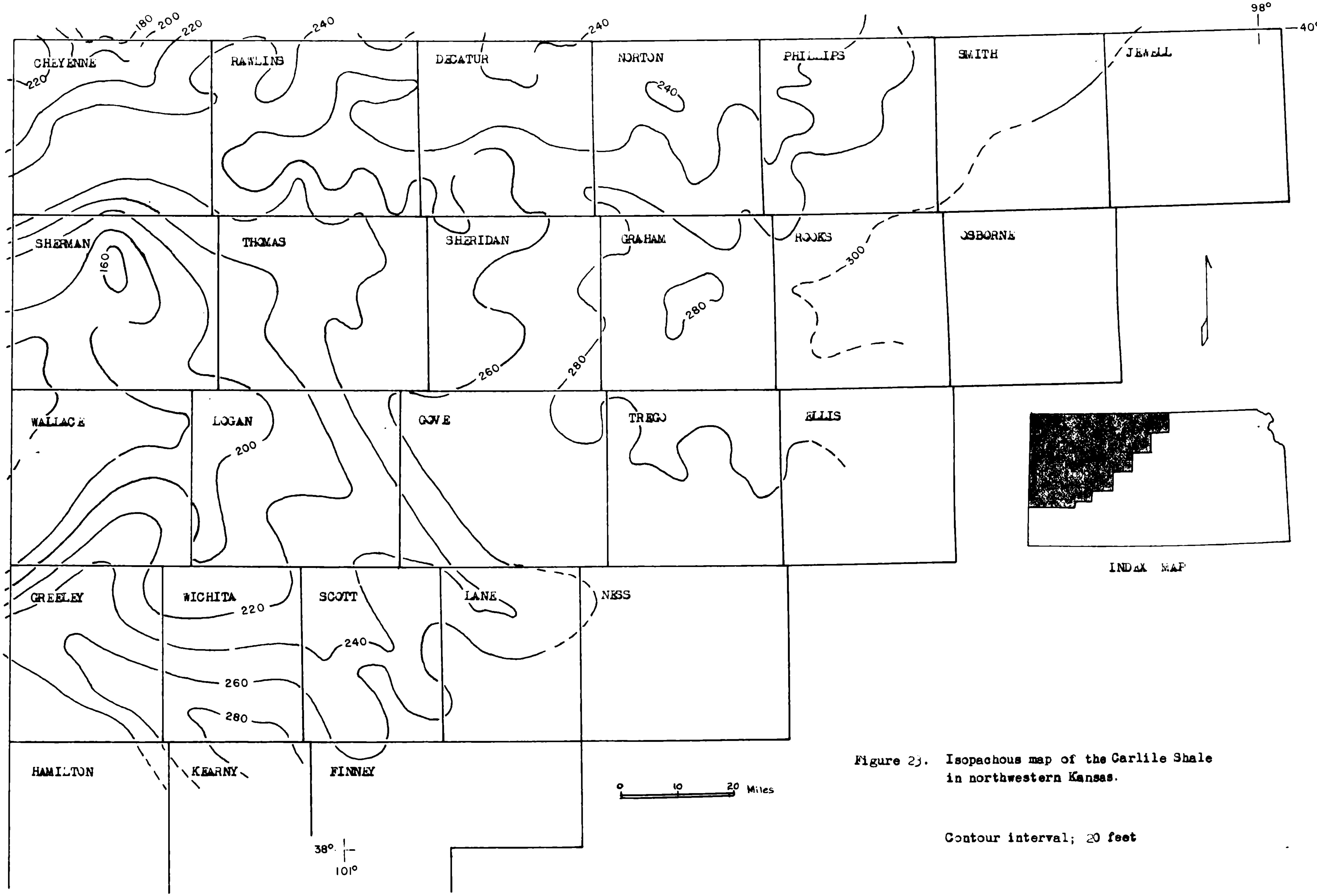


Figure 23. Isopachous map of the Carlile Shale in northwestern Kansas.

Contour interval; 20 feet

salients of thick Carlile strata correspond with areas of relatively thick Codell strata.

The greatest thickness of Carlile strata in Kansas occurs in the northeastern portion of the area of study in the vicinity of Jewell and Osborne Counties. In this area, the Carlile Shale is somewhat more than 300 feet thick.

Fairport Chalk

The isopachous map of the Fairport Chalk (fig. 24) shows the distribution of calcareous shale and limestone in the lower portion of the Carlile in northwestern Kansas. A rather conspicuous belt of thin Fairport strata extends through Sherman, Logan, Gove and Ness Counties along a northwest to southeast line. In this belt, the Fairport has its minimum thickness in Kansas, of about 75 feet. Another, though much less pronounced, belt of relatively thin Fairport having a general northwest to southeast trend extends across the southwest portion of Norton County, through northeastern Grahm County, and into Rooks County. These two belts are nearly parallel. In western Wallace County, and also in the vicinity of southeastern Scott County, the 100 foot contour line delineates other areas of relatively thin Fairport. The areas enclosed by the 80 foot contour line in Sherman County, and the 100 foot contour line in Wallace County, correspond roughly to areas of minimum thickness on the isopachous map of the whole Carlile, as well as the Codell Sandstone. The belt of thin Fairport extending across Sherman, Logan, Gove and Ness Counties also corresponds roughly to an area of thin Codell.

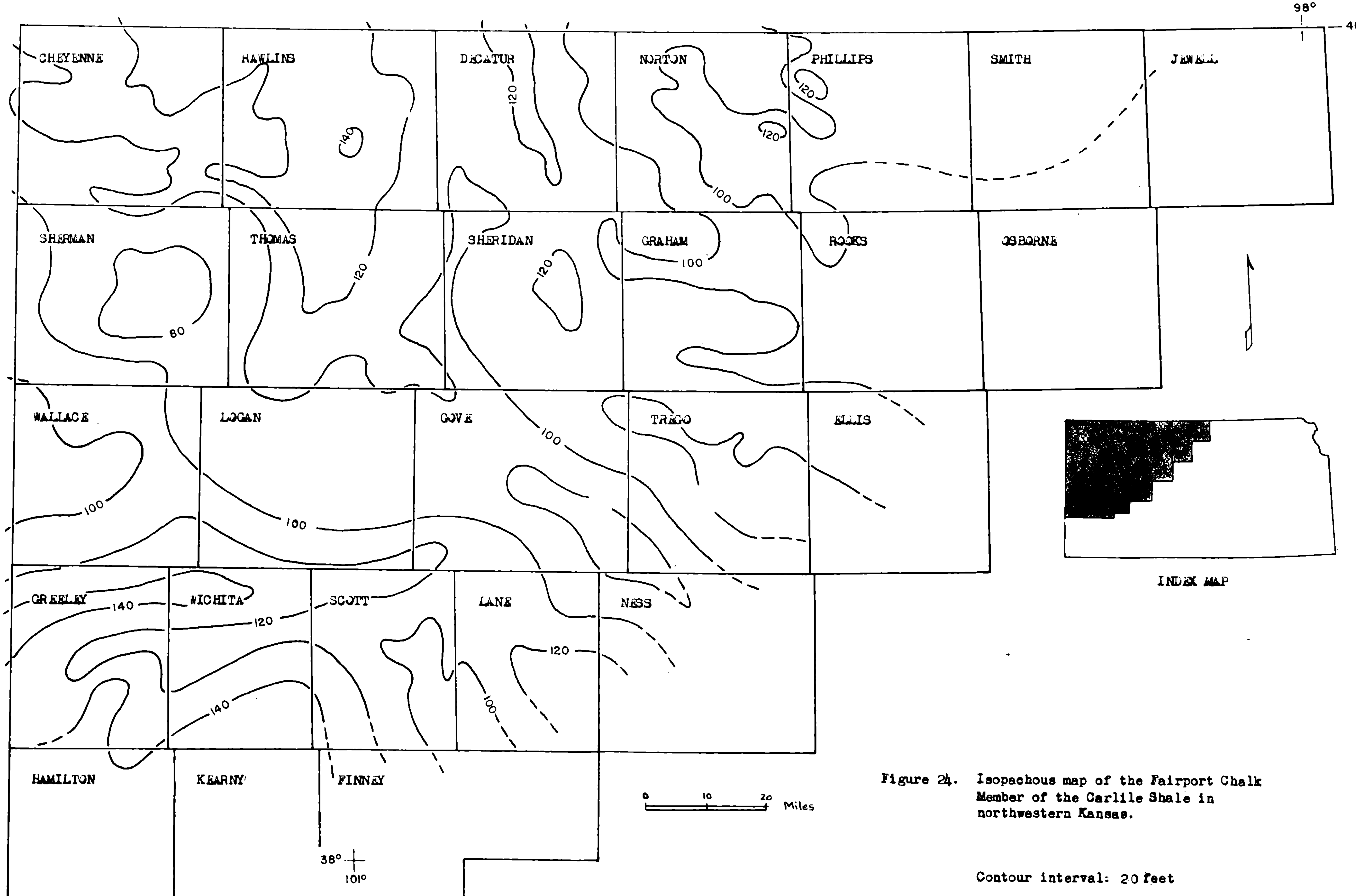


Figure 24. Isopachous map of the Fairport Chalk Member of the Carlile Shale in northwestern Kansas.

