PETROLOGY AND STRATIGRAPHY OF THE KIOWA AND DAKOTA FORMATIONS (basal Cretaceous), NORTH-CENTRAL KANSAS

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by

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APPENDIX I

Work methods

Fieldwork

Detailed reconnaissance mapping (Plate 1) was done in the field on aerial photographs at a scale of 1:20,000. More detailed mapping was done in Ellsworth and Ottawa counties (Plates 2 and 3). The Kiowa-Dakota contact was mapped throughout the area. The Dakota-Graneros contact was mapped in Washington County, and the Permian-Cretaceous contact from McPherson and Ellsworth counties to the Nebraska line. Locations of the remainder of the contacts were compiled from the literature although minor mapping or modification of previously published maps was done in many areas. Surficial deposits were mapped only locally; bedrock-surficial contacts shown on Plates 1, 2, and 3 are not intended to be accurate, but to indicate those areas where abundant surficial cover largely masks bedrock. Plate 1 is a compilation of work by the author and data from numerous sources that are indicated on the illustration.

Mapping was undertaken as a means of studying the stratigraphy of the Kiowa and Dakota formations because the abundance of surficial cover, thickness of the two formations, and width of the outcrop belt do not permit measurement of relatively closely spaced stratigraphic sections spanning the formations. At no place in north-central Kansas can the full thickness of the Dakota Formation be measured, and only locally can exposures spanning almost the complete thickness of the Kiowa Formation be found. Color terms used in description of measured sections are mainly from Goddard and others (1948); terminology used to describe bedding is from McKee and Weir (1953). Fieldwork was completed in the spring of 1965.

Cross-stratification studies

Dip bearings of cross-stratification in Kiowa and Dakota sandstone were measured throughout the broad belt of outcrops in north-central Kansas (Plate 1). In addition, detailed studies were made in Ottawa and Ellsworth counties (Plates 2 and 3). Results of cross-stratification studies in Ottawa County were published by Franks and others (1959) but are reevaluated in this report because of inadvertent assignment of much Kiowa sandstone to the Dakota Formation. Studies of cross-stratification were undertaken to gain insight into transport directions, probable directions in which source areas of the Kiowa and Dakota formations lay, and to aid in interpretation of environments of sedimentation. Cross-stratification studies have also provided information on the direction and nature of the depositional slope.

Cross-strata dip bearings were measured with a Brunton pocket transit and grouped into 5-degree class intervals for purposes of recording. An attempt was made to take one observation per set of cross-strata exposed at each locality. The number of measurements recorded at each locality ranged from 5 to 104. The maximum number of observations made at exposures showing abundant sets of cross-strata commonly was determined by adaptation of the method outlined by Raup and Miesch (1957), who used a graphical estimate of two standard deviations based on 50 observations to approximate a flatness point (Reiche, 1938). Instead of a base of 50 measurements, a base of 25 was used because of the comparative paucity of cross-stratified sets. In Ottawa County, measurement of dip bearings was done by Franks and Coleman, who worked together. Elsewhere, measurements were made by Franks alone. Operator error accordingly should be small.

Systematic measurement of dip bearings was confined to trough-shaped, tabular-planar, and wedge-planar sets of high-angle (dips on the order of

20 to 30 degrees) cross-strata. Local dips of 15 degrees or less were noted but are not shown on the maps (Plates 1, 2, and 3). No dips in excess of 30 degrees were seen in the area. Measurement of the alignment of ripple marks was virtually impossible in many areas owing to the lack of exposure of bedding surfaces of ripple-marked sandstone.

Cross-strata dip bearings, which had been grouped in the field to 5-degree class intervals, were grouped further to 10-degree class intervals, and vector-resultant dip bearings were computed as average dip bearings for each locality by methods similar to those outlined by Pincus (1956, p. 544) and Curray (1956, p. 118). The direction of the vector resultant is given by:

$$\tan \bar{\theta} = \frac{\sum n \sin \theta}{\sum n \cos \theta}$$

where $\bar{\theta}$ is the vector-resultant dip bearing in degrees, θ the midpoint of each class interval, and n the class frequency. For purposes of calculation, each cross-strata dip bearing was assigned a vector length of unity Proration of dip bearing vectors by the amount of dip of the cross-strata may be misleading inasmuch as McKee (1957b, p. 130) has found that the angle of repose of cross-strata is inversely related to current velocity for currents emptying into standing bodies of water.

As a measure of dispersion of cross-strata dip bearings, Reiche (1938, p. 913) defined the "consistency ratio," which is the length of the vector resultant ($\bar{\theta}$) divided by the sum of the vector lengths of each cross-stratum dip bearing. The consistency ratio can be computed by:

$$CR = \left[\frac{(\sum n \sin \theta)^2 + (\sum n \cos \theta)^2}{(\sum n)^2}\right]^{\frac{1}{2}}$$

and it ranges from 0 to 1 (0 to 100 percent). "A random distribution of orientations will give a magnitude of 0 percent ..." and perfect orientation gives a magnitude of 100 percent (Curray, 1956, p. 120).

Standard deviation of cross-strata dip bearings can be calculated by use of the vector-resultant as a mean (Curray, 1956; Pincus, 1956). The standard deviation of data recorded at each locality in Ottawa and Ellsworth counties was calculated by digital computer methods according to the following equation:

$$S\theta = \left[\frac{\Sigma(\theta - \bar{\theta})^2}{(\Sigma n) - 1}\right]^{\frac{1}{2}}$$

where $S\theta$ is the standard deviation, $(\theta - \bar{\theta})$ the difference in degrees between each cell midpoint and the bearing of the vector resultant in degrees and Σn is the sum of the class frequencies or the total number of measurements made at a locality.

The same basic calculations were performed for computation of grand vector resultants and for computation of consistency ratios and standard deviations of individual vector resultants about their respective grand vector resultants for the Kiowa and Dakota formations as well as for both members of the Dakota Formation. The basic premise is that the mean of the population of cross-strata dip bearings is closely approximated by the average (grand vector resultant) of the means (vector resultants for each locality) of the various sets of cross-strata measurements.

Franks and others (1959) showed that the consistency ratio is a good predictor of standard deviation for ratio values between 0.65 and 0.95 by computation of a least-squares regression line of standard deviation on consistency ratio. Their original calculations have been refined for this report using data obtained in both Ottawa and Ellsworth counties. Linear and parabolic equations were fitted to the data. Figure 48 is a scatter diagram on which the standard deviation at each locality is plotted against the consistency ratio. Best fit of the data was ob-

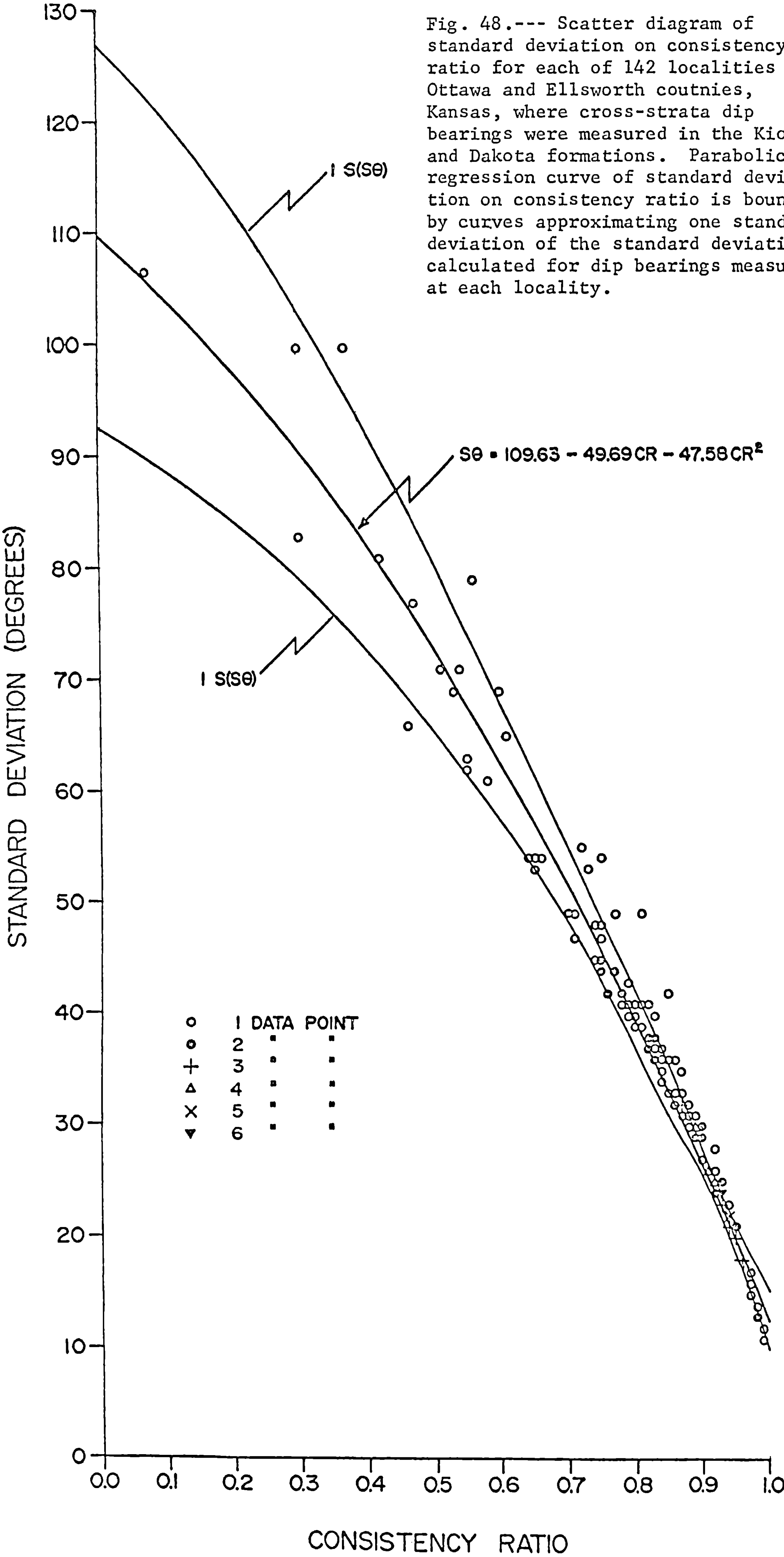

Fig. 48.--- Scatter diagram of standard deviation on consistency ratio for each of 142 localities in Ottawa and Ellsworth coutnies, Kansas, where cross-strata dip bearings were measured in the Kiowa and Dakota formations. Parabolic regression curve of standard deviation on consistency ratio is bounded by curves approximating one standard deviation of the standard deviations calculated for dip bearings measured at each locality.

tained from the equation:

$$S\theta = 109.63 - 49.69CR - 47.58CR^2$$

and goodness of fit was determined by calculating the variance of the data points about the regression line. The bounding curves in Figure 48 approximate one standard deviation of the dependent variable ($S\theta$) about the regression curve.

Although vector resultants, consistency ratios, and standard deviations were calculated by digital computer methods for Ottawa and Ellsworth counties, the regression curve has been used to estimate standard deviation of the cross-strata dip bearings for those localities in other areas for which it was expedient to process data on a desk calculator.

Cross-strata dip bearings were measured at two different sampling densities. In Ottawa and Ellsworth counties an attempt was made to measure cross-strata dip bearings at sandstone exposures approximately 2 miles (3.22 km) apart in order to have uniform areal sampling, but distances between localities studied range from 1 to 5 miles (1.6 to 8.0 km), depending on the abundance of cross-stratified sandstone outcrops. Throughout the remainder of the area studied an attempt was made to measure dip bearings at one locality in each township. Exposures sampled were those nearest the centers of the townships that allowed a minimum of five measurements. To simulate the less dense sampling program for Ottawa and Ellsworth counties, vector resultants computed for those localities nearest the centers of the townships are plotted on Plate 1.

Detailed sampling was done in Ottawa and Ellsworth counties to gain insight into local variations and modality in cross-stratification trends that might be environmentally significant. Detailed sampling also was done to provide a measure of control for wide-spaced sampling contemplated for the remainder of the Kiowa and Dakota outcrop belt in north-central

Kansas.

Results of both detailed and wide-spaced sampling programs are summarized for the Kiowa and Dakota formations in Table 5. The similarity of grand vector resultants in the Dakota Formation and in both its members regardless of the area sampled or the density of sampling is obvious. Similarity also is seen in the dispersion (consistency ratio and standard deviation) of individual vector resultants about grand vector resultants. The only major differences are found in results from the Janssen Clay Member of the Dakota Formation where the small number of localities represented seemingly has biased the results, particularly in Ottawa County. Results obtained from the Kiowa Formation are also generally comparable regardless of the area represented or the density of sampling. Discrepancies mainly reflect the number of localities sampled.

Distributions of vector resultants about the various grand vector resultants computed for the close-spaced and wide-spaced sampling programs in Ottawa and Ellsworth counties, in their combined areas, and in the general map area (Fig. 23, 24, and 25) were compared by use of Kolmogorov-Smirnov statistical tests (Siegel, 1956, p. 47 - 52, 127 136). The one-sample test was used to compare the simulated small sample distributions of vector resultants in Ottawa and Ellsworth counties (independently and combined) with the close-spaced sample distributions, and to test the proposition that the small samples were derived from the large samples or showed no significant differences in means (grand vector resultants) or dispersion of the data. The same test was employed to determine whether or not the small sample distributions of Ottawa and Ellsworth counties could have been derived from the distribution of vector resultants obtained for the whole of north-central Kansas. The two-sample test was used to test the hypothesis that the distributions of vector resultants obtained by both sampling methods in the various areas and combinations thereof were derived from the same parent distribution. Both one-sample and two-sample tests were applied to the distributions of vector resultants for the Kiowa Formation alone, for the whole of the Dakota Formation, and for each member of the Dakota Formation separately. The significance level of the maximum deviation between the various distributions of vector resultants was determined by reference to the graphs published by Miller and Kahn (1962, p. 468 - 469). The hypotheses tested were all found acceptable at the 99 percent level of significance.

Size analyses of sandstone

Representative grab samples of sandstone were collected at each locality where cross-stratification measurements were made on the wide-spaced sample pattern. Other samples were taken at various exposures. The samples were disaggregated using a mortar and rubber-tipped pestle. Some samples of calcite-cemented sandstone were disaggregated by treatment with 6N HCl. The results of the size analyses are biased in favor of friable sandstone. Much coarse-grained to conglomeratic Dakota sandstone contains abundant reworked mudstone and claystone as sand-sized to cobble-sized fragments. Such sandstone was not analyzed partly because of the difficulty of obtaining a disaggregated sample that would be representative of the grain size distribution inherent in the rock.

Size analyses of about 170 samples were made using nested quarter-phi sieves. The phi scale (Krumbein, 1934) was used for plotting and other manipulation of data. Various parameters suggested by Inman (1952), Folk and Ward (1957), and Folk (1964) for description of size, sorting, skewness, and kurtosis of the grain size distributions were calculated (Table 3). Friedman (1962) has shown that parameters suggested by Inman

(1952) and particularly those suggested by Folk and Ward (1957) are good approximations of comparable measures calculated by moment methods.