Contour interval: 20 feet

Central Rawlins County and northern Greeley County are areas of conspicuous thickness for the Fairport Chalk. These areas of relatively thick Fairport strata are elongated, particularly the one in northern Greeley County. It is in Greeley and Wichita Counties that the Fairport apparently reaches its maximum thickness in Kansas of about 150 feet. It will be noted that the two areas wherein Fairport strata are noticeably thick extend toward each other but are separated in Logan County by the belt of minimum thickness previously described. The configuration of the isopachous lines does not suggest any definitive regional trend toward increasing thickness, though the thickness lines themselves have fairly pronounced northwest to southeast trend over much of the state. Also, there does not seem to be any area of relatively thick strata common to both the Fairport and the whole Carlile, excepting possibly northern Greeley County. In northern Greeley County, the presence of relatively thick Fairport strata is expressed on the map of total Carlile thickness by the configuration of the thickness lines. Central Rawlins County and Greeley, and Wichita Counties are areas in which thick Fairport strata corresponds generally with areas of relatively thick Codell.

Isopachous Map of the Blue Hill Shale.

Distribution of the dark gray, noncalcareous Blue Hill Shale, which is shown on Figure 25 by means of an isopachous map. The Blue Hill is thinnest in the southwestern portion of the area of study where it seems to be about 40 feet thick. This area of thin Blue Hill includes parts of Wallace, Greeley, Hamilton and Kearny Counties.

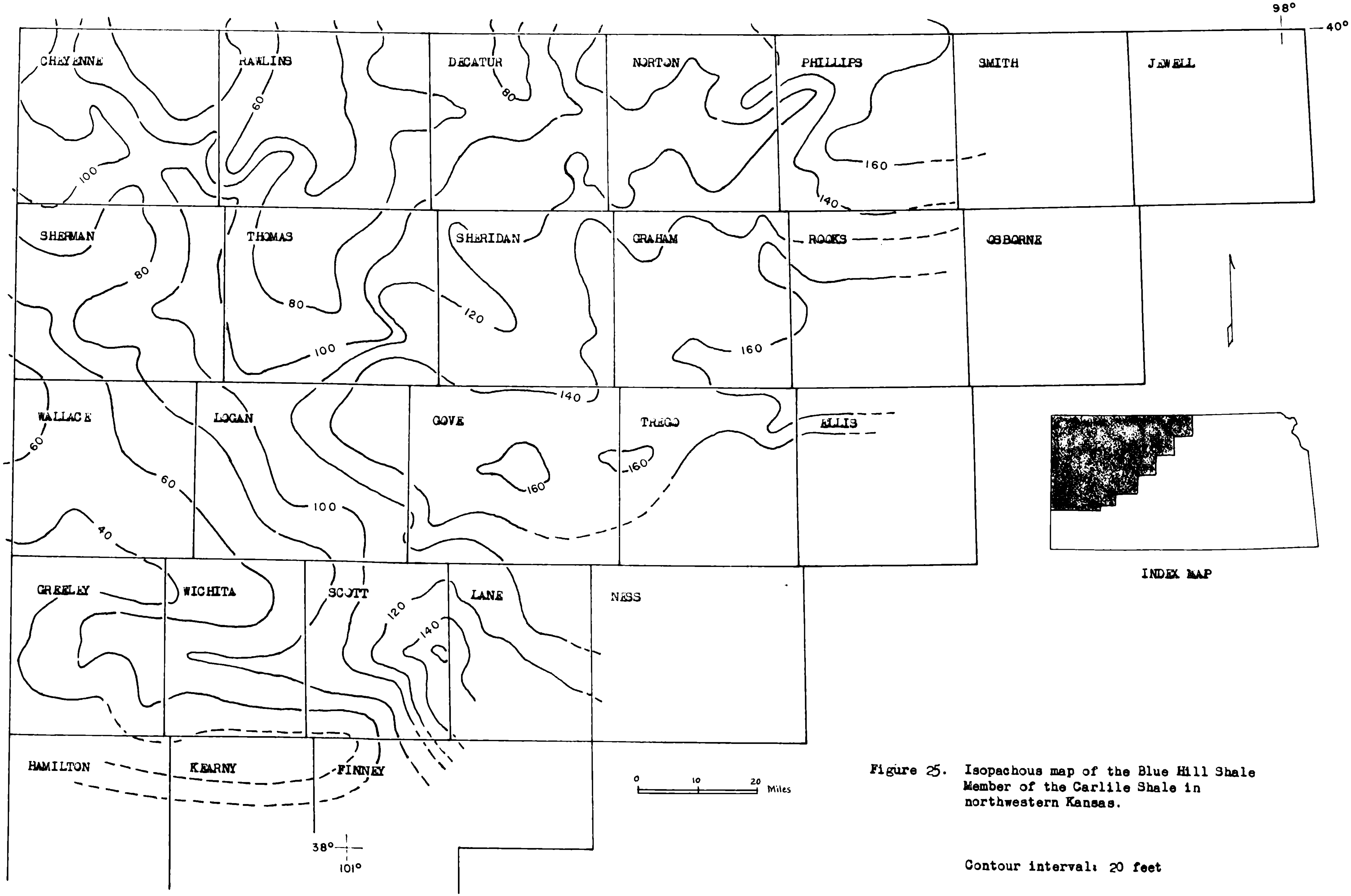


Figure 25. Isopachous map of the Blue Hill Shale Member of the Carlile Shale in northwestern Kansas.

Contour interval: 20 feet

Another area in which the Blue Hill Shale is noticeably thinner occurs in northeastern Kansas, in central Rawlins County and northeastern Cheyenne County.

From these areas of relatively thin strata, the Blue Hill increases irregularly in thickness toward the east. A trough of moderately thick Blue Hill extends northwestward between the two areas of relatively thin Blue Hill. The maximum subsurface thickness of the Blue Hill Shale measured on electrical logs was 174 feet, and this occurs in southern Rooks County. The maximum thickness of the Blue Hill in Kansas, exceeds this, however, and approaches 200 feet in Russell County (Moore, et. al., 1951, p. 24).

When the isopachous map of the Blue Hill is compared with the total thickness map of the Carlile (fig. 23), several relationships can be noted. In western Wallace County, the Blue Hill is thin as is the whole Carlile and the Fairport Chalk Member of the Carlile. Also, the Blue Hill increases in thickness toward the east as does the total Carlile thickness. In Wichita and Kearny Counties, the Blue Hill is relatively thin, whereas the Carlile is relatively thick.

In the preceeding discussion of the Fairport Chalk Member of the Carlile, it was pointed out that a belt of thin Fairport strata extends across Sherman, Logan, Gove and Ness Counties. In this same area, the Blue Hill Shale is relatively thick. In fact, if thicknesses of Blue Hill strata in a given area are compared with thicknesses of Fairport strata in the same area, it will be found that in general they have, with the exception of the western part of Wallace County, an inverse relationship. This inverse relationship seems to disappear toward the east though, where deposition, as interpreted from the isopachous maps, may have been more uniform and continuous. The continued deposition of calcareous muds in local areas, at the time of transition between the Fairport and Blue Hill, may be responsible for the inverse thicknesses relationship between the two units.

In Sherman, Wallace, Greeley and Wichita Counties, the Blue Hill Shale is relatively thin as is the Codell Sandstone. The variations in thicknesses of the Blue Hill Shale and the Codell Sandstone are opposite in Rawlins County, though, where the Codell is relatively thick and the Blue Hill is thin. Also, in the central part of the area studied, the Blue Hill increases in thickness whereas the Codell tends to be of relatively constant thickness.

Ft. Hays Limestone

In addition to preparing isopachous maps for the Carlile Shale and its members, an isopachous map was also prepared for the Ft. Hays Limestone Member of the Niobrara Formation (fig. 26). This was done so as to determine whether or not any significant relationship exists between the variation in thicknesses of the Ft. Hays Limestone and the Carlile Shale, particularly the Codell Sandstone Member of the Carlile.

Figure 26 shows a rather pronounced band of relatively thin Ft. Hays Limestone extending from the Wichita and Scott Counties northward to Rawlins County, and then from Rawlins County northeastward into Nebraska. Other less conspicuous narrow bands of thin Ft. Hays are in Phillips, Rooks, Grahm, Lane and Ness Counties.

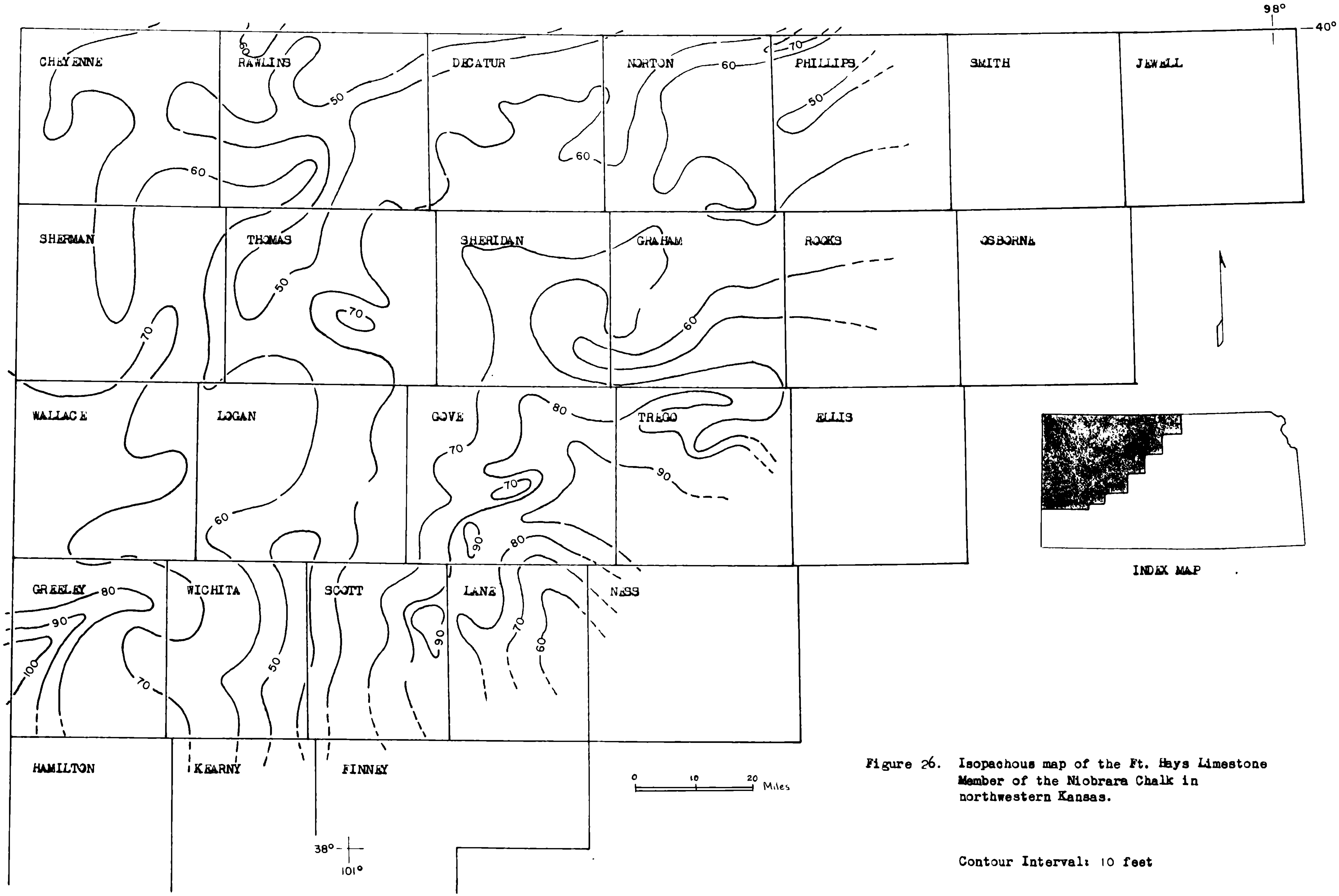


Figure 26. Isopachous map of the Ft. Hays Limestone Member of the Niobrara Chalk in northwestern Kansas.

Contour Interval: 10 feet

A sharply defined area of relatively thick Ft. Hays Limestone occurs in Greeley County and a less well defined area of thick Ft. Hays occurs in Trego and Gove Counties and extends into Scott and Lane Counties. The maximum subsurface thickness of Ft. Hays Limestone exceeds 100 feet and is found in the southwestern part of Greeley County. It is possible, though, that the maximum thickness of the Ft. Hays Limestone in Kansas, might occur in southwestern Trego County. From a regional viewpoint, it would seem that the Ft. Hays becomes thinner to the northeast, but the thinning is by no means regular. Where pronounced thickening of the Ft. Hays is present on electrical logs, the thickening seems to be distributed throughout the unit.

It seems that there is no prominent relationship between the variations in thickness of the Carlile Shale and the Ft. Hays Limestone. A minor similarity occurs in Greeley County where some thickening appears on both maps. Another similarity might be indicated by the 60 foot thickness line on the isopachous map of the Ft. Hays in northern Sherman County. The southward extension of the 60 foot thickness line indicates thinning of the Ft. Hays Limestone in an area where the Carlile Shale (fig. 23) is also thin. Another point to note about the Ft. Hays Limestone in western Sherman and Wallace Counties is that the limestone is of more uniform thickness, as is indicated by the wide spacing of the contour lines. This same feature is also present on the Fairport map.

The Fairport Chalk Member of the Carlile and the Ft. Hays Limestone Member of the Niobrara have their maximum observed thicknesses in the same general area of Greeley County. And, while the area of relatively thick Fairport strata is larger and less sharply defined than that of the Ft. Hays, their general position and orientation are about the same. Both units have an area of relatively constant thickness in Wallace County. In northern Logan County, both the Ft. Hays and the Fairport are relatively thin. However, at this point, a broad northwest by southeast trending belt of thin Fairport strata is intersected by a north-south trending belt of relatively thin Ft. Hays Limestone. In central Rawlins County, eastern Lane County, and other areas where the Fairport is fairly thick, the Ft. Hays is relatively thin. The reverse of this is true in areas such as in the vicinity of the boundary between Scott and Lane Counties. While there is a general northwest by southeast trend to the isopachous lines on the Fairport map, no such trend is evident on the Ft. Hays map.

In eastern Scott County, the Blue Hill Shale and Ft. Hays Limestone are both relatively thick. In Rawlins County, both the Ft. Hays and the Blue Hill Shale are relatively thin. In Greeley County, where the Ft. Hays is fairly thick, the Blue Hill is quite thin. Both the Ft. Hays and the Blue Hill have a nearly constant thickness in western Wallace County.

A comparison of the isopachous maps of the Codell and the Ft. Hays does not find any prominent similarities. In Wallace County, there is a tendency for the Ft. Hays to maintain a relatively uniform thickness in an area of otherwise increasing thickness. This would correspond to an area of minimum thickness of Codell. Also in Greeley County, the Ft. Hays is relatively thick as is the Codell. However, in Rawlins County, the Ft. Hays is relatively thin whereas the Codell is relatively thick.

It has been suggested by Johnson (1930) that the varying thickness of the Codell may be evidence for erosion, and that an inverse relationship may exist between the thicknesses of the Ft. Hays and Codell. The isopachous maps of the Codell and Ft. Hays, prepared as a part of this study of the Codell, however, do not seem to support the existence of any such inverse thickness relationship, at least on a regional basis. Locally, though, such as in Rawlins County, it may be that such a relationship does exist.

CONCLUSIONS

In general, the contact between the limestone at the base of the Ft. Hays and the underlying clastics of the Carlile is sharp and parallel to the bedding planes of the two formations. Over most of the area of study, the Ft. Hays Limestone is underlain directly by a thin noncalcareous sandstone bed containing shark teeth, bone fragments, tubular structures and limonite nodules. The contact between the limestone and the sandstone is sharp and parallel but the contact between the sandstone and the underlying shale is somewhat irregular. The nature of the contact between the limestone and sandstone, and between the sandstone and the underlying clastics of the Carlile, suggests that the thin sandstone bed which occurs in contact with the base of the Ft. Hays Limestone may be a basal sand of the Niobrara. The presence of numerous shark teeth, bone fragments and limonite nodules in this sandstone also supports this idea.

In Kansas, the Codell Sandstone is the uppermost member of three members in the Carlile. To the northwest, in Wyoming, a shale unit (Sage Breaks Shale) is present above a sandstone that is equivalent to the Codell Sandstone (Cobban and Reeside, 1952). The absence of this shale unit in Kansas, suggests that the upper-most part of the Carlile in Kansas, is missing and that an unconformity exists between the Niobrara Chalk and the Carlile Shale. Another possible interpretation of the thin sandstone in the uppermost part of the Carlile is that it may have been deposited during the time in which the Sage Breaks Shale was being deposited in Wyoming.

Marine fossils are present in the Blue Hill Shale underlying the Codell Sandstone and even though the Codell Sandstone lacks good diagnostic fossils, those that are present indicate that the Codell was deposited in a marine environment. The absence of well developed cross bedding suggests a low energy environment of deposition. The streaks and lenses of siltstone in the lower part of the Codell suggest a gradual transition from a relatively quite depositional environment to one of increasing turbulence. The fine grain-size of the better developed sandstones of the Codell and the very argillaceous nature of the sandstone indicate that the clastics were probably deposited relatively far from their source. The presence of glauconite grains suggests that the environmental conditions were somewhat stable. It is probable that the clastics of the Codell were deposited in a shelf-type of environment, possibly in relatively shallow water.

The frosted surfaces of the grains of the Codell suggest the possibility that the grains may have at one time existed in an eolian environment. The fine grain-size of the clastics in the Colorado Group as a whole suggests that the topography in the central interior of North America, was at that time quite low and with the sea bottom probably sloping gently away from shore lines. It is possible that the clastics of the Codell in Kansas, were deposited primarily in response to a gradual lowering of sea level relative to the plane of deposition and erosion, transportation and redeposition of sediments previously deposited at higher levels within the broad area of deposition existing at that time in the central interior of the United States. That these sediments at higher levels were during the course of their transportation reworked and possibly exposed to the atmosphere over and over is indeed a possibility.

Non-deposition is probably the principal reason for the absence of the Codell in Sherman and Wallace Counties (pl. II). A subsurface cross section based on electrical logs (pl. III) shows that the Blue Hill and Codell Members of the Carlile thin rather abruptly in the vicinity of Sherman and Wallace Counties. In the cross section (pl. III), the Fairport does not seem to thin in Sherman and Wallace Counties. However, the isopachous map of the Fairport (fig. 24) does show some thinning relative to its thickness over the rest of northwestern Kansas. It is probable that a high existed or developed in the vicinity of Sherman and Wallace Counties at the time the sediments of the Carlile were deposited. Since the Codell is absent in Sherman and Wallace Counties and the thinning of the Blue Hill Shale is more pronounced than the thinning of the Fairport, it seems probable that the high became more pronounced in the latter part of the time in which the Carlile was deposited. This high may have been associated with movements of the Las Animas Arch (Lee and Merriam, 1954). In the northeastern part of the area, the Codell is absent because of what seems to be a lateral gradation into shale.