Krumbein (1938) suggested that the size distributions of most sediments approximate the normal or lognormal distributions on which so many statistical parameters are based. But numerous writers have noted departures of grain size distributions from normal distributions and have discussed their environmental significance (Doeglas, 1946; Folk and Ward, 1957; Fried, 1962; Middleton, 1962; Spencer, 1963; and Tanner, 1964). Failure to plot on a straight line on arithmetic probability paper revealed that practically all samples of Kiowa and Dakota sandstone analyzed depart in one degree or another from normality (Fig. 49). Visual comparison of probability plots revealed no consistent differences between sandstone belonging to the Kiowa and Dakota formations that could be assigned unequivocably to various environmental factors. Multimodal distributions could be inferred for many samples. One mode commonly was centered near 3 or 3.5 phi; a second mode commonly was centered near 1 or 2 phi, or at somewhat higher or lower values. Truncation in the curves, which can be interpreted in terms of sorting or selective removal of certain size categories (Tanner, 1964), was inconsistent from one sample to the next even within the same formation or member, and locally within the same sandstone body. Perhaps more significant results could have been obtained from the comparisons if it had been feasible to analyze coarse-grained to conglomeratic sandstone in the Dakota Formation in a less biased fashion.

Heavy minerals

Heavy minerals were concentrated from about 50 samples collected from the Kiowa and Dakota formations in Marion, McPherson, Rice, Ellsworth, Barton, and Russell counties (Fig. 1). The area includes strata

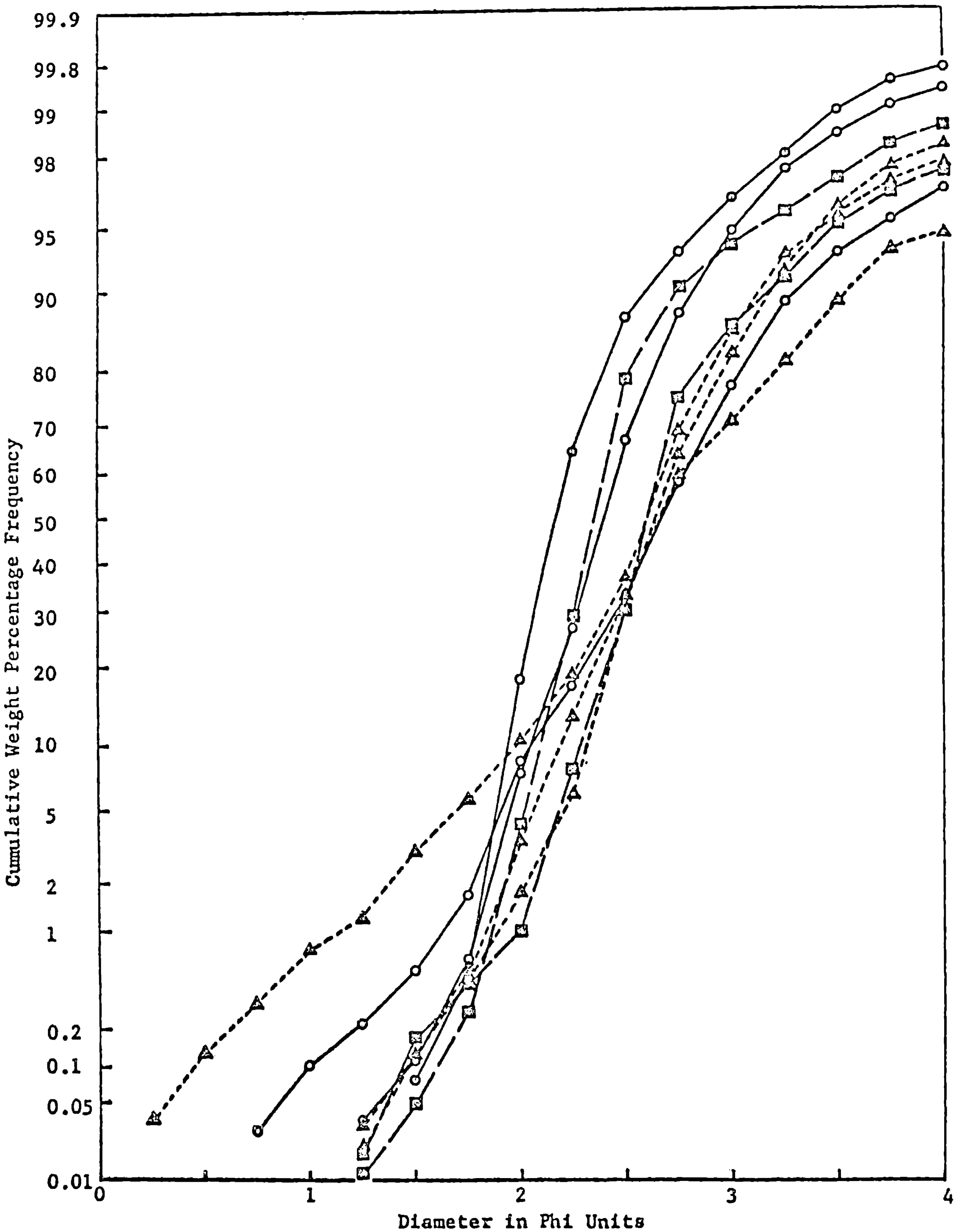

Fig. 49.--- Cumulative probability curves of size data from representative samples of Kiowa and Dakota sandstone, Ellsworth County, Kansas. Open circles, Kiowa Formation; triangles, Terra Cotta Clay Member, Dakota Formation; squares, Janssen Clay Member, Dakota Formation.

ranging from the base of the Kiowa to the top of the Dakota. Concentration was done in bromoform (specific gravity 2.87 at 20°C). Only nonopaque nonmicaceous heavy minerals were counted (Table 7).

The sandstone samples were disaggregated as for sieve analysis, but samples cemented by iron oxide were heated in 8N HCl in which 0.25 gram molecular weight $SnCl_2$ per liter was dissolved. After disaggregation, the samples were screened to provide 50 grams or more of the size ranges 0.044 to 0.125 mm and 0.125 to 0.25 mm. Separations also were attempted from coarser size fractions but few heavy mineral grains were recovered to make analysis worthwhile. If appreciable amounts of iron oxide were detected in the separates, they were treated with the HCl-$SnCl_2$ solution. In general samples from either the Kiowa or Dakota formations yielded amounts of heavy minerals ranging from 0.1 to 0.5 percent by weight.

The separated heavy minerals were mounted on glass slides with clear epoxy resin as suggested by Langford (1962). Line counts of 200 grains per slide were made for the size fraction between 0.44 and 0.125 mm. Counts ranging from 100 to 200 grains per slide were accepted for the fraction between 0.125 and 0.25 mm. Of more than 50 samples prepared, only 44 gave sufficiently large heavy mineral separations to satisfy counting requirements in the size range 0.044 to 0.125 mm. Thirty-one of the 44 samples yielded enough heavy mineral grains to satisfy counting requirements in the range 0.125 to 0.250 mm.

Grain roundness was noted for tourmaline and zircon (Table 7). Classification as round, angular, or showing crystal outlines was done rapidly by inspection but with occasional reference to Powers' (1953) chart. The extent to which roundness estimates are valid for zircon is problematic. A large proportion (as much as 25 percent) of the zircon grains showed distinct cores and shells that seemingly governed their roundness.

Color of tourmaline grains also was noted. The grains were grouped in four major color categories: brown, olive, gray, and blue. Color assignments were made at or near the orientation showing maximum absorption. No definitive trends were obtained except to note that brown and olive grains were most common and that blue grains were very scarce.

Petrographic studies

About 90 thin sections of selected samples of sandstone, siltstone, mudstone, claystone, cone-in-cone structure, siderite concretions, and barite rosettes were examined. Thin sections of sandstone were processed routinely for information on grain shape and kind and abundance of quartz, feldspar, mica, and chert. All properties were estimated by reference to visual aid charts prepared by Folk (1951), Krumbein (1941), Powers (1953), and Terry and Chilingar (1955). Grain counts of mineral species were not made owing to the general similarity of most thin sections and the preponderance of quartz, which exceeds 95 percent of the detrital components in most Kiowa or Dakota sandstone. Studies of undulatory extinction in quartz were not made owing to its limited usefulness and the need for protracted universal stage work for accurate measurements (Blatt and Christie, 1963). Comparable information about source rocks can be obtained from heavy mineral and other data.

Clay mineralogy

Because the Kiowa and Dakota formations are composed chiefly of argillaceous rocks, numerous samples were examined by x-ray diffraction during the course of mapping to see if the field stratigraphic assignments based on lithologic characteristics also coincided with fundamental differences in clay mineralogy. Samples were prepared for x-ray diffraction study by disaggregation with a wrist-action shaker followed by settling in distilled water to obtain particles having equivalent spherical diameters of 2 microns or less. Suspensions that flocculated during settling were washed repeatedly in distilled water. Solutions containing 0.0002 g/l of sodium hexametaphosphate (calgon) were used as a dispersing agent for some samples.

The suspensions obtained from many samples were "droppered" onto glass slides and allowed to dry at room temperature (about 25°C) to obtain oriented preparations. Samples collected in conjunction with study of the measured sections described in Appendix II and illustrated in Plates 4 through 8 were prepared by the smear technique outlined by Gibbs (1965).

Of the group of air-dried slides prepared from each sample, one was treated with glycerol, one heated to 450°C, and another heated at 575°C for one-half hour. Diffraction traces were obtained routinely from the air-dried and glycerated preparations and from the slide heated to 450°C. If diffraction maxima persisted at angles smaller than 8.8°2θ in diffraction patterns of the slide heated to 450°C, the sample heated to 575°C was scanned. X-ray diffraction traces were made using a proportional counting diffractometer and nickel-filtered copper radiation at a scanning rate of 1°2θ per minute. The instrument was operated at 35kv and 18 ma.

The terms "illite" and "kaolinite" are used here as generally accepted. Any component that expanded on treatment with glycerol and gave a distinct reflection at 18A was classed as montmorillonite. The name "chlorite" as used in this report mainly refers to any 14-Angstrom component whose basal spacing did not expand on glyceration and did not collapse below 13.8A on heating to 575°C. However, there are chlorites whose basal spacing does expand on treatment with polar organic compounds and chlorites whose basal spacing does collapse below 13.8A on heating (Van der Marel, 1964; Brindley, 1961b, p. 283 - 286). The name "vermiculite" as used in this report generally refers to 14-Angstrom components that showed variable expansion toward 16A on glyceration and variable collapse below 13.8A on heat treatment. No rigorous attempts at identification of chlorite and vermiculite by acid treatment and cation exchange were made.

Randomly interstratified mixed-layer clays are ubiquitous in the samples studied. Mixed-layer clays whose diffraction maxima showed as skew shoulders on the low-angle side of the illite 001 reflection or as humps between that reflection and 14A generally had illite assigned as one component. Depending on the degree of expansion on treatment with glycerol and the degree of collapse on heating, other components such as montmorillonite, chlorite, or vermiculite were assigned to the mixed-layer structure in accord with the work of Weaver (1956).

Two packed samples of the fraction finer than 2 microns from two samples of Kiowa shale were scanned past $70^{o}2\theta$ for determination of the dioctahedral or trioctahedral character of the contained illite and montmorillonite. The samples were first heated at $575^{o}C$ for one hour to destroy kaolin minerals. Several packed samples of the fraction finer than 2 microns from samples of kaolinitic Dakota and Graneros rocks were scanned over the range from 5^{o} to $70^{o}2\theta$ for observations on the degree of order or disorder as outlined by Brindley (1961a).

APPENDIX II

Measured Sections

1. Composite section measured across Kiowa-Dakota contact starting on north bank of Spring Creek near cen. SW 1/4 sec. 3, T. 18 S., R. 30 W. and continuing to cen. SE 1/4 sec. 4, T. 18 S., R. 30 W., Kiowa County, Kansas. Section measured by Paul C. Franks and Pei-lin Tien.

Thickness (feet)

Dakota Formation, Terra Cotta Clay Member:

Top of hill.

10. Sandstone (so-called "Reeder Sandstone"), very pale yellowish-orange; weathers moderate brown to dusky brown. Fine- to medium-grained; locally contains coarse- to very coarse grained lenses and laminae with abundant clay pellets and fragments. Medium-scale wedge-planar cross-stratification dipping to northwest and west. Iron-oxide cement forms concretionary masses and structures where weathered. Contact with next below not well exposed, but seems undulatory.. 20.0

9. Mudstone (so-called "Kirby Clays"), very light gray to light greenish-gray; weathers grayish orange to dark yellowish orange. Dominantly kaolinitic but contains appreciable illite and "degraded" illite. No obvious bedding; blocky fracture. Grades into or intertongues with mudstone next below. Thickness variable; measured................................. 11.1

8. Mudstone (so-called "Kirby Clays"), very light greenish-gray to yellowish-gray with pale reddish-brown to moderate orange-pink and moderate purplish-red mottles and streaks. Dominantly kaolinitic but containing appreciable illite and "degraded" illite. Highly weathered; abundant reddish-brown to purplish-red stain; granular aggregates of hematite litter weathered slopes; contains spherules of hematite as much as 2 mm in diameter oxidized from siderite(?)................................ 6.0

7. Sandstone (so-called "Greenleaf Sandstone"). Largely covered. Dips 3^{o} to 5^{o} to southwest. Light-gray to very pale orange and pale yellowish-orange; fine- to medium-grained; contains sparse lenses and laminae of very fine grained and coarse-grained sandstone. Small- to medium-scale wedge-planar and tabular-planar cross-

stratification; sparse medium-scale trough cross-stratification and foreset beds; vector-resultant of cross-stratification dip bearings is N89°W; sparse even-bedded to thin-laminated zones. Locally contains clay pebbels and pellets; local lenses as much as 3 ft thick of gray mudstone with red mottles. Sparse vertical worm burrows(?) in even bedded zones. Abundant "limonite" cement at top. Scour-fill contact with next below.................................. 45.0

6. Mudstone (so-called "Spring Creek Clays"), light gray to very light brownish-gray; blocky fracture. Dominantly kaolinitic. Grades into next below...... 3.5

5. Mudstone (so-called "Spring Creek Clays"), light gray with green overtones and abundant moderate reddish-brown to pale red mottles and streaks; weathers pale grayish orange to moderate reddish orange on very light gray background. Dominantly kaolinitic but containing sparse illite and "degraded" illite. Sparse oxidized siderite(?) spherules as much as 2 mm in diameter; no obvious bedding; blocky fracture; abundant granular aggregates of hematite litter weathered slopes. Grades irregularly into next below.. 7.1

4. Mudstone (so-called "Spring Creek Clays"), very light gray with pale pink to pale reddish-purple stain and overtones. Dominantly kaolinitic. Contains abundant siderite and "limonite" spherules as much as 2 mm in diameter and weathers to porous, cellular, crinkly iron-oxide crusts; resistant, forms bench. Grades irregularly into next below. Thickness variable; measured.............................. 1.0

3. Mudstone (so-called "Spring Creek Clays"), light gray with moderate-pink to moderate-red mottles; weathers grayish yellow to pale grayish orange. Dominantly kaolinitic but containing some illite and "degraded" illite. No obvious bedding; dense; conchoidal fracture. Base Dakota Formation......... 2.5

Total thickness Dakota Formation, Terra Cotta Clay Member, measured........ 96.2

Kiowa Formation:

2. Siltstone (so-called "Spring Creek Clays"), grading down to interlaminated siltstone and shale. Very light gray grading down to light-gray; weathers pale orange to pinkish gray. Clay fraction composed largely of kaolin. Laminated to thin-laminated; abundant thin ripple laminae;

abundant carbonaceous imprints and plant debris; sparse mica flakes on laminae. Grades into next below.. 5.5

1. Shale, medium light-gray; weathers light olive gray. Dominantly illitic but contains appreciable kaolinite. Fissile, thin-laminated, plastic; abundant shrinkage cracks on weathered slopes. Base not exposed. Measured........................ 2.8

Total thickness Kiowa Formation measured. 8.3

2. Section measured across Kiowa-Dakota contact in SE 1/4 NW 1/4 sec. 3, T 18 S., R. 30 W., Kiowa County, Kansas. Section starts below stock pond near SW bank of Medicine Lodge River and extends up hill N of stock pond. Measured by Paul C. Franks and Pei-lin Tien.