The elongated shape of the better developed sandstones of the Codell in northwestern Kansas, suggests the possibility of a feature similar to an offshore bar. However, the sedimentary structures of the sandstone unit as seen on the outcrop in northern Ellis County do not seem to fit in with this idea. For example, the more or less rythmic alternation of sandstone or siltstone and sandy shale in the lower part of the Codell does not seem to suggest an offshore bar origin. The writer of this paper is inclined to believe that the location and shape of the sandstone beds was determined by currents which were controlled in part by broad irregularities such as may have existed in the vicinity of Sherman and Wallace Counties, on the surface of the sea bottom.

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APPENDIX

GENERAL EXPLANATION

The following measured sections of outcropping upper Carlile Shale are arranged alphabetically according to locality (i.e. ElA, ElB, ElC,------------FlA, JwA, JwB,------------etc.). The location of these localities is also shown on Plate II.

MEASURED SECTIONS

Thickness feet

Locality ElA

(NW¼, Sec. 17, T. 11 S., R. 17 W., Ellis County, Kansas)

Niobrara Chalk

Ft. Hays Limestone Member

Limestone, light gray to nearly white, weathering to a light yellowish gray, thick bedded, chalky, containing thin lenses and streaks of fine grained sand at the base.

Carlile Shale

Codell Sandstone Member

5. Sandstone, gray weathering to a light yellowish brown, fine grained, argillaceous, noncalcareous, friable, containing numerous light gray anastomosing calcareous tubular structures (0.04 $\pm$ foot in diameter) which have a dominantly vertical orientation. Very faintly defined cross-bedding is present in the upper two feet. Limonite nodules and shark teeth occur sparingly throughout. 5.0

4. Shale, dark gray, noncalcareous, gritty, contains thin beds of fine grained argillaceous sandstone. . . . 0.5

3. Sandstone, gray to light gray, mottled, fine grained, noncalcareous, argillaceous, numerous irregular thin streaks (0.002 $\pm$ foot) of gray to dark gray which become more abundant in the lower part; limonite nodules and staining common throughout. 7.2

2. Siltstone, gray, weathering to a light brownish gray, contains numerous gray streaks of clay material and thin bands of limonite. 2.4

Blue Hill Shale Member — Thickness feet

1. Shale, dark gray, weathering to a gray or dark bluish gray, gritty occasional thin bed (0.05± foot) of very fine grained sandstone, numerous thin (0.003±foot) streaks and plano-convex lenses of siltstone.......................................4.9

Total...20.0

Locality ELB

(NW cor., sec. 20, T. 11 S., R. 18 W., Ellis County, Kansas)

Niobrara Chalk

Ft. Hays Limestone Member

Limestone, light grey to nearly white weathering to a light yellowish to yellowish brown tint, soft, chalky, with thin beds of gray to greenish gray calcareous shale.

Carlile Shale

Codell Sandstone Member

2. Siltstone, light gray, weathering to a light yellowish brown, poorly indurated, somewhat clayey, noncalcareous, containing numerous thin (0.02±foot) fine grained, argillaceous sandstone beds. Upper one to two feet contain numerous light gray anastomosing calcareous tubular structures. Limonite nodules, some containing iron sulfide cores, are abundant in upper few feet.......................................13.2

Blue Hill Shale Member

1. Shale, dark gray, weathering to gray, noncalcareous, slightly blocky, gritty, containing numerous small streaks and plano-convex lenses of siltstone. Numerous thin (0.3±foot) discontinuous beds of gray argillaceous sandstone occurs throughout. A concretion zone occurs about 30 feet below the base of the Ft. Hays Limestone. The concretions vary in size from a few inches up to 6 feet in diameter, and contains numerous veins of light gray calcite......23.5

Shale, dark gray, weathering to dark bluish gray, noncalcareous, very slightly gritty.

Total...36.7

Thickness feet

Locality E1C
(SE¼, sec. 4, T. 11 S., R. 18 W., Ellis County, Kansas)

Niobrara Chalk
Ft. Hays Limestone
Limestone, light gray to light yellowish gray, sandy at base with faintly defined irregular bedding.

Carlile Shale
Codell Sandstone Member
2. Sandstone, light gray, massive, fine grained, noncalcareous, argillaceous, some faintly defined cross-bedding, anastomosing tubular structures scattered throughout. Shark teeth (pavement and cutting types) and limonite nodules occur sparingly, then irregular layers of orange-brown sandstone at top. A plano-convex lens of shale (15 feet wide and 0.5 foot thick), composed of dark gray clay material interbedded with thin beds of light gray argillaceous sandstone, is present in this unit about 5.5 feet below the base of the Ft. Hays. Numerous interlacing tubular structures are present in the sandstone at the base of the shale lens. Codell - Ft. Hays contact is sharp and parallel to the bedding planes of the two units 7.5

1. Sandstone, light gray, nodular weathering, fine grained, noncalcareous, argillaceous, alternates in a somewhat rythmic fashion with poorly defined siltstone beds, tubular structures rare or absent . . .13.0

Total 20.5

Locality E1D
(NE cor., sec. 3, R. 17 W., T. 11 S., Ellis County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray weathering to a light yellowish gray, massive, containing thin beds of greenish gray shale.

Carlile Shale
Codell Sandstone Member
5. Sandstone, light gray weathering to light brownish gray, massive, friable, fine to very fine grained noncalcareous, argillaceous, containing

	Thickness feet
numerous specks and bands of limonite; upper 0.2 ± foot contain sandy shale partings and poorly indurated yellowish brown sandstone; anastomosing tubular structures and sandy limonite material occur sparingly in upper one foot; limonite nodules (0.1 ± foot in diameter) occur sparingly in upper few feet; upper contact sharp and parallel	8.0
4. Sandstone, light gray, weathering to a light brown or brownish gray, friable, fine to very fine grained, noncalcareous, argillaceous, some siltstone beds alternating in a rythmic fashion with the sandstone; limonite staining common; limonite nodules are present but sparce	15.5
Blue Hill Shale Member	
3. Shale, dark gray to brownish gray, very gritty, noncalcareous, blocky, with numerous lenses and thin beds (0.15 ± foot) of siltstone and light gray fine grained argillaceous sandstone; the frequency of the sandstone beds increases upwards and the contact with the overlying sandstone appears to be gradational	6.9
2. Shale, dark gray to dark bluish gray weathering to gray, gritty, noncalcareous, somewhat blocky, with numerous small streaks and lenses of siltstone (ca. 0.003 ± foot thick); the small streaks and plano-convex lenses of siltstone are faintly defined at base but become more numerous and more conspicuous upwards; limonite staining on fractures septarian concretion (4.0 ± feet in diameter) occur in the shale about 40 feet below the base of the Ft. Hays Limestone, upper contact gradational. Shale is spotted about 43 feet below the base of the Ft. Hays Limestone; spots are light gray, somewhat elongated, 0.01 foot or less in diameter, and appears to be composed of light gray clay material and silt-sized particles	16.2
1. Shale, dark gray to gray, slightly gritty, noncalcareous, clayey, selenite crystals numerous, limonite staining on fracture planes.	4.6
Total	51.2

Thickness feet

Locality ELE

(NE cor., NW¼, sec. 12, R. 16 W., T. 11 S., Ellis County, Kansas)
Sections not measured in detail.

Niobrara Chalk

Ft. Hays Limestone Member

Limestone, light gray to light yellowish gray, thick bedded, chalky, with some thin (0.2 ± foot) gray, calcareous, shale beds.

Carlile Shale

Codell Sandstone Member

5. Sandstone, light gray weathering to light brownish gray, massive, fine grained, argillaceous, noncalcareous, friable, weathered surface pitted; upper contact sharp and parallel to bedding 12.8

4. Siltstone, light gray weathering to a light yellowish brown or brownish gray, sandy, poorly indurated, noncalcareous, contains a few thin (0.05 ± foot) hard bands of limonite. 15.6

Blue Hill Shale Member

3. Shale, dark gray, very gritty, noncalcareous, alternating with 0.2 - 0.3 foot thick beds of gray to light brownish gray, noncalcareous siltstone; bands of limonite are also common; upper contact appears to be gradational 6.6

2. Shale, dark gray weathering to gray, gritty, noncalcareous, contains numerous streaks and planoconvex lenses (0.005 ± foot thick) of siltstone, some sandy siltstone beds (0.1 ± foot thick) are present; shale contains numerous light gray spots in upper one foot 10.2

1. Shale, dark gray, weathering to gray, slightly gritty, noncalcareous with a septarian concretion zone (about four feet thick) in upper part.

Total 45.2

Thickness feet

Locality E1F
(NW cor., SW¼, sec. 22, T. 12 S, R. 16 W., Ellis County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray weathering to a light yellowish gray with a brownish tint, thick bedded, chalky, with some thin beds (0.1 to 0.3 foot) of greenish gray shale; limestone somewhat sandy at base.

Carlile Shale
Codell Sandstone Member
2. Sandstone, gray weathering to a yellowish brown with a slight orange tint, fine grained, noncalcareous, argillaceous, friable; yellowish gray sandy calcareous tubular structures (0.05 ± foot) are very abundant, becoming matted, appear to extend upward into the overlying Ft. Hays Limestone and downwards into the underlying sandstone; part of a relatively flat lying Inoceramas shell was found 0.7 foot below Ft. Hays Limestone; vertebra and shark teeth fairly common; some limonite nodules at base; upper contact sharp and parallel to bedding. 1.0

1. Sandstone, light gray, weathering a light gray with a yellowish brown tint, massive, noncalcareous, argillaceous, weathered surface coarsely pitted; light gray tubular structures common in upper two feet; upper contact sharp but slightly irregular. . . . 3.0

Covered.