Thickness (feet)

Dakota Formation, Terra Cotta Clay Member:

Covered.

7. Sandstone (so-called "Greenleaf Sandstone), very pale orange; weathers grayish orange to pale reddish brown and very light gray. Very fine to fine-grained; even-bedded and cross-stratified; small- to medium-scale tabular- and wedge-planar cross-strata dipping to northwest; even bedding in sets as much as 2 ft thick. Sparse mica flakes and black opaques. Scour-fill contact with next below. Top not exposed; measured... 8.0

6. Mudstone (so-called "Spring Creek Clays"), light-gray with green overtones and abundant moderate reddish-brown to pale-red and moderate reddish-orange mottles and streaks on very light gray background. Dominantly kaolinitic but containing some illite and "degraded" illite. Sparse granular aggregates of hematite and "limonite" on weathered slopes; spherules of siderite in relatively fresh mudstone. No obvious bedding, blocky fracture. Grades irregularly into next below. Thickness variable; measured....................... 10.2

5. Mudstone (so-called "Spring Creek Clays"), very light gray with pale-pink to pale reddish-purple stain and overtones. Dominantly kaolinitic but contains appreciable illite and "degraded" illite. Contains abundant siderite and "limonite" spherules as much as 2 mm in diameter and weathers to porous, cellular, and crinkly iron-oxide crusts, moderate brown to blackish-red; resistant and forms bench with rough

surface composed of miniature hoodoos. Grades irregularly into next below. Thickness variable; measured.. 2.6

4. Mudstone (so-called Spring Creek Clays), very light gray with moderate-pink mottles; weathers grayish yellow to pale grayish orange. Dominantly kaolinitic but contains sparse illite and "degraded" illite. No obvious bedding; dense, conchoidal fracture. Base Dakota Formation. Thickness variable, measured................................ 1.5

Total thickness Dakota Formation, Terra Cotta Clay Member, measured........ 22.3

Kiowa Formation:

3. Siltstone (so-called "Spring Creek Clays"), very light gray; locally weathers pale orange to pale brown where stained by iron oxide. Even-laminated to thinly ripple-laminated; contains lenses of argillaceous siltstone as much as 0.9 ft thick showing contorted lamination. Sparse mica flakes, abundant carbonaceous debris and plant imprints on bedding planes. To southeast grades into 15-foot sandstone sequence, (so-called "Greenleaf Sandstone"), very fine to fine-grained, light yellowish-gray, and showing abundant medium-scale wedge-planar cross-stratification, contains black opaques, grains of pink quartzite, and mica flakes. Grades into next below... 5.2

2. Interbedded shale and siltstone (so-called "Spring Creek Clays"). Very light gray to light-gray and light brownish-gray. Contains kaolinite and some illite. Laminated to thin-laminated; abundant contorted laminae; sparse ripple laminae. Abundant carbon as leaf imprints and plant debris; sparse mica flakes. Grades into next below............... 1.3

1. Shale, medium light-gray; weathers light olive gray with local orange to reddish-brown stain. Largely kaolinitic but containing abundant illite and some "degraded" illite. Fissile, thin-laminated; plastic when wet, abundant shrinkage cracks on weathered slopes. Contains scattered discontinuous zones of discoidal concretions of impure siderite as much as 0.2 ft thick and 2 ft long that weather into angular fragments as much as 4 cm in long dimension. Base covered.................................Exposed 11.6

Total thickness Kiowa Formation measured. 18.1

3. Section measured across Dakota-Graneros contact 0.1 mile northwest cen. N 1/2 sec. 6, T. 15 S., R. 10 W., Ellsworth County, Kansas, on west side of road. Section starts at base of Dakota mudstone and claystone exposed in grader ditch. Measured by Paul C. Franks.

Thickness (feet)

Graneros Shale:

Covered.

15. Shale, medium dark-gray; weathers medium light gray with brown overtones and to puffy light olive-gray slope. Kaolinitic but contains appreciable illite and illite-montmorillonite mixed-layer clay. Thin-laminated, fissile; sparse very light gray to dark yellowish-orange siltstone laminae; sparse white kaolin seams containing appreciable montmorillonite as much as 0.1 ft thick; abundant jarosite stain; sparse imprints of pelecypods. Sharp contact with next below ....Exposed, 6.0

Total thickness Graneros Shale measured.. 6.0

Dakota Formation, Janssen Clay Member:

14. Sandstone, grayish-orange; weathers pale grayish orange to dark yellowish orange; very fine grained; laminated to thin-bedded; laminae commonly wavy; bedding commonly masked by calcite cement; sparse dark-gray shaly partings. Abundant limonitic speckles and stain, sparse gypsum as crystals and cement; locally may contain siderite cement. Grades into next below.................................... 1.5

13. Shale, medium dark-gray with brown overtones; weathers medium light gray to light brownish gray. Dominantly kaolinitic but contains appreciable illite and mixed-layer clay. Nonsilty; thin-laminated; contains intercalated sandstone laminae near top and siltstone laminae near base; scattered lenses as much as 0.5 ft thick of interlaminated siltstone and shale. Abundant carbonized plant debris; carbon flecks, fragments, and films; jarosite stain. Grades into next below by alternation of lithology............................ 4.2

12. Siltstone, very light gray to very light brownish-gray; weathers very light gray to yellowish gray and dark yellowish orange depending on abundance of "limonite" and jarosite stain. Thin even laminae in upper parts, wavy laminae at base. Carbon as flecks and fragments; micaceous. Nearly vertical tubes about 1 cm in diameter and up to 10 cm long may be either root impressions or burrows. Contact with next below is both

scour-fill and gradational by alternation of lithology. Thickness somewhat variable, but approximates....... 2.1

11. Shale, dark brownish-gray to dark-gray; weathers medium gray with blue to brown overtones; thin-laminated, fissile, papery to platy. Dominantly kaolinitic but contains appreciable illite and chloritic or vermiculitic mixed-layer clay. Abundant carbon as flakes, films, and fragments; sparse jarosite stain. Grades into next below.................................. 0.9

10. Lignite, brownish-black; thin wavy laminae, papery; argillaceous; contains abundant fragments of carbonized wood, imprints of stems and leaves. Sparse jarosite stain. Grades sharply into next below..... 0.6

9. Shale, medium dark-gray with brown overtones; weathers medium light gray. Dominantly kaolinitic. Thin-laminated to indistinctly laminated; sparse very light gray siltstone laminae with faint jarosite stain. Silt content increases downward. Grades sharply into next below.. 1.6

8. Lignite, as above, but with dark yellowish-orange limonitic stain.................................. 0.4

7. Shale, medium dark-gray grading down to dark gray; fissile; carbonaceous towards base. Kaolinitic but contains sparse montmorillonite and chloritic or vermiculitic mixed-layer clay. Contains laminae and beds of very light gray siltstone as much as 0.1 ft thick in upper half; siltstone shows wavy thin-laminae and plant imprints. Gypsum crystals on weathered slopes. Grades into next below............. 2.6

6. Lignite, as above................................ 0.8

5. Siltstone grading down to sandstone. Medium light-gray with brown overtones grading down to very pale orange; weathers pinkish gray grading down to light gray or moderate yellowish brown. Contains abundant medium-gray siltstone or mudstone laminae in lower parts. Sandstone, very fine grained and silty. Upper parts of sequence show no obvious bedding; becomes progressively thin-laminated and ripple-laminated downward. Micaceous; abundant carbon as flecks, fragments, and films; limonitic stain in basal sandstone. Grades sharply into next below. 5.4

4. Lignite, as above. Grades sharply into next below.. 0.3

3. Shale grading down into mudstone. Brownish-black grading down to medium dark-gray; weathers medium

gray grading down to light gray. Dominantly kaolinitic, but contains sparse illite and chloritic or vermiculitic mixed-layer clay. Fissile, thin-laminated and papery becoming blocky downward. Shale very carbonaceous and nonsilty...................... 2.6

2. Lignite, as above. Grades sharply into next below.. 0.4

1. Shale grading down to mudstone, medium dark-gray with brown overtones; weathers very light brownish gray to medium light gray with bluish to brown overtones. Dominantly kaolinitic, but containing sparse illite and chloritic or vermiculitic mixed-layer clay. Nonsilty; thin-laminated with good fissility in upper 2 to 5 ft; poor fissility though laminated in lower parts. Abundant very pale orange siltstone laminae and pods in lower part; siltstone weathers out as dark yellowish-orange platelets. Contains carbon as flecks and films; jarosite and "limonite" stain on fracture and bedding surfaces; gypsum crystals on weathered slope.....................................Exposed, 15.2

Total thickness Dakota Formation, Janssen Clay Member, measured............ 38.6

4. Section measured across Dakota-Graneros contact starting at base of faceted spur, 0.1 mile south of cen. W 1/2 sec. 19, T. 15 S., R. 9 W., Ellsworth County, Kansas. Measured by Paul C. Franks.

Graneros Shale: Thickness (feet)

Covered.

11. Shale, dark-gray; weathers medium light gray with bluish overtones. Dominantly kaolinitic but containing appreciable illite and mixed-layer clay. Thin-laminated, fissile and papery, plastic. Sparse zones of discoidal impure siderite concretions; sparse light gray siltstone beds as much as 0.1 ft thick. Forms slopes littered with fragments weathered from siderite concretions and siltstone seams; gypsum crystals on weathered slopes. Abundant jarosites and "limonite" stain on bedding surfaces and fractures. Base Graneros Shale........................Exposed, 5.0

Total thickness Graneros Shale measured.. 5.0

Dakota Formation, Janssen Clay Member:

10. Siltstone and sandstone with interbedded shale. Siltstone and sandstone, moderate yellowish-brown to light olive-gray; intercalated shale, medium light gray;

abundant "limonite" stain. Sandstone, very fine grained. Shale dominantly kaolinitic but contains sparse illitic and mixed-layer clay. Bedding indistinct. Weathers to rubbly slope of iron-oxide cemented fragments; abundant iron-oxide concentrated in top 0.5 ft; forms bench. Grades laterally either into moderate dark-gray to light brownish-gray mudstone and thin-laminated shale or to very fine grained sandstone. Interfingers with next below.... 2.9

9. Siltstone, alternating light brownish-gray and pinkish-gray to very pale-orange laminae; weathers pale grayish orange to very light gray. Laminae locally wavy and contorted and contain variable amounts of interstitial clay and carbon as flecks and films; micaceous. Nearly vertical tubes as much as 1 cm in diameter and 10 cm long filled with "limonite". Synaeresis(?) cracks on bedding surfaces. Resistant; forms ledge. Interfingers with next below.. 2.3

8. Siltstone, light brownish-gray to light pinkish-gray, grading down to moderate brownish-gray; weathers very light brownish gray to light brownish gray with abundant platelets of dark yellowish-orange siltstone on weathered slopes. Abundant interlaminated gray kaolinitic claystone in basal parts. Abundant subvertical burrows or root imprints filled by "limonite" as much as 1 cm in diameter and 10 cm long; carbon as flecks and fragments; micaceous; jarosite and "limonite" stain along bedding and fracture surfaces; hard. Grades sharply into next below..................... 2.2

7. Shale, medium dark-gray; weathers light gray; thin-laminated, fissile, papery, hard. Dominantly kaolinitic. Basal 0.3 ft has sparse intercalated mudstone and siltstone pods and wavy laminae. Lignitic just above basal silty zone; otherwise sparse carbon as flecks and films; sparse jarosite stain mainly near base. Grades sharply into next below by alternation of lithology and increase in silt content.... 2.1

6. Mudstone, medium-gray to medium dark-gray; weathers medium light gray with bluish cast; carbonaceous. Kaolinitic. Laminated in upper part but with poor fissility; blocky to platy fracture. Scattered argillaceous "limonite" concretions as much as 0.5 ft in diameter. Grades into next below............ 4.7

5. Siltstone and sandstone, medium dark-gray to dark-gray; weathers medium light gray. Very fine grained

sandstone at base, siltier in upper parts; indistinct wavy and contorted thin bedding or thin laminae. Abundant interstitial kaolinite; abundant carbon as fragments, flecks, and films; sparse jarosite and "limonite" stain. Wavy contact with next below. Forms crumbly ledge.......... 2.1

4. Mudstone, very light gray with abundant moderate-red mottles; weathers to puffy very pale orange to dark grayish-pink slope; abundant yellowish-orange iron-oxide stain in top 2 ft. Kaolinitic. Plastic near top, nonplastic below; very silty near base. Abundant siderite spherules disseminated in gray parts; much of the siderite largely oxidized to hematite. Grades sharply into next below.. 7.7

3. Siltstone, very light gray but much weathered and stained dark yellowish orange by iron-oxide; moderate-red mottles where fresh. Contains abundant limonitic speckles relict from siderite(?) spherules. Thin- to medium-bedded; sparse gray shaly laminae.................................... 4.5

2. Claystone, medium light-gray grading down to medium dark-gray with sparse dusky-red mottles; weathers to puffy light gray slope stained pale grayish orange by wash from next above. Dominantly kaolinitic. Plastic; laminated and fissile in upper parts; no obvious bedding in lower parts. Grades sharply into next below..................... 5.6

1. Mudstone, medium light-gray with sparse moderate-red mottles; weathers to puffy light gray and yellowish-gray slope; abundant yellowish-orange iron-oxide stain top 0.1 ft. Dominantly kaolinitic. Hard, blocky to conchoidal fracture; contains abundant siderite spherules as much as 1 mm in diameter in gray mudstone between mottles...Exposed, 1.7

Total thickness Dakota Formation, Janssen Clay Member, measured............ 35.8

5. Composite section measured across Kiowa-Dakota contact in secs. 28 and 33, T. 15 S., R. 7 W., Ellsworth County, Kansas. Top of section is in exploration trench near cen. SW 1/4 sec. 28; bottom of section is base of cutbank of Smoky Hill River near cen S 1/2 sec. 33. Measured by Paul C. Franks and Robert W. Scott.

Thickness (feet)

Dakota Formation, Terra Cotta Clay Member:

Covered

28. Sandstone. Basal 2 ft, yellowish-orange owing to abundant "limonite" cement; very fine to fine-grained; crinkly, laminated bedding; abundant interstitial clay. Higher parts, weather moderate yellowish brown; medium-grained; high- and low-angle cross-laminae in tabular and wedge-planar sets less than 5 ft thick; set boundaries about horizontal; vector resultant of cross-stratification dip bearings is about N37°W; also horizontal lamination; abundant iron-oxide stain and cement giving rise to diffusion structures; abundant interstitial clay. Scour-fill contact with next below; sandstone thickens to southeast to replace most of the Dakota section described below down to bed number 19................Exposed, 4.5

27. Claystone grading down to mudstone; light-gray grading to very light gray; sparse red mottles in upper 0.5 ft. Blocky fracture in upper 1 ft; trace amounts of carbon as fragments and flecks; clay fraction composed almost exclusively of kaolinite. Grades irregularly into next below.................. 4.7

26. Siltstone, very light gray, hard, kaolinitic. Abundant "limonite" in top 0.2 ft; abundant carbon flecks, fragments, and plant imprints define indistinct wavy lamination in basal 0.2 ft; sandy in basal 0.1 ft... 3.1

25. Siltstone, very light gray to white; hard; kaolinitic. Suggestion of wavy laminae and thin-laminae in basal 3 ft; sparse limonite stain along laminae. Forms resistant ledge.................................. 5.3

24. Siltstone, light-gray with red-brown mottles and subvertical stringers. Mottling less intense in upper 1 ft where indistinct horizontal lamination apparent. Argillaceous; sparse yellowish-brown speckling from alteration of siderite(?) spherules. Clay fraction composed almost completely of kaolinite. Grades sharply into next below........................... 5.0

23. Siltstone or sandstone, yellowish-gray with abundant "limonite" stain near top. Silt-sized to very fine grained; sparse films and seams of gray shale. Ripple-laminated, micaceous; carbon as flecks and woody fragments. Grades sharply into next below.............. 1.1

22. Mudstone, medium light-gray; sparse lenticular siltstone laminae; blocky fracture. Clay fraction largely composed of kaolin. Grades sharply into next below.. 1.7

21. Siltstone or sandstone, yellowish-gray with "limonite" stain. Silt-sized to very fine grained; sparse films and laminae of gray shale carrying carbon flecks. Ripple-laminated, micaceous, sparse carbonized wood fragments.......................... 1.4

20. Siltstone, medium light-gray with brown overtones; thin-laminated, fissile, blocky fracture. Abundant carbon as flecks and woody fragments; most argillaceous near base. Grades sharply into next below.. 1.0

19. Mudstone and claystone. Largely light-gray and very light gray to light greenish-gray mudstone with abundant moderate-red mottles as much as 0.15 ft in long dimension. Mottles form aggregates or nearly vertical streaks as much as 1 ft in long dimension. Top 1 ft is light gray with sparse mottling. Encloses lenses of plastic medium-gray to medium dark-gray claystone as much as 3 ft thick and about 5 ft above base of unit. Clay fraction largely composed of kaolinite... 11.4

18. Covered interval. Scattered exposures of gray to greenish-gray kaolinitic mudstone and claystone with red mottles....................................... 14.0

17. Claystone grading down to shale and siltstone. Claystone, light gray with dark red-brown mottles; mottling less important downward. Basal 1 to 2 ft of sequence are shale containing siltstone laminae. Shale, light-gray to very light gray. Siltstone laminae concentrated in basal 0.5 ft, dusky-yellow to moderate-red; abundant iron-oxide stain in basal silty interval. Clay fraction composed mainly of kaolinite. Gives way laterally to medium light gray and light gray mudstone and claystone with moderate-red mottling; dark yellowish-orange "limonite" stain common; blocky fracture; sparse gypsum crystals on fracture surfaces; contains sparse subspherical clay-siderite(?) concretions as much as 1 ft in diameter near base. Base Dakota Formation...................................... 6.0

Total thickness Dakota Formation,
Terra Cotta Clay Member, measured........ 59.2

Kiowa Formation:

16. Zone of iron-oxide concentration, moderate reddish-brown to dark yellowish-orange; abundant gypsiferous coatings along subhorizontal, wavy hematitic veinlets. Silty, argillaceous. Clay fraction composed mainly of kaolinite and "degraded" illite. Grades irregularly into next below and next above. Gives way laterally to ripple-laminated and horizontally laminated sandstone containing shaly lamiane, U-shaped <u>Arenicolites</u> burrows, and abundant iron-oxide stain and cement in top 2.5 ft................ 0.5

15. Intercalated siltstone, mudstone, and sandstone. Siltstone and mudstone are very light gray to medium gray; sandstone is yellowish gray, very fine grained, friable except where locally cemented by calcite. Clay fraction composed mainly of kaolinite and "degraded" illite. Sequence is micaceous; contains sparse carbon flecks along bedding surfaces; laminated to thin-bedded interfingers laterally with sandstone next below and with sandstone like that described above. Thickness variable but approximates.......................... 1.3

14. Sandstone, yellowish-gray, stained pink and red by clay wash from basal Dakota. Very fine to fine-grained; sparse clay pellets in basal 2 ft. Small- and medium-scale wedge-planar to tabular high-angle cross-lamination; cross-stratification dip bearings highly varied but mainly to southwest; set boundaries about horizontal or inclined a few degrees in direction of dip of cross-strata; sparse micro-cross-beds. Symmetrical transverse and interference ripple marks common on set boundaries; wave lengths less than 0.3 ft. Ripple and even lamination more common in upper 2 to 3 ft than cross-stratification. Calcite cement locally forms calcareous concretions as much as 6 ft long and 3 ft thick near top of sandstone. Friable, micaceous; sparse shaly partings, grains of pink quartzite; sparse U-shaped <u>Arenicolites</u> burrows in upper 2 to 3 ft. Sharp contact with mudstone next below. Thickness variable; thickens southward to interfinger with and to replace most of the section described below. Measured,............. 7.5

13. Mudstone, light gray, grading down to medium light gray. Kaolinitic and illitic; indistinct lamination; sparse carbon flecks; jarosite stain near base; silty near middle of unit. Sharp contact with next below. Pinches out to south............................... 1.5

12. Sandstone and siltstone grading down to argillaceous siltstone. Very light gray grading to medium light-gray in basal 1 ft; sparse yellowish-orange "limonite" stain. Very fine grained to silt-sized; ripple-laminated in upper parts; sparse clay films in upper parts; bedding indistinct in lower parts. Undulose contact with next below; seems to grade laterally into sandstone.................................. 3.0

11. Mudstone, brownish-gray, indistinctly laminated, plastic; contains abundant dissiminated carbon flecks. Clay fraction largely kaolinitic. Grades sharply into next below; pinches out to south....... 1.0

10. Siltstone and sandstone interlaminated with shale. Very light gray with medium-gray shale laminae; weathers dark yellowish-orange; ripple-laminated. Sandstone, very fine grained, most abundant at top and bottom of sequence. Sequence contains sparse U-shaped _Arenicolites_ burrows; micaceous, carbon as flecks and woody fragments, sparse marcasite and siderite nodules. Grades laterally into sandstone; sharp contact with next below....................... 3.1

9. Siltstone and shale, interlaminated. Very light gray and medium-gray; weathers dark yellowish orange. Clay fraction largely kaolinitic but with appreciable "degraded" illite. Ripple-laminated; proportions of shale increase downward. Where shale is more abundant than siltstone, siltstone forms bands and contorted laminae less than 1 cm thick. Jarosite stain in basal 2 ft; scattered marcasite nodules; micaceous; sparse carbon flecks on bedding surfaces. Grades laterally into sandstone and siltstone like next above; grades sharply into next below.................................. 3.7

8. Claystone grading down to siltstone and mudstone. Dark-gray grading down to light-gray with brown overtones; poor fissility in upper 0.5 ft. Clay fraction largely kaolinitic. Yellowish-gray to brownish-gray argillaceous veins penetrate into siltstone and mudstone from upper claystone. Sparse carbonaceous flecks and fragments, mainly in lower 5.5 ft.. 7.0

7. Claystone, grayish-black grading down to brownish-gray. Clay fraction composed mainly of kaolinite and "degraded" illite and montmorillonite. Upper 2 ft very carbonaceous or lignitic and transected by yellowish-gray to brownish-gray veinlets less than 4 mm thick; veinlets decrease in abundance

downward. Blocky fracture, indistinct lamination in upper 1.5 ft. Scattered carbonaceous flecks, carbonized wood fragments, and leaf imprints below upper lignitic claystone...................... 4.3

6. Claystone, as above with carbonaceous or lignitic top; medium light-gray at base and carrying sparse discoidal impure siderite concretions and "limonite" stain in basal 1 ft. Clay fraction composed mainly of "degraded" illite but contains appreciable kaolinite.................................... 4.6

5. Sandstone with interlaminated silt and shale. Very light gray and medium-gray; weathers light brown to dusky brown and pale orange. Very fine grained, thin-bedded to thin-laminated, ripple laminae common. Shale ranges from silty to non-silty. Local calcareous cement, scattered marcasite nodules; micaceous, glauconitic; sparse <u>Arenicolites</u> burrows. Prominant zone of discoidal impure siderite concretions less than 0.2 ft thick marks top. Grades sharply into next below.......... 4.0

4. Shale, medium light-gray grading down to olive-gray. Clay fraction composed mainly of "degraded" illite or illite and montmorillonite but contains appreciable kaolin. Upper 3.5 ft stained by jarosite; thin-laminated, fissile. Upper parts very plastic and contain abundant marcasite nodules strung out along bedding; lower parts less plastic and contain abundant impure siderite seams or concretions less than 0.1 ft thick.................... 9.2

3. Shale, medium dark-gray, fissile, thin-laminated. Clay fraction composed mainly of illite and montmorillonite. Contains sparse beds less than 0.2 ft thick of very light gray siltstone or sandstone; "limonite" stain on weathered surfaces; silt-sized to very fine grained; calcite cement, micaceous, glauconitic; locally almost completely replaced by marcasite, particularly where carbon fragments are common. Concretionary impure siderite bed 0.1 to 0.2 ft thick marks top of sequence. Seam of cone-in-cone 0.05 ft thick about 1 ft below siderite bed expands locally to form cone-in-cone concretions up to 1 ft thick. Sparse sand-filled, Y-shaped burrows and scattered fish scales.......... 5.3

2. Zone of cone-in-cone concretions. Very fine grained sandstone bed 0.1 to 0.2 ft thick marks top of zone; very light gray where fresh; symetric transverse ripple marks on bedding surfaces; calcareous cement;

locally replaced by marcasite, particularly where carbon fragments are common. Cone-in-cone conretions project downward from sandstone bed into underlying shale; sandstone bed locally warped over tops of the concretions; some concretions partly encased by sandstone bed. Cone-in-cone concretions as much as 1 ft thick and 4 ft long; concretions have shale cores........................ 1.5

1. Shale, medium dark-gray, thin-laminated, fissile; scattered gypsum crystals on laminae; upper parts contorted around cone-in-cone concretions next above. Clay fraction composed mainly of illite and "degraded" illite. Sparse marcasite nodules and impure siderite concretions up to 0.2 ft thick and 1 ft in diameter strung out along bedding; sparse thin beds of very fine grained sandstone as above..................................Exposed, 4.2

Total thickness Kiowa Formation, measured. 61.7

6. Section measured across Kiowa-Dakota contact on northeast bank of Smoky Hill River near cen. N 1/2 SW 1/4, sec. 1, T. 16 S., R. 7 W., Ellsworth County, Kansas. Measured by Paul C. Franks.

Thickness (feet)

Dakota Formation, Terra Cotta Clay Member:

Covered.

24. Sandstone, very pale orange; weathers dark yellowish orange to dusky brown and dark reddish brown. Fine- to medium-grained, sparse coarse grains; basal foot has abundant interstitial clay. Higher parts show small- to medium-scale, high-angle tabular or wedge-planar cross-stratification and even bedding. Abundant iron-oxide cement throughout. Scour-fill contact with next below...........................Exposed, 3.0

23. Siltstone, sandstone, and mudstone. Heterogeneous sequence of siltstone to very fine grained sandstone interbedded with mudstone. Siltstone and sandstone, very light gray to very pale orange; weather to form prominent ledges as much as 1.5 ft thick stained moderate reddish brown to dark yellowish orange and dusky red; ledges have granular surfaces probably derived from oxidation of siderite grains or pellets as much as 2 mm in diameter; locally calcareous and gypsiferous. Other siltstone and sandstone beds as much as 1 ft thick, thin- or ripple-laminated, very pale orange to dark yellowish-orange and moderate-

brown, micaceous. Intercalated mudstone, medium gray; weathers light gray; kaolinitic; commonly thin-laminated and holding scattered laminae of siltstone; forms beds less than 1 ft thick. Sequence grades sharply but irregularly into next below.. 25.0

22. Claystone, light-gray grading down to medium light-gray; abundant moderate-red mottles in upper parts; abundant dark yellowish-orange to grayish-red stain in upper three ft; weathers medium red to pale brown and very pale orange. Dominantly kaolinitic. Abundant granular aggregates of hematite on weathered slopes in top 2 ft. Grades into next below......... 6.1

21. Shale, medium light-gray with brownish overtones; weathers light gray. Nonsilty, kaolinitic; poorly thin-laminated to fissile. Grades sharply into next below.. 1.0

20. Siltstone, brownish-gray grading down to very light gray; locally top two ft are very carbonaceous and brownish black. Kaolinitic; hard, blocky fracture; top and basal two ft shows even thin-lamination or ripple-lamination; sparse medium-gray shale seams and films. Micaceous, abundant carbon flecks, fragments, and films; sparse jarosite stain. Grades sharply into next below.. 12.3

19. Siltstone and sandstone interbedded with shale. Siltstone and sandstone are light grayish orange; shale is medium dark gray. Sequence is thin- and ripple-laminated; contains about 30 percent silty shale; micaceous. Sandstone beds, very fine grained, as much as 0.5 ft thick. Grades into next below....... 4.0