Total 4.0

Locality E1G
(SW¼, sec. 26, T. 12 S., R 16 W., Ellis County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray, chalky, present on outcrop as a thin cap rock, deeply weathered.
Carlile Shale
Codell Sandstone Member
6. Sandstone, gray to light gray, weathering to a yellowish brown, noncalcareous, argillaceous, scattered limonite nodules; upper contact sharp and parallel

Thickness
feet

to bedding, lower contact somewhat wavy 1.0

5. Sandstone, light gray weathering to light yellowish brown, massive, fine grained, noncalcareous, argillaceous. 6.7

4. Sandstone, light gray weathering to light yellowish brown, fine to very fine grain, noncalcareous, more argillaceous than overlying sandstone 8.9

3. Siltstone, light gray weathering to light yellowish brown, noncalcareous; sandstone beds of similar appearance in upper few feet; very argillaceous at base; scattered streaks of dark gray shale are common especially in lower part; scattered bands and nodules of limonite 14.9

Blue Hill Shale Member

2. Shale, dark gray weathering to a dark brownish gray, very gritty with several beds of sandstone (lithology like above), noncalcareous, numerous small streaks and plano-convex lenses (0.005 ± foot thick) of clay material and sandstone; limonite stain common; upper contact appears to be gradational 2.3

1. Shale, dark gray, weathering to gray, gritty, somewhat blocky, noncalcareous, spotted in upper part, thin (0.005 ± foot) light gray streaks and lenses of siltstone, rather common in upper part, limonite stain and selenite crystals fairly abundant; a few thin beds of sandstone are present; large septarian concretion (up to 8 feet in diameter) occur in the shale at 41 and 46 feet below the base of the Ft. Hays. 13.9

Total 47.7

Localities E1H and E1I

(E1H-NW¼, sec. 21, T. 13 S., R. 17 W., Ellis County, Kansas; E1I-West side of SW¼, sec. 17, T. 13 S., R. 17 W., Ellis County, Kansas)

Niobrara Chalk

Ft. Hays Limestone Member

Limestone, light gray weathering with light yellowish brown tint, chalky, deeply weathered; seemingly quite sandy at base.

	Thickness feet
Carlile Shale	
Codell Sandstone Member	
6. Shale, gray to greenish gray weathering to a brownish gray, gritty, clayey; location of upper contact questionable.	0.2
5. Sandstone, gray weathering to a yellowish brown, numerous thin (0.2 foot or less) light gray beds of calcareous material, a few thin beds of shale; anastomosing, light gray, calcareous tubular structures are present though not conspicuous; lower contact somewhat irregular.	2.8
4. Sandstone, light gray weathering to a light brownish gray, noncalcareous, very argillaceous, friable, with numerous gray streaks of clay material; limonite stain and nodules common.	6.2
3. Siltstone, light gray weathering to a light brownish gray, sandy, noncalcareous, friable, contains numerous thin (0.01 ± foot) dark gray streaks and lenses of shale and a few thin (0.1 ± foot) beds of very fine grained sandstone; weathers with a somewhat nodular appearance, upper contact fairly sharp	8.3
Blue Hill Shale Member	
2. Shale, gray, mottled with dark gray, very silty, noncalcareous, somewhat blocky, scattered thin (0.1 foot ±) very fine grained sandstone beds; limonite stain common; small selenite crystals common; upper contact gradational	3.0
1. Shale, dark gray to gray, noncalcareous, gritty with very small streaks and plano-convex lenses of siltstone and sandstone fairly common in the upper 22 feet, scattered thin (0.1 foot ±), very fine grained, limonite stained sandstone beds; a few fish scales are present; septarian concretion zone is present about 30 feet below the base of the Ft. Hays; limonite stain on fractures; selenite crystals common; upper contbct gradational.	25.0
Total	45.5

Thickness feet

Locality ElJ
(SW¼, sec. 26, T. 13 S., R. 19 W., Ellis County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray weathering to a light yellowish gray, massive, chalky, scattered thin beds of greenish gray shale; gray to yellowish brown tubular structures in lower one foot.

Carlile Shale
Codell Sandstone Member
5. Shale, dark gray to greenish gray, calcareous, streaked, gritty. 0.2

4. Sandstone, gray weathering to a yellowish brown, fine grained, noncalcareous, argillaceous; lower contact somewhat irregular. 0.4

3. Sandstone, light gray weathering with a light yellowish brown tint, fine grained, argillaceous, with numerous thin (0.005 ±) gray streaks of clay material; some limonite stains; weathered surface somewhat nodular; lower contact somewhat irregular. . . 4.0

Blue Hill Shale Member
2. Shale, dark gray to gray weathering to a brownish gray, mottled, very gritty, noncalcareous, somewhat blocky; thin streak, lenses and beds of firm ground sandstone common 2.2

1. Shale, dark gray, somewhat blocky, gritty, noncalcareous; thin (0.005 ± foot) streaks and plano-convex lenses of light gray siltstone common in approximately the upper 24 feet; scattered fine grained argillaceous sandstone beds ranging up to 0.3 foot thick; upper contact gradational 32.3

Total 39.1

Localities ElK and ElL
(SW¼, sec. 28, T. 15 S., R. 20 W., Ellis County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray weathering to a light yellowish gray, chalky.

Thickness
feet

Codell Sandstone Member

3. Shale, gray weathering to a brownish gray, somewhat calcareous, gritty; anastomosing tubular structures are present in upper foot and seem to extend into the overlying Ft. Hays Limestone 2.4

2. Sandstone, gray weathering to a yellowish brown, thin bedded, fine grained, argillaceous, calcareous with numerous thin (0.01 ± foot) light gray calcareous streaks; limonite stain abundant; a few thin (0.01 ± foot) light gray, very fine grained, sandy limestone beds are present in the lower 0.5 foot. 3.6

Blue Hill Shale Member

1. Shale, dark gray to gray, gritty, noncalcareous, containing scattered thin (0.005 ± foot) streaks and plano-convex lenses of siltstone; scattered thin (0.1 ± foot) fine grained argillaceous sandstone beds; quite sandy in upper four feet; septarian concretion zone occurs approximately 25 feet below base of Ft. Hays Limestone; limonite stain common on partings; upper contact sharp 24.1

Total 30.1

Locality F1A

(SW cor., SE¼, sec. 35, T. 21 S., R. 29 W., Finney County)

Niobrara Chalk

Ft. Hays Limestone Member

Limestone, light gray to light yellowish gray, chalky, deeply weathered.

Carlile Shale

Codell Sandstone Member

2. Shale, dark gray weathering to brownish gray, noncalcareous, gritty, numerous thin streaks and lenses of siltstone; a few thin (0.01 ± foot) argillaceous sandstone beds; anastomosing tubular structures (0.02 ± foot in diameter) composed of yellowish brown sandy material. 7.7

Blue Hill Shale Member

1. Shale, dark gray weathering to gray, noncalcareous, slightly gritty with a few thin (0.005 ±) streaks and lenses (some of which are plano-convex) of siltstone. Portions of upper contact questionable. 11.4

Total 19.1

Thickness feet

Locality JwA
(NW¼, sec. 17, T. 2 S., R. 6 W., Jewell County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray weathering with a light yellowish brown tint, thick bedded, chalky, scattered thin beds of shale.

Carlile Shale
Codell Sandstone Member
2. Sandstone, gray weathering to a yellowish brown, fine grained, argillaceous, noncalcareous, poorly indurated, contains numerous thin (0.005 ±) streaks of gray clay material; upper contact sharp and parallel to bedding 1.0

Blue Hill Shale Member
1. Shale, dark gray, slightly gritty, noncalcareous, limonite stain common on bedding planes and fractures; interval between 20 and 40 feet below the base of the Ft. Hays Limestone contains some scattered streaks and plano-convex lenses of siltstone; septarian concretions are present at about 22 feet and 40 feet below the base of the Ft. Hays; some highly weathered fossil shell fragments were found about 20 feet below the base of the Ft. Hays . . 49.0

Total 50.0

Locality JwB
(NW¼, sec. 14, T. 2 S., R. 8 W., Jewell County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray to light yellowish gray, thick bedded, somewhat sandy at base; few tubular structures near base.

Carlile Shale
Codell Sandstone Member
2. Sandstone, light gray to gray weathering to yellowish brown, upper 0.4 foot calcareous, lower 0.3 foot noncalcareous, very argillaceous, poorly undurated streaks of gray clay material; upper contact sharp and apparently parallel to bedding; lower contact somewhat irregular 0.7

	Thickness feet
Blue Hill Shale Member	
1. Shale, dark gray, weathering to a grayish brown, noncalcareous, somewhat blocky in upper part; a few sandy limonite nodules are present ca. 2.0 below Codell Sandstone.	4.0
Total	4.7

Locality JwC
(SW$\frac{1}{4}$, sec. 10, T. 4 S., R. 10 W., Jewell County, Kansas)

Niobrara Chalk

Ft. Hays Limestone Member

Limestone, light gray weathering to light yellowish gray, thick bedded, chalky, sandy in lower one foot.