18. Sandstone, very pale orange; weathers very light gray to light grayish-orange. Fine-grained; cross stratified; high-angle, wedge-planar, and tabular sets about 2 ft thick; cross-beds dip mainly to northwest; sparse horizontally laminated sets as much as 2 ft thick. Micaceous, sparse interstitial clay, generally clean, sparse grains of pink chert and black opaques; sparse claystone fragments and pebbles; friable. Forms bench and grades southward into sequence of interbedded sandstone, siltstone, and shale. Grades sharply into next below.. 5.5

17. Mudstone, medium-gray, grading down to light olive-gray. Dominantly kaolinitic; indistinctly laminated near top; blocky fracture below. Sparse laminae of fine-grained sandstone near top; sparse jarosite stain. Grades sharply into next below..................... 2.0

16. Claystone and mudstone. Claystone grades down to mudstone as silt content increases. Very light gray with green and yellow overtones and abundant moderate-red mottles. Dominantly kaolinitic; plastic; weathers to puffy variegated slope ranging from pinkish gray to pale red. Grades into next below................ 20.8

15. Siltstone, light gray with brown overtones. Argillaceous; clay fraction kaolinitic but contains appreciable illite and "degraded" illite; plastic; bedding indistinct; micaceous. Generally stained by wash from next above. Grades into next below.... 1.5

14. Mudstone and sandstone. Mudstone grades down into interlaminated mudstone and sandstone in basal 3 ft. Mudstone, medium light-gray; weathers very light gray. Clay fraction kaolinitic, but contains appreciable illite; plastic; micaceous; contains carbon flecks and fragments; laminated where intercalated with sandstone. Sandstone, grayish-orange; weathers very light gray; very fine grained, micaceous. Sequence thickens to south and interfingers with sandstone next below.............................. 5.7

13. Sandstone, very pale orange; weathers white to light grayish orange and very light gray. Very fine to fine-grained; cross-bedded, sparse horizontal laminae; cross-strata mainly in tabular sets as much as 2.5 ft thick, sparse wedge-planar sets; set boundaries locally dip as much as 5 degrees in reverse direction from cross-strata; vector resultant of cross-stratification dip bearings is N55°W; horizontal laminae in sets as much as 1.5 ft thick; sparse gray shaly partings. Micaceous, sparse grains of pink quartzite and black opaques. Forms prominent bench and thins southward. Scour-fill contact with next below...................................... 12.0

12. Mudstone grading down to claystone. Very light gray grading down to light-gray and light greenish-gray with pale-red to dark reddish-brown mottles; weathers white to very pale orange with moderate reddish-orange to dark grayish-pink stain in mottled parts. Clay fraction contains kaolinite and some illite and "degraded" illite; blocky to conchoidal fracture, waxy luster in basal two ft. Grades into next below.. 3.9

11. Claystone, light-gray; weathers very light gray; nonfissile but laminated to thin-laminated. Composed largely of kaolinite but contains appreciable illite and "degraded" illite; hard, waxy luster; contains carbon flecks and fragments. Grades sharply into next below...................................... 1.2

10. Mudstone, very light gray with moderate reddish-brown mottles in lower half; weathers white or very pale orange with moderate reddish-orange to pale reddish-brown stain. Clay fraction composed largely of kaolinite, illite, and "degraded" illite; hard, blocky fracture; indistinctly laminated in basal and top 0.5 ft. Contains sparse grains or pellets of hematite probably derived from siderite........................ 3.9

9. Claystone, grayish-black grading down to moderate olive-gray; weathers medium light gray to very light gray with olive to brown overtones. Composed largely of kaolinite, illite and "degraded" illite; plastic; weathers to puffy slope littered with sparse gypsum crystals. Indistinctly laminated but non-fissile; contains carbon as flecks, fragments, and films; thin-laminated and lignitic in upper 0.5 ft. Grades sharply into sandstone next below by increase of silt and sand content. Base Dakota Formation............................. 2.4

Total thickness Dakota Formation, Terra Cotta Clay Member, measured........ 110.3

Kiowa Formation:

8. Sandstone, moderate-red to dark yellowish-orange. Fine-grained, very argillaceous; bedding indistinct; abundant iron-oxide cement; weathers to concretionary masses, lumps, and aggregates less than 1 ft thick and 2 ft in long diameter cemented by iron oxide. Grades irregularly into next below...................................... 1.0

7. Mudstone grading down to shale. Medium light-gray to medium-gray; weathers light gray; upper parts stained dark yellowish orange by wash from next above. Laminated toward base. Clay fraction composed largely of kaolinite, illite, and "degraded" illite; silt content decreases downward; sparse jarosite stain. Basal 0.5 ft contains siltstone or very fine grained sandstone laminae. Grades sharply into next below by alternation of lithology.. 3.1

6. Sandstone, siltstone, and shale, interbedded. Shale laminae increase in abundance downward. Siltstone and sandstone, very light gray to light-gray; shale, medium-gray; sequence weathers very pale orange to dark yellowish orange. Thin-bedded and ripple- and even-laminated. Prominent close-spaced vertical

joints in sandy and silty parts. Contains sparse marcasite or pyrite nodules; nodular concentrations of calcite cement, disseminated iron-oxide cement in upper foot; micaceous; small, nearly vertical burrows about 2 mm in diameter in sandy and silty parts. Grades sharply into next below by loss of lamination and decrease in abundance of silt..... 7.5

5. Mudstone and shale, medium-gray; weathers light gray to light olive gray. Composed largely of kaolinite, illite, and "degraded" illite; non-fissile in upper 1 ft; otherwise thin-laminated. Abundant discoidal concretions of impure siderite as much as 0.3 ft thick and 3.5 feet long along bedding planes.............. 13.8

4. Shale, medium-gray; weathers light gray to light olive gray. Composed mainly of illite and montmorillonite, but contains appreciable kaolinite; thin-laminated; abundant discoidal concretions of impure siderite as much as 0.1 ft thick and 2 ft in long diameter below zone of cone-in-cone. Top marked by sandstone bed about 0.2 ft thick; medium gray to pale yellowish-orange, calcareous cement, glauconitic, numerous marcasite nodules. Concretions of cone-in-cone with radial arrangement of cones locally project downward into the shale from the base of the sandstone bed; concretions as much as 0.5 ft thick and 2 ft in long diameter............................. 5.8

3. Shale, medium dark-gray; weathers medium light-gray. Clay fraction composed largely of illite and "degraded" illite; laminated; silty, abundant gypsum crystals on weathered slope. Contains beds of very fine grained dark yellowish-orange sandstone as much as 1 ft thick; laminated, calcareous, glauconitic, marcasite nodules. Sequence grades sharply into next below... 4.7

2. Siltstone grading down to mudstone. Brownish-gray; weathers light gray with brown overtones. Abundant carbon as fragments, flecks, and film; micaceous. Basal 0.5 ft has laminae of dark yellowish-orange siltstone or very fine grained sandstone; sandy base grades laterally into ripple-laminated and cross-bedded very fine grained sandstone; bedding surfaces of sandstone show nearly symmetrical transverse ripple marks striking N40°W.......................... 4.2

1. Shale, medium dark-gray, light-brown to dark reddish-brown stain along sandstone seams. Dominantly illitic; thin-laminated; gypsum crystals on weathered slopes.

Sandstone seams as much as 0.1 ft thick; very fine grained, micaceous, calcareous...................... 3.3

Total thickness Kiowa Formation measured. 43.4

7. Section measured across Permian-Cretaceous contact in cutbank in NE 1/4 NW 1/4 SW 1/4 sec. 1, T. 17 S., R. 6 W., Ellsworth County, Kansas. Measured by Paul C. Franks.

Thickness (feet)

Kiowa Formation:

Covered.

4. Shale, medium-gray with olive-gray to reddish-brown overtones and jarosite stain; weathers moderate olive gray. Clay fraction composed mainly of illite and montmorillonite but contains appreciable kaolinite. Thin-laminated, fissile. Top marked by weathered zone of cone-in-cone concretions as much as 1 ft thick; upper parts of sequence contain scattered gypsum crystals. Base marked by silty limestone or coquina bed about 0.1 ft thick; dusky red to blackish-red; contains Turritella, Ostraea and other pelecypods. Sparse discoidal impure siderite concretions.................................Exposed, 12.2

3. Shale, medium-gray with olive-gray to reddish-brown stain; weathers moderate olive gray. Clay fraction composed largely of illite and montmorillonite but contains appreciable kaolinite; very sparse chlorite near base. Thin-laminated, fissile, plastic. Wavy contact with next below. Base Kiowa Formation...... 22.0

Total thickness Kiowa Formation measured. 34.2

Unconformity.

Ninnescah Shale:

2. Mudstone, moderate light-green to light greenish-gray; thin-laminated, but poor fissility; blocky fracture. Illitic and chloritic; sparse espansible mixed-layer clay. Top 0.1 to 0.4 ft stained moderate reddish brown to dark yellowish orange by iron oxide; dolomitic cement near top forms thin resistant ledge. Grades irregularly into next below................. 2.9

1. Mudstone, moderate reddish-brown to grayish-red; blocky to conchoidal fracture; locally indistinctly laminated. Illitic, chloritic, and containing sparse vermiculitic or chloritic mixed-layer clay. Contains sparse irregular seams of pale-green to light greenish-gray dolomitic mudstone as much as 1 ft thick. Sparse beds

less than 0.1 ft thick of silty, micaceous, white to light greenish-gray dolomite; scattered concretions of white to light greenish-gray silty dolomite as much as 0.3 ft thick and 0.6 ft long. ....Exposed, 9.5

Total thickness Ninnescah Shale measured. 12.4

8. Composite section measured in sec. 32, T. 17 S., R. 5 W. and in sec. 5, T. 18 S., R. 5 W., McPherson County, Kansas. Section starts near cen. east line sec. 32 and continues in box canyon in N 1/2 NE 1/4 sec. 5. The section corresponds approximately to the so-called natural corral section measured by Twenhofel (1924, p. 32) and spans the Permian-Cretaceous and Kiowa-Dakota contacts. Measured by Paul C. Franks and Robert W. Scott.

Thickness (feet)

Dakota Foramtion, Terra Cotta Clay Member:

Covered.

16. Sandstone, weathered dark yellowish orange to dusky brown. Poorly sorted, medium- to coarse-grained with clay pebbles and granules of quartz and chert. Bedding obscured by iron-oxide cement.......Exposed, 5.0

15. Claystone, grading down to interlaminated siltstone and claystone. Pale-brown grading down to light-gray; weathers grayish orange pink to grayish red grading down to grayish orange and very light gray. Clay fraction dominantly kaolinitic but containing abundant illite and appreciable mixed-layer illite-montmorillonite. Claystone is plastic; fissile where intercalated with siltstone; siltstone laminae show lenticular distribution and variable abundance; laminae both inclined and horizontal. Abundant mica flakes in siltstone; carbon flecks in brownish-gray claystone. Sequence grades laterally to gray claystone and mudstone with abundant moderate-red mottles. Base Dakota Formation.............................. 8.1

Total thickness Dakota Foramtion, Terra Cotta Clay Member, measured........ 13.1

Kiowa Formation:

14. Sandstone, pale grayish-orange; weathers moderate reddish brown to moderate brown and dusky brown, particularly in upper half where iron-oxide cement is abundant. Fine-grained. Abundant iron-oxide diffusion structures obscure bedding; cross-stratified and even-bedded in sets as much as 2 ft thick; cross strata small- to medium-scale tabular-planar and trough;

vector resultant is S47°E; bedding sets commonly separated by shaly partings and bounding surfaces marked with both transverse and interference ripples. Abundant fossils as molds and casts on bedding surfaces in upper parts; mainly disarticulated pelecypods and Turritella. Shaly partings and reworked shale fragments in basal 1.5 ft. Grades into next below.............................. 9.4

13. Interbedded siltstone and very fine grained sandstone. Light-gray; abundant limonitic stain in upper parts. Argillaceous; mainly thin-bedded to thin-laminated; sparse ripple laminae and contorted pods of siltstone and sandstone in more argillaceous portions. Micaceous, sparse carbon flecks. Grades into the next below by alternation of lithologh in basal 1.5 ft....................................... 15.3

12. Shale, medium dark-gray, plastic, thin-laminated. Kaolinitic and illitic but contains appreciable mixed-layer illite-montmorillonite. Contains sparse siltstone laminae and contorted pods. Sparse carbon flecks and fragments; sparse burrows as much as 1 cm in diameter. Grades into next below by alternation of lithology............................ 1.5

11. Shale, light brownish-gray with abundant "limonite" stain. Kaolinitic and illitic but contains appreciable mixed-layer illite-montmorillonite. Silty and sandy, thin-laminated to liminated, plastic; abundant carbon flecks and fragments, micaceous..... 2.2

10. Sandstone, very pale orange to grayish-orange. Very fine grained; even horizontal laminae and cross laminae in sets as much as 2 ft thick; cross strata are mainly in tabular sets whose dip averages S80°E. Sparse wedge planar sets. Asymmetrical and symmetrical transverse ripple marks on set boundaries strike about N50°W. Sparse leaf imprints and burrows; abundant tracks and trails on bedding surfaces.......Exposed, 8.5

Covered interval.. 13.2

9. Shale, medium light-gray; weathers moderate olive-brown; sparse jarosite stain. Dominantly illitic and kaolinitic but contains abundant mixed-layer illite-montmorillonite. Thin-laminated, plastic; contains abundant discoidal concretions of impure siderite as much as 0.2 ft thick...........Exposed, 10.4

8. Shale, medium light-gray to medium dark-gray; weathers moderate olive brown; sparse dark yellowish-orange stain. Illitic, kaolinitic, and mont-

morillonitic. Thin-laminated, sparse silty laminae. Zone of cone-in-cone concretions about 6 ft below top; cone-in-cone locally overlies shale containing abundant Turritella. Siltstone bed 1.7 ft thick about 8.8 ft above base of unit; dark yellowish-orange to light-gray; contains gypsum crystals and sparse carbon fragments and flecks................Exposed, 17.8

Covered interval.. 24.2

7. Shale, moderate olive-gray grading down to light olive-gray. Illitic, montmorillonitic, and kaolinitic. Thin-laminated, plastic. Contains sparse beds as much as 0.1 ft thick of siltstone and very fine grained sandstone................................Exposed, 3.6

6. Shale, medium dark-gray. Dominantly illitic and montmorillonitic but contains abundant kaolinite. Thin-laminated. Sparse pelecypod imprints and fish scales on partings. Grades sharply into next below... 1.6

5. Conglomeratic siltstone and sandstone. Olive-gray to dark yellowish-orange. Poorly sorted; locally dominantly silt, elsewhere fine-grained sand; abundant pebbles of chert, quartzite, and vein quartz. Argillaceous, abundant iron-oxide stain. Base Kiowa Formation.................................... 0.1

Total thickness Kiowa Formation measured. 107.8

Ninnescah Shale:

4. Mudstone, grayish yellow-green, sparse dark yellowish-orange stain. Composed mainly of illite and kaolinite but contains mixed-layer illite-montmorillonite. Blocky fracture; no obvious bedding. Weathered top of Ninnescah Shale. Grades sharply into next below............................ 2.8

3. Siltstone, yellowish-gray to pale olive, stained grayish yellow to dark yellowish orange. Laminated to thin-laminated. Abundant gypsum crystals on weathered slopes.................................... 5.5

2. Mudstone, olive-brown; abundant manganese-oxide stain on fracture surfaces. Dominantly illitic but contains appreciable montmorillonite and chlorite. Blocky fracture; no obvious bedding. Contains nearly horizontal veinlets as much as 2 cm thick of gypsum and manganese oxide near top. Grades into next below............................. 1.2

1. Mudstone, reddish-brown to moderate-brown; sparse greenish-gray mottles. Dominantly illitic, but contains appreciable montmorillonite and chlorite. Locally thin-laminated, but bedding mainly obscure; blocky fracture. Sparse seams or beds of greenish-gray mudstone as much as 0.3 ft thick.......Exposed, 19.8

Total thickness Ninnescah Shale measured. 29.3

9. Section measured across Permian-Cretaceous contact and Kiowa-Dakota contact at Coronado Heights near cen. SE 1/4 sec. 36, T. 16 S., R. 4 W., and near cen. west line SW 1/4 sec. 31, T. 16 S., R. 3 W., Saline County, Kansas. Section measured by Paul C. Franks.