Codell Sandstone Member	
3. Sandstone, light gray to gray, weathering to a yellowish brown, noncalcareous, very argillaceous; poorly indurated, small (0.3 ± foot in length) shark teeth are fairly common; limonite, solid nodules and hollow concretionary forms are common in lower 0.3 foot, upper contact sharp and parallel; lower contact sharp and somewhat irregular.	1.1
2. Shale, dark gray weathering to a brownish gray, noncalcareous, streaked with gray clay material in lower 0.4 foot; a few limonite nodulars occur in the upper part near the contact of the overlying Ft. Hays Limestone.	0.7
1. Shale, dark gray, weathering to gray, noncalcareous, some limonite staining; streaks and lenses of siltstone are present in the shale downwards to about 40 feet below the Ft. Hays, but are not present in the upper few feet; septarian concretions are present in a zone about 36 to 40 feet below the base of the Ft. Hays; much of the section is covered.	40.0
Total	41.8

Thickness feet

Locality McA
(SW¼, SW¼, sec. 12, T. 9 S., R. 10 W., Mitchell County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray weathering to light yellowish gray, chalky, somewhat shaly to thick bedded, slightly sandy at base, numerous thin pelecypod shells at base which are somewhat conglomerite.

Codell Sandstone Member
2. Sandstone, light gray to gray, weathering to yellowish brown, massive, fine grained, argillaceous, poorly indurated, noncalcareous, mottled with gray clay material; limonite staining common with a few scattered limonite nodules; small (0.05 ± foot in length) shark teeth fairly common 3.0

Blue Hill Shale Member
1. Shale, dark gray weathering to gray, mottled with light gray, slightly gritty, noncalcareous. 2.0

Total 5.0

A septarian concretion zone is present about 22 feet below the base of the Ft. Hays Limestone; the concretions are sandy; some oscillation-type ripple marks and some cross-bedding is present in the concretion zone.

Locality NsA
(NE¼, sec. 19, T. 17 S., R. 22 W., Ness County)

Niobrara Chalk
Ft. Hays Limestone
Limestone, light gray weathering to a light yellowish gray with a slight brownish tint, chalky; few scattered tubular structures (0.05 ± foot in diameter)

Carlile Shale
Codell Sandstone Member
3. Sandstone, light gray to gray weathering to a yellowish brown, friable, fine grained, argillaceous, containing numerous thin (0.02 ± foot) light gray streaks of calcareous material; calcareous tubular structures

Thickness feet

(up to 0.1 foot in diameter) are fairly common; a few shark teeth are present; upper contact is sharp and parallel to bedding; lower contact is sharp and possibly somewhat irregular 3.0

2. Shale, dark gray, gritty, with bands and lenses of brownish gray siltstone, blocky, noncalcareous, limonite staining common. 5.8

1. Shale, dark gray to gray, somewhat blocky, noncalcareous; limonite staining on partings is common; scattered thin (0.005 ± foot) streaks and plano-convex lenses of siltstone which are most abundant in upper 7.0 feet; scattered thin beds (0.1 ± foot) of siltstone; septarian concretion zone about 28 feet below base of Ft. Hays Limestone. 18.0

Total 26.8

Locality NsB
(SE¼, sec. 30, T. 20 S., R. 26 W., Ness County, Kansas)

Niobrara Chalk
Ft. Hays Limestone
Limestone, light gray weathering to a light yellowish gray, thick bedded, chalky.

Carlile Shale
Codell Sandstone Member
2. Siltstone, gray with dark gray streaks of clay material, poorly indurated, upper few tenths foot is calcareous, otherwise noncalcareous; scattered thin (0.1 ± foot) bands of limonite; upper one foot seems to be a little more argillaceous; upper contact sharp and parallel 4.0

Blue Hill Shale Member
1. Shale, dark gray to gray, gritty, noncalcareous; scattered thin (0.1 ± foot) beds of sandy siltstone; thin (0.005 ± foot) streaks and lenses of siltstone are fairly common, especially in the upper 7 feet; septarian concretion zone is present about 28 feet below base of Ft. Hays Limestone; upper contact gradational 24.5

Total 28.5

Thickness feet

Locality NsC
(NW¼, sec. 1, T. 17 S., R. 22 W., Ness County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray weathering to a light yellowish gray with a slight brownish tint, chalky, badly fractured.

Carlile Shale
Codell Sandstone Member
3. Shale, gray to brownish gray, sandy, highly calcareous, except lower 0.7 foot which is only slightly calcareous, light gray limy streaks in upper 0.4 foot; upper contact sharp and parallel to bedding. 2.4

2. Sandstone, gray weathering to yellowish brown, fine grained, argillaceous, thin bedded, numerous thin (0.005 ± foot) somewhat wavy light gray streaks of calcareous material parallel to the bedding; a few light gray calcareous tubular structures having a dominantly vertical habit; upper contact sharp and parallel to bedding; lower contact is sharp and possibly somewhat irregular 2.4

Blue Hill Shale Member
1. Shale, dark gray to gray, gritty, noncalcareous; scattered thin (0.2 ± foot) fine grained, argillaceous, sandstone beds and thin (0.005 ± foot) streaks and lenses of siltstone, both of which are especially abundant in the upper nine feet, and rather common in the upper 22 feet. 24.3

Total 29.1

Locality ObA
(NW¼, sec. 24, T. 7 S., R. 14 W., Osborne County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray weathering to a light yellowish gray, chalky, sandy in lower one foot.

Thickness feet

Carlile Shale

Codell Sandstone Member

3. Sandstone, gray weathering to a yellowish brown, mottled, fine grained, friable, argillaceous, noncalcareous, somewhat calcareous in upper few tenths of a foot; upper contact fairly sharp and parallel to bedding planes; lower contact sharp and seemingly parallel. 1.0

Blue Hill Shale Member

2. Shale, dark gray to gray, somewhat gritty, noncalcareous; numerous thin bands or stringers of limonite; selenite crystals abundant. 13.9

1. Shale, dark gray to gray, gritty, noncalcareous, limonite staining on bedding planes; numerous thin (0.005 ± foot) streaks and lenses of siltstone, interval between, 18 and 22 feet below the base of the Ft. Hays is very silty; selenite crystals common 9.2

Total 24.1

Locality ObB

(SW¼, sec. 10, T. 6 S., R. 13 W., Osborne County, Kansas)

Niobrara Chalk

Ft. Hays Limestone Member

Limestone, light gray weathering to a light yellowish gray, chalky, thick bedded, sandy at base.

Carlile Shale

Codell Sandstone Member

3. Sandstone, gray weathering to a yellowish brown with a slight orange tint, bottom 0.3 foot mottled gray, fine grained, poorly indurated, argillaceous, noncalcareous; upper contact sharp and parallel to the bedding planes; lower contact sharp and seemingly somewhat irregular. 1.0

Blue Hill Shale Member

2. Shale, dark gray to gray, somewhat blocky, slightly gritty, noncalcareous, selenite crystals common, limonite staining also common, a few thin sandstone lenses in extreme lower part. 16.2

Thickness feet

1. Shale, dark gray, somewhat blocky, gritty, noncalcareous, numerous thin (0.005 ± foot) gray, streaks and plano-convex lenses of siltstone; selenite crystals and limonite staining common; scattered thin (0.05 ± foot) light gray sandy siltstone beds weathering to a yellowish brown; large septarian concretions up to 5 feet in diameter occur about 33 feet below the base of the Ft. Hays. 23.7

Total 40.9

Locality ObC
(SE¼, SW¼, sec. 24, T. 8 S., R. 13 W., Osborne County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray weathering to a light yellowish gray, chalky, thick bedded.

Carlile Shale
Codell Sandstone Member
4. Sandstone, gray weathering to a yellowish brown, mottled with gray in lower 0.8 foot, fine grained, argillaceous, noncalcareous; few scattered iron oxide concretions; upper contact sharp and parallel; lower contact sharp and somewhat irregular. 2.0

Blue Hill Shale Member
3. Shale, dark gray to gray, noncalcareous, containing a few scattered gritty zones; limonite staining and selenite crystals common. 9.7

2. Shale, dark gray to gray, somewhat blocky, gritty, noncalcareous, with numerous thin (0.005 ± foot) streaks and plano-convex lenses of siltstone, scattered thin (0.1 ± foot) beds of sandy siltstone; limonite staining and selenite crystals common on partings and fractures; large calcareous septarian concretions up to 5 feet in maximum diameter occur at about 43 feet and 55 feet below the base of the Ft. Hays Limestone; upper contact gradational 44.9

Thickness feet

1. Shale, dark gray, noncalcareous, slightly gritty; upper contact gradational 3.0

Total 59.6

Locality ObD

(SW¼, sec. 32, T. 9 S., R. 12 W., Osborne County, Kansas)

Niobrara Chalk

Ft. Hays Limestone Member

Limestone, light gray weathering to a light yellowish gray, chalky, somewhat sandy at base.

Carlile Shale

Codell Sandstone Member

2. Sandstone, gray weathering to yellowish brown, fine grained, argillaceous, noncalcareous, poorly indurated, deeply weathered, mottled with gray in lower 0.9 foot; upper and lower contacts sharp and parallel to bedding 1.7

Blue Hill Shale Member

1. Shale, dark gray to gray, weathering to a brownish gray in upper 1.5 feet, noncalcareous, somewhat clayey, with limonite stain common. 3.0

Total 4.7

Locality ObE

(NW cor. SW¼, sec. 5, T. 10 S., R. 13 W., Osborne County, Kansas)

Niobrara Chalk

Ft. Hays Limestone Member

Limestone, light gray weathering to light yellowish gray, chalky,thick bedded, light gray tubular structures in lower one foot.

Carlile Shale

Codell Sandstone Member

3. Sandstone, gray weathering to yellowish brown, fine grained, argillaceous, noncalcareous; containing anastomosing light gray calcareous tubular structures in upper one foot; upper contact sharp and parallel to bedding; lower contact sharp and somewhat irregular. 2.8

	Thickness feet
2. Shale, dark gray weathering to a brownish gray, noncalcareous, somewhat clayey.	6.1
1. Siltstone, light gray weathering to a light brownish gray, mottled with dark gray clay material, noncalcareous, limonite staining common, septarian concretion zone is present about 15 feet below the base of the Ft. Hays Limestone	23.0
Covered.	
Total	31.9

Locality RoA
(SW¼, sec. 33, T. 7 S., R. 16 W., Rooks County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray, weathering to a light yellowish gray, chalky.

Carlile Shale
Codell Sandstone Member

5. Sandstone, gray weathering to a yellowish brown, fine grained, argillaceous, noncalcareous, with dark gray streaks of clay material.	0.3
4. Shale, dark gray, slightly gritty, noncalcareous; limonite bands and staining and small selenite crystals are common	7.4
3. Shale, dark gray to gray, gritty, noncalcareous, containing numerous thin (0.005 ± foot) light gray streaks and lenses of siltstone; upper contact gradational	1.4
2. Siltstone, gray weathering to a light brownish gray, with streaks of dark gray clay material, poorly indurated, sandy, noncalcareous; upper contact gradational	3.6

Blue Hill Shale Member

1. Shale, dark gray to gray, gritty, somewhat blocky, noncalcareous; limonite stains and nodular fairly common; numerous streaks and lenses of siltstone; scattered thin (0.1 ± foot) beds of sandy siltstone; numerous small crystals of gypsum	18.2
Total	30.9

Thickness
feet

Locality RoB & RoC
(RoB- SW cor., SE¼, sec. 25, T. 7 S., R. 18 W., Rooks County, Kansas)
(RoC- SW cor., NE¼, sec. 25, T. 7 S., R. 18 W., Rooks County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray weathering to a light yellowish gray, chalky, thick bedded, sandy in lower 0.5 foot.

Carlile Shale
Codell Sandstone Member
3. Sandstone, gray, weathering to a yellowish brown, argillaceous, noncalcareous, deeply weathered 0.2

2. Shale, dark gray to gray, weathering to brownish gray in upper one foot, gritty, noncalcareous, few limonite nodules, scattered thin streaks and lenses of siltstone; limonite staining common; some thin (0.02 ± foot) sandy siltstone beds; upper contact sharp and parallel to bedding 5.1

Siltstone, gray weathering to a brownish gray or yellowish brown, sandy, noncalcareous, limonite staining common; upper and lower contact gradational. 5.1

Blue Hill Shale Member
1. Shale, dark gray to gray, gritty, noncalcareous, containing numerous thin (0.005 ± foot) streaks and lenses of siltstone; limonite staining common; some thin (0.3 ± foot) beds of fine grained argillaceous sandstone or siltstone; large (up to 5 feet in diameter) calcareous septarian concretion zone is present at about 33 feet below the base of the Ft. Hays Limestone. 40.8

Total 51.2

Locality TrA
(NW¼, sec. 1, T. 15 S., R. 22 W., Trego County, Kansas)

Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray weathering to a light yellowish gray, chalky, thick bedded.

Thickness feet

Carlile Shale
Codell Sandstone Member
4. Shale, dark gray weathering to a brownish gray, sandy and very silty, noncalcareous 1.9

3. Sandstone, gray weathering to a brownish gray, fine grained argillaceous, noncalcareous. 1.7

Blue Hill Shale Member
2. Shale, dark gray, gritty, noncalcareous, with numerous thin streaks and lenses of siltstone 15.0

1. Shale, dark gray, slightly gritty, noncalcareous. . . . 3.0

Total 21.6

Locality SmA
(SE¼, sec. 34, T. 4 S., R. 11 W., Smith County, Kansas)

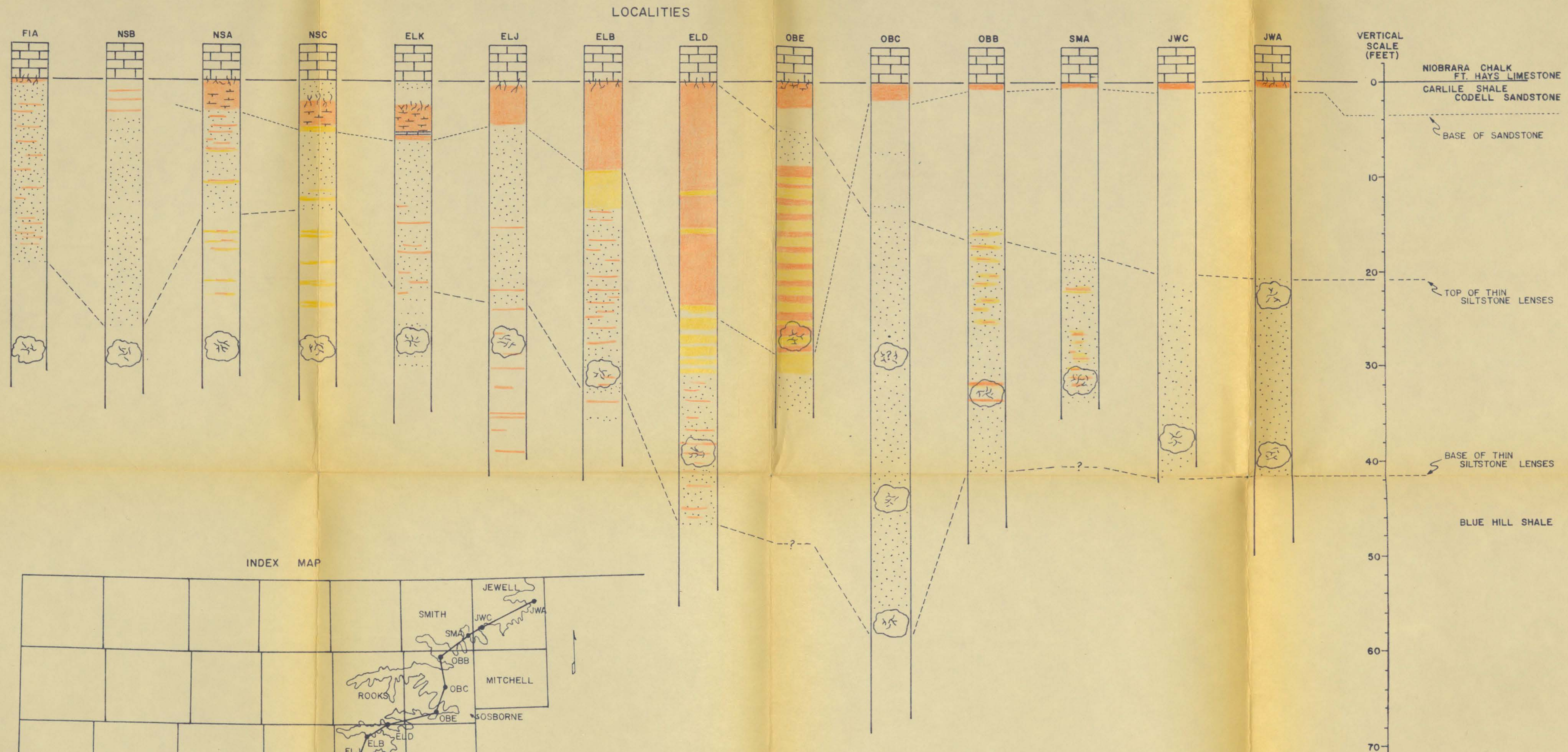
Niobrara Chalk
Ft. Hays Limestone Member
Limestone, light gray weathering to a light yellowish gray, chalky, thick bedded.

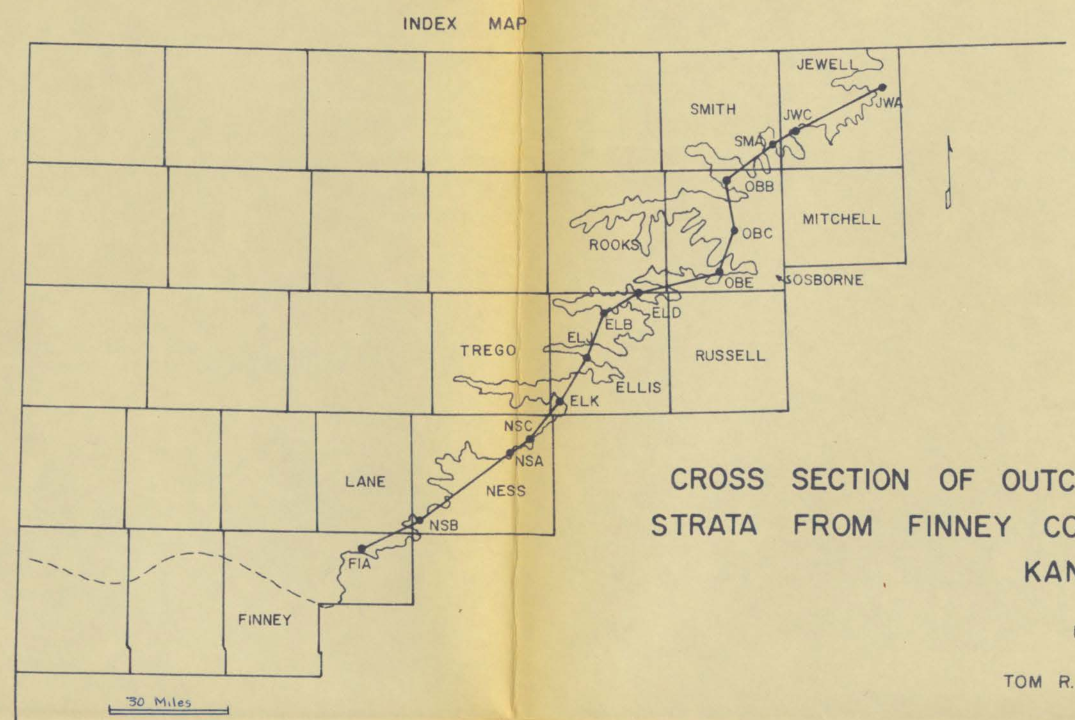
Carlile Shale
Codell Sandstone Member
2. Sandstone, gray weathering to yellowish brown, deeply weathered, fine grained, argillaceous, noncalcareous; scattered limonite nodules; upper contact sharp and parallel to bedding; lower contact fairly sharp and seemingly somewhat irregular 0.6