Thickness (feet)

Dakota Formation, Terra Cotta Clay Member:

Top of hill.

7. Sandstone, very pale grayish-orange; weathers dark yellowish orange to grayish brown and various shades of dark red. Fine- to medium-grained; sparse coarse grains and granules of chert in scattered lenses; sparse lenses of very fine to fine-grained sandstone; cross-stratified and even-bedded; medium- to large-scale tabular- and wedge-planar cross-beds with vector resultant at S23^{o}E; even bedding is laminated to thin-bedded in sets up to 3 ft thick. Scattered lenses of clay pellet conglomerate in which individual pellets are as much as 3 cm long; variable amounts of interstitial clay; micaceous, sparse grains of pink chert and black opaques. Scour-fill contact with next below.. 56.0

6. Clay-pebble conglomerate. Sandstone matrix is grayish orange to moderate yellowish brown; weathers pale reddish brown to blackish red with vesicular surface derived by leaching of clay pellets; poorly sorted, fine- to medium-grained; abundant interstitial clay. Detrital clay fragments range from granules to contorted masses of claystone as much as 0.6 ft long; composed largely of mottled Dakota claystone and mudstone; sparse fragments of very fine grained Kiowa(?) sandstone and fragments of weathered concretions of impure siderite from Kiowa shale. Weathers to form pitted or "vesicular" case-hardened, iron-oxide cemented surface...................................Exposed, 3.2

Total thickness Dakora Formation, Terra Cotta Clay Member, measured........ 59.2

Covered interval. Probably includes Kiowa-Dakota contact 2.6

Kiowa Formation:

5. Claystone, medium dark-gray to brownish-gray; weathers light olive gray to very pale orange; plastic. Composed largely of illite and mixed-layer illite-montmorillonite, but contains appreciable kaolinite........................Exposed, 1.0

4. Sandstone, grayish-orange. Very fine to fine-grained; thin- and ripple-laminated; symmetrical and asymmetrical transverse ripple marks on bedding surfaces; sparse small-scale low-angle wedge-planar cross-laminae in sets as much as 0.6 ft thick separated by shaly partings. Prominant vertical jointing; tracks and trails on rippled surfaces; sparse U-shaped Arenicolites burrows. Micaceous; abundant iron-oxide cement in top 1 ft. Grades into next below................ 4.5

3. Interlaminated sandstone, siltstone, and shale. Proportions of shale increase downward. Sandstone and siltstone, pale grayish-orange to dark yellowish-orange; interlaminated shale, medium light-gray; sequence weathers very pale orange to grayish orange and light gray with "limonite", manganese-oxide, and jarosite stains. Ripple- and thin-laminated; sandstone very fine grained. Sandstone and siltstone from beds as much as 0.2 ft thick; micaceous. Grades into next below.................. 5.1

2. Shale, medium-gray to medium dark-gray; weathers olive gray to light gray. Thin-laminated, fissile; plastic. Composed largely of illite and mixed-layer illite-montmorillonite, but contains appreciable kaolinite. Zones of concretions of impure siderite as much as 0.2 ft thick and 1.5 ft in diameter in upper 15 ft; abundant gypsum crystals on weathered slopes; abundant jarosite stain.............Exposed, 19.8

Covered interval. Abundant landslide debris including Kiowa and Dakota sandstone fragments and fragments of cone-in-cone. Probably inderlain by Kiowa Shale.. 35.0

Total probable thickness Kiowa Formation measured.................... 65.4

Ninnescah Shale:

Covered interval. Break in slope at top of coyered interval may approximate Permian-Cretaceous contact 30.1

1. Mudstone, grayish-red to reddish-brown; sparse seams of pale yellowish-green mudstone as much as 0.1 ft thick. Clay fraction composed chiefly of illite and lesser amounts of chlorite or vermiculite. Conchoidal fracture; indistinctly laminated but only slight fissility..........Exposed, 17.1

Total probable thickness Ninnescah Shale measured........................... 47.2

10. Section of Longford Member, Kiowa Formation, measured along gully near cen. SE 1/4 sec. 23, T. 16 S., R. 1 E., Dickinson County, Kansas. Measured by Paul C. Franks.

Thickness (feet)

Kiowa Formation:

Covered.

10. Shale, light olive-gray to dusky-yellow. Highly weathered. Clay fraction composed largely of montmorillonite and illite, but containing abundant kaolinite. Plastic, thin-laminated; scattered concretions of impure siderite less than 0.2 ft thick strung out along bedding....................Exposed, 2.3

9. Shale, very light gray with abundant reddish-brown to dark yellowish-orange stain; weathers light brownish gray. Clay fraction composed mainly of illite and "degraded" illite, but contains abundant kaolinite. Plastic, thin-laminated; weathers to puffy slope littered with abundant gypsum needles. Contains abundant radial aggregates of gypsum as much as 0.2 ft in diameter; shaly lamination contorted about gypsum aggregates; aggregates associated with abundant "limonite" stain. Grades into next below..................... 1.8

8. Shale, light-gray to yellowish-gray; weathers very light gray. Composed largely of illite and montmorillonite, but contains abundant kaolinite. Plastic, thin-laminated; sparse silty laminae; weathers to puffy slope. Pyritic nodules associated with abundant "limonite" stain and partly altered to fine-grained soft aggregates of gypsum. Grades into next below.. 4.7

7. Shale, medium dark-gray; weathers medium light gray. Dominantly kaolinitic, but contains appreciable illite,

montmorillonite and a vermiculite component. Plastic, laminated, blocky fracture; silty in basal 0.2 ft. Grades into next below............... 1.0

Total thickness upper part Kiowa Formation measured........................ 9.8

Kiowa Formation, Longford Member:

6. Siltstone, pinkish-gray to dark pinkish-gray; weathers grayish orange. Thin-laminated to thin-bedded; hard; forms resistant ledge. Bedding surfaces show abundant symmetric transverse ripple marks with wavelengths from 0.1 to 0.3 ft and striking mainly E-W; micro-cross-stratification; sparse interference and linguloid current ripple marks; ripple marks mainly in upper 1 ft. Sparse nearly vertical burrows as much as 2 cm in diameter and 14 cm long. Micaceous, sparse black opaque grains; abundant iron-oxide cement in top 0.5 ft. Grades unevenly into next below; thickness measured.................................. 4.7

5. Siltstone and mudstone, light brownish-gray grading down to medium-gray; weathers dark pinkish gray to yellowish orange. Clay fraction composed largely of kaolinite, but contains abundant illite and montmorillonite. Thin-bedded grading down to thin-laminated. Abundant "limonite" stain; sparse carbon as flecks and fragments............................ 5.2

4. Claystone, medium dark-gray to dark-gray with brown overtones grading down to medium gray to medium light-gray containng patches of dark gray. Composed largely of kaolinite, but contains abundant montmorillonitic and chloritic to vermiculitic mixed-layer clay. Plastic, nonfissile; weathers to puffy medium-gray slope. Upper foot very nearly lignitic; largely kaolinitic. Sparse pyrite or marcasite nodules; abundant hematite stain near top. Grades into next below... 9.4

3. Claystone and mudstone, light-gray to medium light-gray with dark reddish-brown to dusky-red mottles; mottling most prominent near base. Composed largely of montmorillonite and chlorite or vermiculite and interstratified montmorillonite-chlorite mixed-layer clay, but contains appreciable kaolinite; basal parts composed almost exclusively of mixed-layer clay containing kaolinite, montmorillonite, and vermiculite or chlorite. Plastic; no obvious lamination; weathers to puffy light-gray slope with reddish-brown stain.

Near base locally contains contorted pods and fragments reworded from variegated claystone at top of Permian. Base Longford Member, Kiowa Formation.. 5.4

Total thickness Longford Member, Kiowa Formation, measured................ 24.7

Total thickness Kiowa Formation measured 34.5

Unconformity.

Wellington Formation:

2. Claystone, variegated, mainly grayish-red but streaked, stained, and mottled moderate yellowish-brown, greenish-yellow, dusky red, white, grayish-purple, and pale yellowish-gray. Composed almost completely of kaolinite; contains white nodules composed of kaolinite and halloysite. Weathers to puffy reddish-purple slope with abundant white blotches; silty near base; waxy conchoidal fracture in upper parts where nonsilty. Paleosoil at top of Permian. Grades irregularly into next below. Thickness variable but approximates......... 3.0

1. Mudstone, greenish-gray to grayish-yellow; abundant dark yellowish-orange to light olive-brown stain. Composed largely of illite and montmorillonite, but contains appreciable chlorite and kaolinite. Silty near base where intercalated with limestone next below and laminated; blocky fracture. Thickness variable but approximates..................... 1.5

Carlton(?) Limestone Member, Wellington Formation. Platy, dolomitic limestone. Not measured.

Total thickness Wellington Formation measured.............................. 4.5

11. Section measured across Kiowa-Dakota contact along U.S. Highway 81 and west line of sec. 25, T. 12 S., R. 3 W., Ottawa County, Kansas. Section starts about 0.1 miles south of NW 1/4 sec. 25 and is completed in roadcut about cen. west line SW 1/4 sec. 25. Measured by Paul C. Franks.

Thickness (feet)

Dakota Formation, Terra Cotta Clay Member:

Top of hill.

25. Mudstone, very light gray with moderate-red to pale red mottles and streaks; weathers grayish olive to

pale yellowish orange; abundant "limonite" stain in top 2 ft. Clay fraction composed almost exclusively of kaolinite. Plastic; no obvious bedding; sparse gypsum crystals on fracture surfaces. Grades sharply into next below...Exposed, 2.5

24. Mudstone, medium-gray to medium dark-gray with dusky red to moderate-red mottles. Clay fraction composed almost exclusively of kaolinite. Blocky fracture, plastic when wet. Grades sharply into next below.. 1.2

23. Siltstone, very light gray with sparse moderate-red to dark-red streaks and mottles. Streaks mainly follow inclined fractures that extend into sandstone next below. Argillaceous, kaolinitic; blocky fracture, no obvious bedding. Grades sharply into next below.. 1.2

22. Sandstone, dark yellowish-orange; weathers light brown to moderate brown. Very fine grained; bedding masked by iron-oxide cement. Micaceous, silty; contains abundant relict siderite(?) grains and scattered lenses of gray mudstone with red mottles. Occupies scour in mudstone next below; pinches out laterally. Thickness measured................................ 2.7

21. Mudstone, very light gray with sparse moderate-red mottles; weathers very light gray splotched with moderate-red and yellowish-gray. Dominantly kaolinitic. Hard; abundant limonitic stain. Grades sharply into next below. Thickness variable owing to scour and fill by sandstone next above; measured. 1.0

20. Mudstone grading down to claystone. Medium light-gray grading down to light brownish-gray; sequence weathers light gray. Clay fraction largely kaolinitic but contains appreciable illite and mixed-layer illite-montmorillonite. Conchoidal fracture in upper parts, blocky fracture below; nonplastic in upper parts, plastic below. Locally contains lenses of and grades laterally into gray mudstone with red mottles like that next above. Abundant carbon as films, flecks, and leaf imprints in basal parts; sparse limonitic and jarosite stain. Grades into next below. Thickness variable; measured....................... 3.0

19. Interlaminated claystone and lignite. Claystone is grayish red; lignite brownish gray. Clay fraction composed largely of kaolinite, but contains appreciable illite. Sequence is thin-laminated. Abundant carbon as flecks, fragments, films; abundant leaf imprints

and carbonized wood fragments. Sparse jarosite and limonitic stain. Grades into claystone next below. Thickness variable; measured................ 0.4

18. Claystone grading down to siltstone. Medium dark-gray with brown overtones grading down to light gray with brown overtones; sequence weathers light brownish gray grading down to very light gray. Clay fraction dominantly kaolinitic but contains some illite and montmorillonite. Claystone is cut by abundant fractures coated with yellowish-gray jarosite stain. Sequence is plastic in upper parts, nonplastic below; siltstone is argillaceous. Blocky fracture; abundant carbon as flecks and fragments in upper parts; sparse carbon below. Grades into next below............................. 6.5

17. Claystone, very light gray grading down to light greenish-gray with abundant moderate-red to pale red mottles and streaks; mottled parts stained grayish orange by abundant "limonite". Dominantly kaolinitic but contains appreciable illite and montmorillonite. Weathered slopes of mottled parts littered with abundant granular aggregates of hematite. Grades irregularly into next below.... 7.6

16. Siltstone, very light gray; weathers dark yellowish orange with limonitic stain and cement. Forms resistant ledge. Abundant "limonite" and hematite after granules of siderite. Wavy, thin bedding and crinkly laminae. Abundant very fine sand grains, micaceous, sparse clay pebbles at base. Grades irregularly into next below. Thickness variable. Measured....................................... 1.5

15. Siltstone grading down to interlaminated siltstone, mudstone, and claystone. Light gray grading down to interlaminated light gray and medium light-gray; weathers very light gray. Indistinct lamination and blocky fracture in upper parts; ripple laminae and wavy or pod-like contorted thin laminae in lower parts. Sparse carbon flecks, sparse jarosite and "limonite" stain; siltstone generally argillaceous; clay fraction dominantly kaolinitic. Grades gradually into next below................... 3.4

14. Claystone, light-gray with brown overtones; plastic, blocky fracture, somewhat silty. Dominantly kaolinitic but contains some illite and montmorillonite. Sparse "limonite" stain on fracture surfaces. Grades gradually into next below.......................... 2.0

13. Mudstone, very light gray with dusky red mottles that increase in size and frequency downward. Dominantly kaolinitic but contains some illite and mixed-layer illite-montmorillonite. Plastic, blocky fracture. Grades irregularly into next below.. 4.8

12. Mudstone, greenish-gray with grayish-red mottles; weathers dark yellowish orange. Illitic and kaolinitic. Crinkly to wavy indistinct laminae and thin bedding. Calcareous and dolomitic; contains abundant siderite grains and pellets and weathers to prominent ledge with granular iron-oxide crust. Grades irregularly into next below.... 1.4

11. Mudstone grading down to claystone. Light-gray with moderate-red to moderate reddish-brown mottles and dapples; weathers to puffy very light gray to yellowish-orange slope. Dominantly kaolinitic but contains some illite and mixed-layer illite-montmorillonite as well as montmorillonite; basal foot more illitic. Claystone in basal foot where mottling most intense; unmottled in basal 0.5 ft. Abundant "limonite" stain on fracture surfaces; sparse granular aggregates of hematite on weathered slopes. Plastic, shaly in basal foot.. 6.7

Total thickness, Dakota Formation, Terra Cotta Clay Member, measured........ 45.9

Kiowa Formation

10. Sandstone, pale grayish-orange; weathers dark yellowish orange to grayish orange. Fine- to very fine grained; thin ripple laminae in lenticular beds as much as 0.7 ft thick; abundant shale films or partings in basal 0.5 ft; sparse shale partings near top. Micaceous, sparse grains of pink quartzite and black opaques. Sparse U-shaped *Arenicolites* burrows and various tracks and trails on bedding surfaces; sparse load casts on some partings. Abundant "limonite" cement and stain, particularly in top 0.3 ft. Ripple marks include transverse symmetrical types with rounded crests and wave lengths of about 0.2 ft; transverse ripples strike about N80°W. Grades sharply into next below.. 1.6

9. Siltstone grading down to interlaminated shale and sandstone. Medium dark-gray to light gray with brown overtones; weathers very light gray to grayish

orange. Thin wavy and ripple laminae. Sandstone very fine grained and weathers out as ripple-laminated beds as much as 0.2 ft thick. Interlaminated shale largely kaolinitic but contains abundant illite and "degraded" illite. Sparse U-shaped Arenicolites burrows; carbon as flecks and fragments; micaceous. Grades sharply into next below....................................... 4.1

8. Siltstone, medium dark-gray with brownish cast to medium-gray; weathers medium light gray. Argillaceous; clay fraction composed largely of kaolinite but contains abundant illite and montmorillonite; thin laminated in upper parts; lamination indistinct in lower parts. Abundant carbon as flecks and fragments; locally approaches lignite. Sparse jarosite and "limonite" stain. Thickness........... 6.5

7. Claystone, light brownish-gray; weathers very light gray. Very plastic; blocky fracture. Composed largely of illite and montmorillonite but contains abundant kaolinite. Sparse carbon flecks. Intercalated with upper parts of sandstone next below.... 3.0

6. Sandstone, pale grayish-orange; weathers dark yellowish orange to moderate reddish brown and dark reddish brown. Mainly fine- to medium-grained; locally contains scattered coarse grains or lenses of coarse-grained sandstone; upper parts mainly very fine to fine-grained with abundant iron-oxide cement and sparse leaf imprints Medium- to large-scale wedge-planar cross stratification dipping mainly to southwest; thin-laminated to thin-bedded near top; diffusion structures of iron oxide locally mask bedding; parting lineation on some cross-bed surfaces. Sparse mica flakes, sparse grains of pink quartzite and black opaques; sparse seams and lenses of plastic light gray shale. Contact with next below partly scour-fill, but sequence also intercalated with next below. Thickness measured........ 13.8

5. Sandstone, pale orange; weathers light yellowish brown to yellowish orange. Very fine to fine-grained; even horizontal and ripple laminae; sparse small- to medium-scale wedge-planar cross-lamination. Micaceous, sparse grains of pink quartzite and black opaque. Local calcareous cement forms concretionary masses as much as 2 ft thick and 6 ft long. Sparse nearly vertical burrows; sparse gray shale seams and laminae. Base covered......................Exposed, 9 0

Covered interval....................................... 31.5

4. Claystone, very light gray to light brownish-gray grading down to medium dark-gray. Composed largely of kaolinite, illite, montmorillonite, and mixed-layer illite-montmorillonite. Basal 0.2 ft bleached and stained grayish orange. Plastic. ....Exposed, 2.0

3. Sandstone, very light gray to grayish-orange; weathers dark yellowish orange to moderate reddish brown. Very fine grained; sparse lenses, seams, and films of silty gray shale containing illite, montmorillonite and abundant kaolinite; ripple-laminated. Abundant iron-oxide stain and cement in top 0.3 ft; otherwise friable. Micaceous, scattered marcasite nodules. Base not exposed; thickness measured...... 7.2

2. Covered interval. Probably masks gradational contact between sandstone next above and shale next below... 3.3

1. Shale, medium light-gray. Plastic, thin-laminated; silty, micaceous; carbon flecks on bedding surfaces. Composed mainly of illite, mixed-layer illite-montmorillonite, and montmorillonite, but contains abundant kaolinite. Abundant intercalated beds as much as 0.2 ft thick of very fine grained sandstone or siltstone, grayish-orange weathering dark yellowish orange; thin-laminated, micaceous. Base not exposed; thickness measured................................. 4.2

Total thickness Kiowa Formation measured. 86.2

12. Type section for Longford Member, Kiowa Formation, measured from creek bottom about 0.25 miles S cen. W line sec. 9, T. 10 S., R. 1 E. (about 200 ft south of bridge) to top of roadcut about 0.15 miles N SW cor. sec. 9, T. 10 S., R. 1 E., Clay County, Kansas. Measured by Paul C. Franks.

Thickness (feet)

Kiowa Formation:

Top of hill.

19. Siltstone, very light brownish-gray; weathers pinkish gray to pale yellowish orange. Thin wavy laminae and even laminae weathering to sets 0.1 to 0.5 ft thick. Contains sparse mica flakes; sparse limonitic stain; sparse pyrite nodules. Abundant concretionary masses with calcite cement as much as 5 ft thick and 10 ft long near top; concretions stand out in relief and hold abundant disseminated pyrite. Abundant carbon as flecks and films. Grades sharply into next below ....Exposed, 8.8

18. Siltstone, light-gray to light brownish-gray; weathers very pale orange to grayish orange. Indistinct thin wavy and thin even laminae with abundant carbon flecks, films, and fragments on bedding surfaces; sparse mica flakes; carbonized wood commonly replaced by pyrite; argillaceous. Grades into next below.............. 3.7

17. Siltstone, pale grayish-orange. Bedding largely masked by limonitic stain; chalky texture, but hard and weathers to form prominent ledge. Irregularly distributed calcite cement; basal bed 0.1 to 0.2 ft thick and cemented by calcite stands out in relief... 4.5

16. Siltstone, very light gray with sparse grayish-orange "limonite" stain along bedding surfaces; weathers yellowish gray to very pale orange. Thin indistinct wavy laminae; weathers to beds 0.1 to 1 ft thick. Hard, but does not stand out in relief. Sparse interstitial clay. Scour-fill contact with next below.. 3.1

15. Shale, medium-gray to medium light-gray with sparse limonitic stain; weathers very light gray to yellowish gray. Kaolinitic but contains some montmorillonite. Thin-laminated to laminated; poor fissility; silty. Thickens southward to become carbonaceous, silty mudstone. Grades sharply into next below........... 0.7

14. Silstone, light-gray; weathers yellowish gray. Bedding indistinct; abundant interstitial clay, sparse mica flakes..........................Exposed, 2.9

Covered interval...................................... 7.9

13. Siltstone, light gray to very light gray; weathers very light gray to yellowish orange and yellowish gray. Thin-laminated and ripple-laminated; bedding inclined 5 or 6° to the north. Variable amounts of interstitial clay; where interstitial clay is abundant, contains contorted posd of less argillaceous siltstone measuring 1 cm thick and up to 3 cm long. Carbon as leaf and stem imprints on bedding planes locally abundant; local calcareous cement forms discoidal concretions as much as 0.2 ft thick; concretions contain scattered pyrite nodules........... 14.5

12. Sandstone and siltstone, light-gray to very light gray with abundant yellowish-orange limonitic stain. Very fine grained to silt-sized; friable; sparse interstitial clay; sparse grains of pink quartzite and flakes of mica No obvious bedding. Grades sharply into next below.. 1.3

11. Sandstone, very light gray; mainly weathered dark yellowish orange to light brown and dusky brown with abundant limonitic and manganese-oxide stain. Fine- to coarse-grained; mainly medium-grained; thin-bedded to wavy laminated; contains sparse medium gray mudstone seams and pellets; sparse interstitial clay; abundant pyrite nodules; friable. Scour-fill contact with next below.................. 4.0

10. Mudstone, light-gray with brownish overtones grading down to light brownish-gray. Dominantly kaolinitic but contains some montmorillonite and sparse chloritic or vermiculitic mixed-layer clay. Abundant limonitic stain on fracture surfaces in siltiest parts; conchoidal fracture in upper parts; blocky fracture in lower parts. Sparse light-gray siltstone laminae near base. Bedding mainly indistinct. Grades into next below.. 4.6

9. Mudstone, very light gray to light yellowish-gray with abundant purplish-red to moderate reddish-brown mottles. Dominantly kaolinitic but contains sparse illite, montmorillonite, and a chloritic or vermiculitic mixed-layer clay. Plastic; blocky fracture. Grades sharply into next below........... 4.8

8. Siltstone, light-gray to very light gray with brown overtones. Bedding not obvious; locally calcareous; carbon fragments towards base; abundant limonitic stain. Grades into next below...................... 1.7

7. Mudstone, light-gray with brown overtones and moderate reddish-brown to reddish-brown mottles. Largely kaolinitic but contains montmorillonite and perhaps mixed-layer vermiculite-montmorillonite. Less silty towards base; abundant carbon fragments in basal 1 to 2 ft. Grades sharply into next below............... 11.1

6. Lignitic shale, pale brown. Thin wavy laminae; abundant carbon as flecks, films, and carbonized wood fragments; abundant jarosite stain. Grades laterally into mudstone containing isolated fragments of carbonized wood. Grades sharply into next below.... 0.5

5. Siltstone grading down to mudstone. Light-gray grading down to light-gray with reddish-brown mottles. Clay fraction composed mainly of montmorillonite and illite. Abundant grayish-yellow to yellowish-orange limonitic stain in upper 1 ft. Blocky to conchoidal fracture.. 12.2

4. Mudstone, light-gray grading down to light brownish-gray. Clay fraction composed mainly of illite and montmorillonite but contains sparse kaolinite and perhaps chlorite or vermiculite. Very silty towards base; bedding indistinct; blocky fracture; abundant carbon in basal 3 ft as flecks, films, fragments, and imprints of stems and leaves; abundant jarosite stain on randomly oriented fractures.. 8.8

3. Mudstone, medium-gray with brown overtones and sparse moderate-red mottles; abundant "limonite" and jarosite stain along fracture surfaces. Clay fraction composed almost completely of montmorillonite but contains sparse illite and vermiculite or chlorite. Nonplastic, blocky fracture; sparse carbon flecks, films, and imprints of plant debris. Base Longford Member, Kiowa Formation........................... 3.0

Total thickness Longford Member, Kiowa Formation, measured................ 98.1

Unconformity.

Wellington Formation:

2. Mudstone, reddish-brown. Thin-laminated to laminated but with poor fissility; blocky fracture. Clay fraction composed mainly of illite but contains, appreciable montmorillonite and chlorite. Scattered laminae bleached yellowish gray in top 0.5 ft. Abundant limonitic or hematitic cement in top 0.5 ft. Grades sharply into next below................. 3.4

1. Mudstone, light-gray to moderate greenish-gray; weathers dusky yellow. Thin-laminated but with poor fissility; blocky fracture. Clay fraction composed mainly of illite but contains appreciable montmorillonite and chlorite. Base covered. ....Exposed, 1.5

Total thickness Wellington Formation measured................................ 4.9

Note: The Permian-Cretaceous contact and the base of the Longford Member, Kiowa Formation, also are exposed near cen. W 1/2 NW 1/4 sec. 16, T. 10 S., R. 1 E. where the Permian-Cretaceous contact is some 17 or 18 feet higher than in the section described above and corresponds approximately to the middle of unit 5. The topmost Permian mudstone is intensely weathered and variegated. It contains abundant kaolinite, illite, and montmorillonite as well as minor amounts of chloritic or vermiculitic mixed-layer clay, and is overlain by a carbonaceous mudstone and lignitic sequence as well as by gray mudstone with abundant red mottles similar to material described under unit 7 above.

13. Section measured from Longford Member, Kiowa Formation, into overlying Kiowa Formation near cen. W 1/2 sec. 32, T. 9 S., R. 1 E., Clay County, Kansas. Section complements type section of Longford Member in sec. 9, T. 10 S., R. 1 E., Clay County, Kansas. Measured by Paul C. Franks.

	Thickness (feet)
Kiowa Formation:	
Covered.	
4. Shale, light-gray to light olive-gray; weathers light gray to moderate olive brown. Composed mainly of montmorillonite but contains abundant illite and kaolinite. Thin-laminated, plastic. Sparse jarosite stain; sparse layers of discoidal concretions of impure siderite. Grades sharply into next below. Top covered....................Exposed,	4.0
3. Shale, very light gray. Dominantly kaolinitic but contains abundant illite and montmorillonite. Silty, plastic; laminated to thin-laminated, poor fissility; sparse limonitic stain along lamination. Grades sharply and irregularly into next below.............	1.1
Total thickness Kiowa Formation, upper part, measured.....................	5.1
Longford Member, Kiowa Formation:	
2. Siltstone, very light gray with brown overtones; weathers yellowish gray to white. Sparse "limonite" stain; hard; ripple and even thin laminae; micro-cross-lamination in sets as much as 0.2 ft thick. Local calcite cement forms concretions as much as 3 ft in diameter; abundant limonitic cement in top 0.1 ft. Symmetric transverse ripple marks with wave lengths as great as 0.2 ft common on bedding surfaces. Grades irregularly into next below.......	5.2
1. Siltstone, very light brownish-gray with carbonaceous brownish-gray thin laminae; weathers light grayish orange. Laminated to thin-laminated; ripple and wavy laminae. Sparse "limonite" stain; argillaceous ....Exposed,	2.0
Total thickness Longford Member, Kiowa Formation, measured................	7.2
Total thickness Kiowa Formation, measured	12.3

14. Composite section measured across Permian-Cretaceous contact near cen. S 1/2 sec. 26, T. 5 S., R. 3 E., Washington County, Kansas. Section starts in creek bottom about 0.15 miles east of cen. S 1/2 of section and is continued in north-south gully at cen. S 1/2 of section. Section measured by Paul C. Franks.