Blue Hill Shale Member
1. Shale, dark gray, gritty, noncalcareous, containing thin (0.005 ± foot) gray streaks and lenses of siltstone downward from 20 feet below the base of the Ft. Hays Limestone; large (up to 4 feet in diameter) calcareous septarian concretions occur about 33 feet below the base of the Ft. Hays Limestone 35.0

Total 35.6

PLATE I





CROSS SECTION OF OUTCROPPING UPPER CARLILE STRATA FROM FINNEY COUNTY TO JEWELL COUNTY, KANSAS

BY

TOM R. MCKELLAR

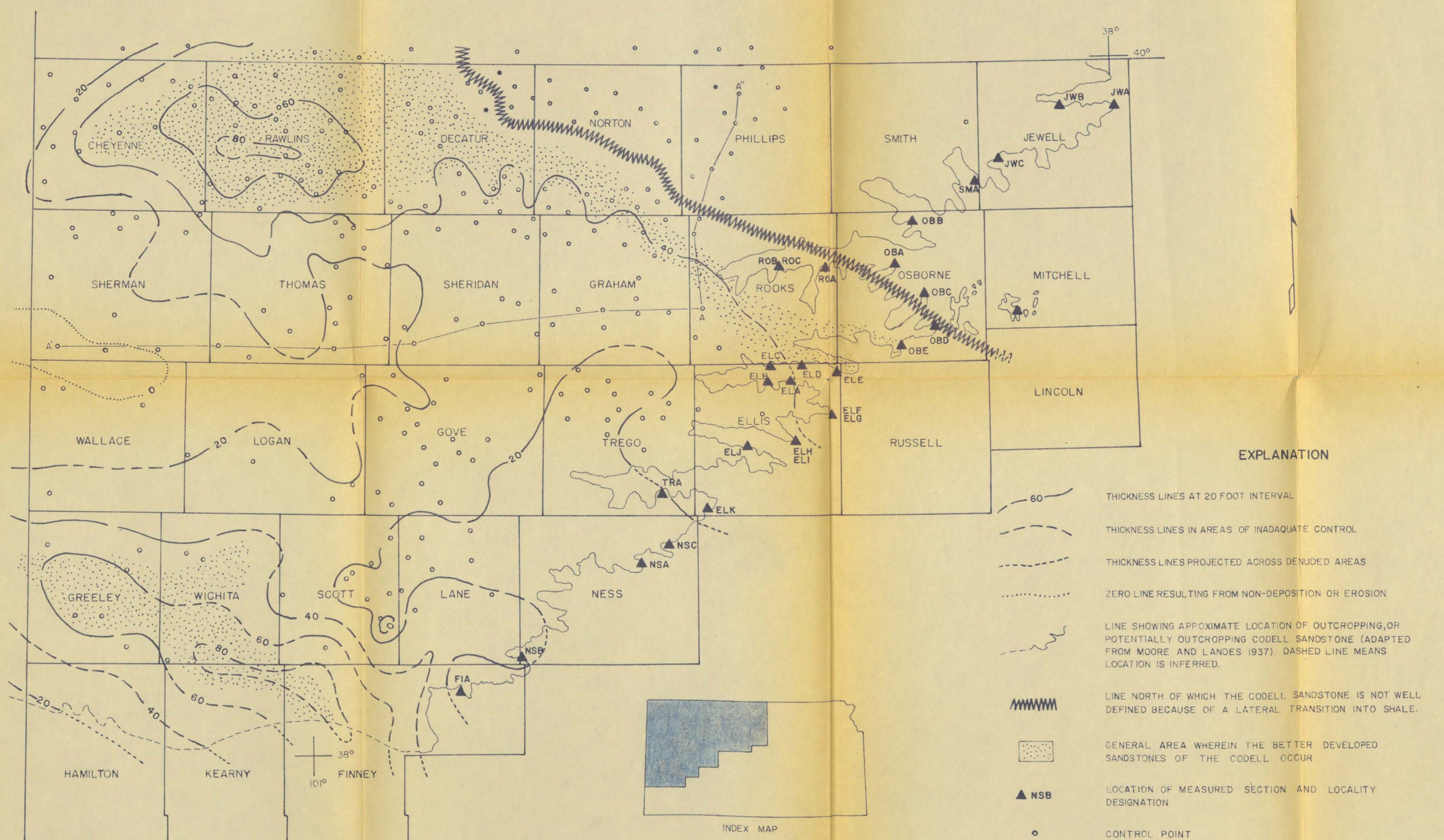
MAY, 1962

EXPLANATION

SANDSTONE	LIGHT GRAY, FINE TO VERY FINE GRAINED, ARGILLACEOUS, NONCALCAREOUS	
SILTSTONE	LIGHT GRAY, NONCALCAREOUS	
SHALE	DARK GRAY TO GRAY, CONTAINS NUMEROUS THIN (0.005± FOOT), LIGHT GRAY LENSES OF SILTSTONE, NONCALCAREOUS	
SHALE	DARK GRAY TO GRAY, NONCALCAREOUS	
SEPTARIAN CONCRETION		
ANASTOMOSING TUBULAR STRUCTURES		

PLATE II

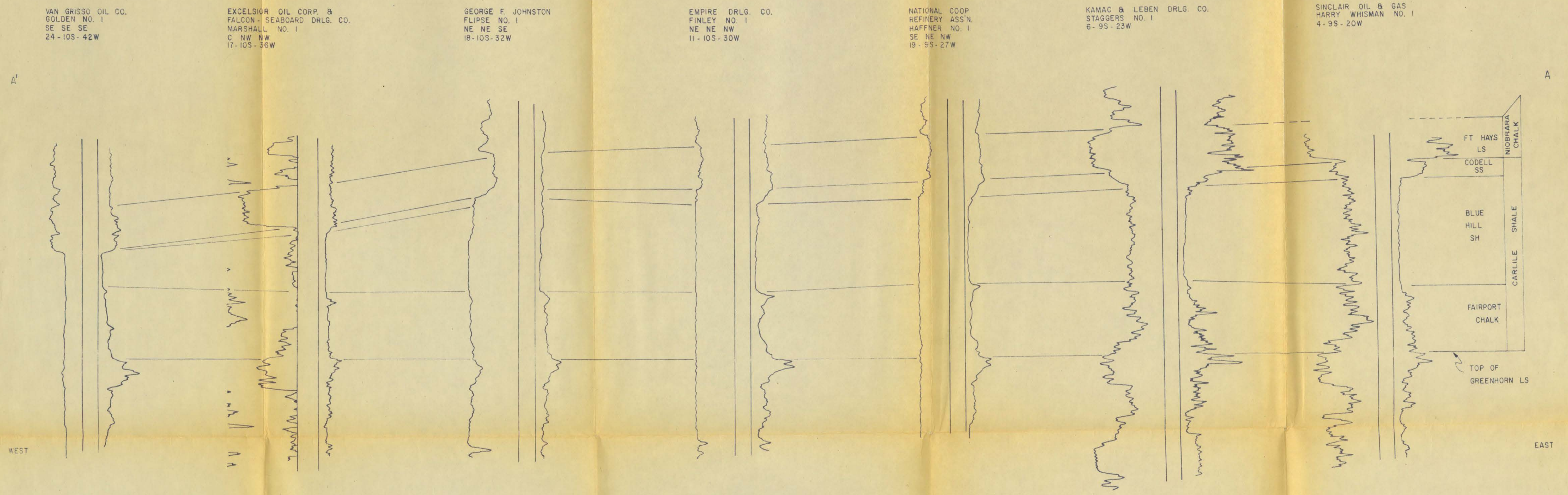
ISOPACHOUS MAP OF THE CODELL SANDSTONE IN NORTHWESTERN KANSAS



MAP COMPILED BY TOM R. MCKELLAR

MAY, 1962

BASE MAP ADAPTED FROM MAP BY UNITED STATES GEOLOGICAL SURVEY



EAST-WEST SUBSURFACE CROSS SECTION OF THE CARLILE SHALE AND THE LOWER PART OF THE NIOBRARA CHALK IN NORTHWESTERN KANSAS

BY

TOM R. MCKELLAR

LINE OF CROSS SECTION SHOWN ON PLATE II

VERTICAL SCALE 1 INCH = 100 FEET

MAY, 1962