	Thickness (feet)
Dakota Formation, Terra Cotta Clay Member:	
Covered.	
12. Mudstone, light yellowish-gray to very pale olive with abundant moderate-red mottles; weathers to puffy moderate yellowish-brown to very light gray slope with abundant moderate-red stain and mottling. Mottles in fresh material are as much as 3 cm across. Dominantly kaolinitic but contains appreciable illite and mixed-layer illite-montmorillonite. Locally, basal parts contain abundant grains of siderite as much as 2 mm in diameter. Grades into next below........ ....Exposed,	7.0
11. Mudstone, brownish-gray, weathers light gray. Dominantly kaolinitic but contains appreciable illite and montmorillonite. Plastic, indistinctly laminated near base, blocky fracture. Abundant pale red to moderate reddish-brown stain along fracture surfaces. Grades sharply into next below...........	3.0
10. Siltstone, light-gray to very light gray with brown overtones. Clay fraction dominantly kaolinitic but contains abundant montmorillonite and appreciable illite. Indistinct contorted thin or ripple laminae; cut by vertical joints; contains carbon as flecks and fragments............................	2.7
9. Shale, dark gray, fissile, thin-laminated, plastic; sparse siltstone laminae. Dominantly kaolinitic but contains abundant montmorillonite and sparse illite..	0.7
8. Siltstone, light brownish-gray; abundant jarosite and "limonite" stain on weathered surfaces. Thin wavy laminae. Slightly argillaceous; clay fraction composed almost completely of kaolinite. Abundant plant imprints, sparse carbon flecks and fragments. Grades sharply into next below......................	0.5
7. Siltstone, light-gray to medium light-gray. Crude irregular thin laminae; dense, abundant silica cement; contains carbon flecks and fragments........	0.7

6. Siltstone, very light gray to light-gray; weathers very light gray. Encloses lenticular zone with abundant pale reddish-brown to pale-red streaks and mottles; weathered slopes of mottled parts littered with granular aggregates of hematite. Somewhat argillaceous; clay fraction composed almost completely of kaolinite and only sparse montmorillonite or vermiculite. Local zones as much as 2 ft thick near base weather out in relief and contain abundant silica cement. Sequence tends to be indistinctly laminated, hard; blocky fracture.......................... 7.9

5. Siltstone, very light gray; generally weathers white. Upper parts commonly have pale-red to moderate reddish-orange mottles. Hard, abundant silica cement in upper 2 ft; weathers into rounded hummocks. Sparse granular aggregates of hematite on weathered slopes of mottled zones. Indistinctly laminated near base. Abundant limonitic cement in upper 0.2 ft. Grades into next below.. 6.1

4. Siltstone grading down to interbedded siltstone and sandstone. Nearly white to light-gray or medium light-gray depending upon carbon content; locally weathers dark yellowish orange to light brown. Sandstone very fine grained. Upper parts have thin wavy laminae and sparse sandstone beds as much as 0.1 ft thick; sandstone in lower parts present as thin beds and lenses as much as 1.5 ft thick, also as pods and laminae. Contains scattered lenses and layers of dark-gray dominantly kaolinitic mudstone and nearly black lignite. Abundant carbon as fragments, flecks, and films, particularly in silty parts; pyrite nodules abundant where sequence is most carbonaceous, particularly in lower 1 to 3 ft; sparse gypsum crystals in silty parts; jarosite stain on weathered surfaces. Undulose contact with next below. Thickness somewhat variable. Measured............................... 8.4

3. Siltstone, light gray with brownish-gray overtones to moderate greenish-gray; sparse moderate reddish-brown mottles. Argillaceous, thin-laminated. Clay fraction dominantly kaolinitic but contains sparse illite and mixed-layer illite-montmorillonite. Contains carbon fragments and flecks; sparse jarosite stain. Base not exposed; thickness measured........................ 2.1

Total thickness Dakota Formation, Terra Cotta Clay Member, measured........ 39.1

Covered interval... -1.0

Wellington Formation:

2. Mudstone, dark grayish-orange to dark yellowish-gray and pale olive, with moderate-red mottles; weathers very light gray to pale greenish yellow and light grayish orange splotched with moderate reddish brown; becomes dominantly light olive gray downward. Dominantly illitic and montmorillonitic but contains appreciable kaolinite. Silty, micaceous; blocky fracture though plastic; lamination not obvious. Weathered top of Permian Wellington Formation; elevation about 1 ft higher than lowest Dakota described above owing to irregularity of erosion surface cut on top of the Permian. Grades into next below.. 2.5

1. Shale, medium-dark greenish-gray; weathers pale yellowish gray with local limonitic stain. Dominantly illitic and montmorillonitic but contains appreciable chlorite. Silty, laminated to thin-laminated; micaceous. Contains sparse beds of limestone or dolomite as much as 0.3 ft thick; grayish-orange to pale yellowish-orange. Base not exposed; thickness measured......................... 9.9

Total thickness Wellington Formation measured................................ 12.4

15. Section measured across Dakota-Graneros contact along north-draining gully in SE 1/4 NW 1/4 SE 1/4 sec. 31, T. 2 S., R. 1 E., Washington County. Measured by Paul C. Franks.

Thickness (feet)

Graneros Shale:

Covered.

9. Shale, medium light-gray to medium-gray with brownish overtone; weathers dark yellowish gray to moderate olive gray; abundant jarosite and "limonite" stain near base. Thin-laminated, very plastic. Dominantly montmorillonitic but contains appreciable kaolinite and some illite. Slope shows sign of numerous small landslips. Zone of elliptic or discoidal cone-in-cone concretions as much as 2 ft thick and 4 ft long about 3 or 4 ft above base; also contains concretions of impure siderite, as much as 2 ft long and 0.2 ft thick above and below zone of cone-in-cone. Contact with Dakota next below seems sharp..............Exposed, 10.0

Total thickness Graneros Shale measured. 10.0

Dakota Formation, Janssen Clay Member:

8. Claystone, very light-gray to light gray with brownish overtones; weathers very light gray. Dominantly kaolinitic but contains appreciable montmorillonite and sparse illite. Plastic, sparse carbon fragments, no obvious bedding. Sharp contact with next below...................... 1.2

7. Sandstone, moderate yellowish-orange to very pale orange. Very fine to fine-grained, thin-laminated to laminated; contains sparse interbeds of medium light-gray to light-gray siltstone and shale. Sparse mica flakes, trace amounts of black opaques and pink quartzite, carbon as films on laiminae. One-half mile west, andstone thickens and replaces most of section described below; has molds and casts of pelecypods near top. Sharp contact with next below........... 3.2

6. Mudstone, light brownish-gray to moderate brownish-gray; weathers very light gray to white with brown overtones. Dominantly kaolinitic but contains appreciable illite and montmorillonite. Bedding indistinct; variable silt content, decreasing toward base; upper and lower parts plastic. Carbon as disseminated flecks and fragments most abundant in basal 1 to 2 ft; contains siderite spherules as much as 1 mm in daimeter. Sharp contact with next below.. 8.6

5. Claystone, dark brownish-gray; weathers medium gray. Dominantly kaolinitic but contains appreciable illite and montmorillonite as well as vermiculitic or chloritic mixed-layer clay. Plastic, blocky fracture; no obvious bedding except for indistinct lamination in central parts of unit; contains abundant macerated carbonaceous matter............................... 0.8

4. Claystone, light brownish-gray with sparse dark yellowish-orange stain as seams and films along fracture surfaces; weathers very light brownish gray. Plastic, blocky fracture; sparse carbon fragments. Dominantly kaolinitic but contains appreciable illite and mixed-layer illite-montmorillonite. Grades into lignite next below by increase in frequency of carbonaceous films and development of lamination........ 4.7

3. Claystone, dark brownish-gray, sparse yellowish-orange stain on fractures. Dominantly kaolinitic but contains some illite and sparse vermiculitic or chloritic mixed-layer clay. Plastic, indistinctly laminated, blocky fracture. Seam of thin-laminated jarosite-stained brownish-black lignite in top 0.3 ft 9.1

2. Siltstone, very light gray; weathers yellowish orange. Thin-bedded in upper parts, thin-laminated below, but weathering to beds as much as 0.2 to 0.5 ft thick; locally ripple laminated. Contains carbon as flecks and fragments on bedding surfaces; vertical burrows or root or reed imprints as much as 3 mm in diameter locally present. Grades sharply into next below.. 6.0

1. Siltstone, very light gray; weathers to moderate to dark yellowish orange where stained by iron-oxide. Indistinct thin bedding in upper parts; blocky fracture; sparse carbon flecks and fragments........ 9.0

Total thickness Janssen Clay Member, Dakota Formation, measured............... 42.6

16. Section measured across Permian-Cretaceous contact in SW 1/4 NE 1/4 sec. 12, T. 2 S., R. 3 E., Washington County, Kansas. Section starts in north-flowing gully at top of Hollenberg Limestone Member(?), Wellington Formation, and includes lower parts of Terra Cotta Clay Member, Dakota Formation. Measured by Paul C. Franks.

Thickness (feet)

Dakota Formation, Terra Cotta Clay Member:

Covered.

7. Sandstone, pale grayish-orange to moderate yellowish-brown; weathers dusky brown. Very fine grained near top of exposure; grades downward to medium- and coarse-grained; sparse, scattered very coarse grains near base. Even lamination and micro-cross-beds in upper parts; medium-scale tabular cross-strata in fine-, medium-, and coarse-grained parts; cross strata dip mainly S60°W to S80°W. Abundant leaf fossils in rubble from upper parts. Contact with next below not well exposed, but seems disconformable. Largely covered...................................Exposed, 18.0

6. Mudstone and shale interbedded with siltstone and sandstone. Mudstone and shale as medium-gray beds as much as 2.5 ft thick weather light gray to very light gray. Siltstone and sandstone very light gray; weather very pale orange to dark yellowish orange and dark reddish-brown. Clay fraction largely kaolinitic but contains abundant illite and lesser amounts of montmorillonite and mixed-layer illite-montmorillonite. Shaly parts thin-laminated and fissile; mudstone and shale commonly plastic; mudstone shows blocky fractures. Sandstone very fine grained; siltstone and sandstone thin-laminated

to thin-bedded, or show microcross-stratification and ripple laminae in sets as much as 0.5 ft thick; micaceous, sparse grains of pink quartzite and yellow-gray feldspar, sparse black opaques; friable. Siltstone and sandstone amount to 40 percent or less of unit; most abundant in upper 3 to 5 ft. Contact with next below not well exposed, but seems gradational.. 10.6

5. Mudstone, light gray with dusky-red mottles and speckles; weathers light gray to yellowish gray with pale pink blotches; mottling most abundant near base. Clay fraction composed almost completely of kaolinite but contains sparse montmorillonite. Plastic, waxy luster on fresh fractures; indistinct lamination in upper 1 ft. Thickness somewhat variable; measured.................................. 6.8

4. Siltstone, variegated, very light gray grading downward to moderate bluish-gray to moderate greenish-gray; mottled and streaked dusky-red and blackish-red; weathers very light gray with nearly vertical grayish-red streaks. Argillaceous; clay content increases toward base; dominantly kaolinitic but contains some illite and montmorillonite. Abundant hematite stain in upper 0.1 ft. Blocky fracture; local indistinct lamination. Granular aggregates of hematite on weathered slopes. Unconformable on Permian next below. Thickness variable; measured.................................. 5.3

Total thickness Dakota Formation, Terra Cotta Clay Member, measured........ 40.7

Unconformity

Wellington Formation:

3. Mudstone, variegated, dark reddish-brown to moderate grayish-red and greenish-gray; weathers pale reddish brown, light grayish red, and pale grayish yellow green; colors are concentrated in bands or seams 0.5 to 3.3 ft thick; individual bands of one dominant color are dappled with other colors. Upper 3 ft generally pale reddish-brown but show streaks of medium light gray, pale red, pale yellowish orange, light yellowish green, and grayish yellow green in top 1 to 1.5 ft; abundant "limonite" stain at contact with overlying Dakota Formation. Poorly laminated; silty, micaceous, noncalcareous. Clay fraction composed mainly of illite with some chlorite and sparse montmorillonite near base; becomes increasingly montmorillonitic upward, but uppermost 1.5 ft composed almost completely of kaolinite and illite, but with sparse montmorillonite. Thickness variable, measured....... 10.3

2. Limestone, yellowish-gray to light olive-gray; weathers grayish orange; dolomitic, finely crystalline, thin-laminated to thin-bedded. Grades into shale next below.. 0.2

1. Shale, greenish-gray; weathers light grayish yellow to yellowish gray. Dominantly illitic but contains appreciable chlorite. Thin-laminated; lenticular laminae in siltier parts. Calcareous, dolomitic; carbonate concentrated in upper parts. Sharp, wavy contact with limestone next below.................. 6.9

Hollenberg Limestone Member(?), Wellington Formation:

Not measured. Light olive-gray to yellowish-gray and grayish-yellow; weathers grayish orange; commonly stained light brown by slope wash. Argillaceous, very finely crystalline, dolomitic; crinkly to wavy laminae and thin laminae. _____

Total thickness Wellington Formation measured................................ 17.4

17. Section measured in Terra Cotta Clay Member, Dakota Formation, in NW 1/4 NE 1/4 SE 1/4 sec. 12, T. 2 S., R. 3 W., Washington County, Kansas. Section corresponds to those parts of the section measured in SW 1/4 NE 1/4 sec. 12 more than 33 feet above base, or about 3.4 feet above the base of unit 7, and illustrates the sort of lateral variation found in the Dakota Formation, Measured by Paul C. Franks.

Thickness (feet)

Dakota Formation, Terra Cotta Clay Member:

Covered.

4. Sandstone, largely covered; base probably marked by break in topography. Weathered grayish orange to grayish brown and dark reddish brown. Medium-grained with abundant seams of clay-pebble conglomerate; clay pebbles up to 14 mm long; abundant well-rounded granules of chert and quartzite; quartz overgrowths on sand grains and limonitic stain common; micaceous. Medium-scale high-angle tabular cross-strata dipping S50°W to N70°W......... ....Exposed, 15.0

Covered interval, probably claystone or mudstone......... 20.1

3. Mudstone, light-gray to light yellowish-gray grading down to light greenish-gray with moderate-red mottles and streaks; weathers to dark yellowish gray to light yellowish-gray puffy slope with pale red stain. Domi-

nantly kaolinitic but contains some illite and montmorillonite. Blocky to conchoidal fracture; sparse hematite grains probably derived by oxidation of siderite litter-weathered slopes. Grades sharply into next below...................... 4.7

2. Mudstone, greenish-gray with abundant moderate-red to dusky-red mottles; weathers to light-gray to moderate-red puffy slope. Dominantly kaolinitic but contains some illite and montmorillonite. Plastic; blocky to conchoidal fracture. Grades sharply into next below............................. 6.0

1. Mudstone, medium light-gray with dusky red and moderate-red mottles; weathers very light gray with grayish-yellow, pale red, and moderate-red splotches; heamatite grains derived by oxidation of siderite litter-weathered surfaces. Dominantly kaolinitic but contains sparse montmorillonite, illite, and vermiculitic(?) mixed-layer clay. Very silty in lower parts; blocky to conchoidal fracture..Exposed, 3.7

Total thickness Terra Cotta Clay Member, Dakota Formation, measured............... 49.5