DESCRIPTION OF A DAKOTA (CRETACEOUS) CORE FROM CHEYENNE COUNTY, KANSAS

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ABSTRACT

A Dakota (Cretaceous) core from the Guy F. Atkinson No. 1 Beaumeister well in sec. 31, T. 2 S., R. 39 W., Cheyenne County, Kansas, is described in detail. The 487-foot cored section extends from the lower part of the Graneros Shale almost completely through the Dakota Group into the Cheyenne Sandstone. Lithologic descriptions are presented, as well as data on fossils, porosity and permeability, clay mineralogy, and other pertinent information.

INTRODUCTION

Since discovery of oil in Cretaceous beds in the Denver Basin in 1949, there have been intensive efforts to locate additional producing areas in southwestern Nebraska and eastern Colorado. Although northwestern Kansas, including Cheyenne County, may be regarded as part of the Denver Basin petroleum province, little attention has been given to rocks of Mesozoic age, even the Cretaceous, in the state. Developments have progressed, however, to the extent that the easternmost fields in the Denver Basin are about 50 miles from the Kansas border; major oil and gas fields are no more than 80 miles west of the state line (Rocky Mountain Association of Geologists, 1954). It seems feasible that petroleum reserves may be found in similar rocks in Kansas (Merriam, 1958). Because little information is available concerning Cretaceous rocks between the outcrop area on the east and densely drilled areas in the Denver Basin on the west, the core taken from the Guy F. Atkinson No. 1 Beaumeister well, which is about half way between the two areas, should merit special consideration at this time. Because of paucity of information, it is impossible to make comparisons or detailed correlations; thus conclusions must be tentative.

The dry wildcat test from which the core was taken, the Guy F. Atkinson No. 1 Beaumeister in the SE¼ SE¼ NE¼ sec. 31, T. 2 S., R. 39 W., was started in April 1955 and completed in May 1955 at a total depth of 3,010 feet measured from an altitude of

3,266 feet (RB) above sea level. No tops or shows were reported on the scout ticket. No electric or radioactivity log was run, but samples are available. Core was taken from Cretaceous rocks between depths of 1,997 and 2,484 feet. Additional core was taken from the Morrison Formation (Jurassic), but that core is not discussed here.

In addition to the No. 1 Beaumeister well, only nine other tests had been drilled in the county prior to December 1957.* A summary of information concerning these wells is presented in Table 1. With the exception of the Ben. F. Brack No. 1 "B" Judy, which produced a small amount of oil from the Marmaton (Pennsylvanian) before being abandoned, all tests have been dry. Two other wells besides the Guy F. Atkinson No. 1 Beaumeister reported testing Cretaceous rocks. The Texas Company No. 1 Walz (SW¼ NW¼ NE¼ sec. 3, T. 5 S., R. 42 W.) ran a drillstem test at a depth of 2,188 to 2,200 feet, in the lower part of the Graneros Shale, for one hour and recovered 30 feet of watery drill mud. Bottom hole pressure was 415 pounds. The Ben F. Brack No. 2 Judy (NE¼ NE¼ NE¼ sec. 35, T. 1 S., R. 39 W.) tested the upper part of the Dakota at a depth of 2,001 to 2,074 feet for one-half hour and recovered 900 feet of fresh water. Bottom hole pressure was 440 pounds. Another drillstem test in the Dakota at 2,081 to 2,090 feet, tool open for one-half hour, returned a strong blow, and 290 feet of fresh water was recovered.

Although many wells have reported uphole shows of oil or gas, the only production recorded in Kansas from beds of Mesozoic age was gas from the Goodland field, in Sherman County. Gas

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* Since this report was prepared, additional wells have been drilled in Cheyenne County, principally as a result of the discovery by Phillips Petroleum Company of the Llanos field in adjacent Sherman County. By the end of 1958 four tests were completed and three were drilling in Cheyenne County. Two other locations were announced, but later abandoned.

The completed wells are: Westheimer and Neustadt No. 1 Glasco (cen. SE¼ SE¼ sec. 10, T. 1 S., R. 38 W., elev. 3,087 feet., T.D. 4,976 ft.), Phillips No. 1 St. Francis (cen. NE¼ SW¼ sec. 15, T. 4 S., R. 39 W., elev. 3,500 ft., T.D. 5,520 ft.), Lawton No. 1 Johnson (cen. NW¼ SW¼ sec. 2, T. 4 S., R. 41 W., elev. 3,472 ft., T. D. 5,397 ft.), and Jackson, Shear, and Parker No. 1 Eggers (NW¼ NW¼ SW¼ sec. 23, T. 5 S., R. 37 W., elev. 3,333 ft., T. D. 5,210 ft.). None of these wells reported testing Cretaceous rocks; the Phillips No. 1 St. Francis was a stratigraphic test and no information was released immediately.

The three wells drilling at the end of 1958 were: Phillips No. 1699 Evergreen (cen. SW¼ NE¼ sec. 16, T. 2 S., R. 37 W.), another stratigraphic test; Lawton No. 1 Rueb (cen. SE¼ NE¼ sec. 13, T. 3 S., R. 42 W., elev. 3,640 ft., T. D. 5,512 ft.) testing zones in the Pennsylvanian, and Atomic No. 1 Mundhenke (cen. NE¼ SE¼ sec. 18, T. 4 S., R. 39 W., elev. 3,524 ft.) drilling at a depth of 4,567 feet.

The Lawton No. 1 Rueb well may discover the first commercial production in Cheyenne County, as tests have indicated some oil in Pennsylvanian rocks, probably Lansing-Kansas City.

TABLE 1.—*Summary of oil and gas tests drilled in Cheyenne County, Kansas.*

Well	Location	Surface altitude	Date completed	Total depth	Tops			
					Lansing	Mississippian	Arbuckle	Precambrian
Brack 1 "B" Judy	NW SE NW 26-1-39W	3,123	5-21-51	5,142	4,180	4,855	5,045	5,139
Brack 2 Judy	NE NE NE 35-1-39W	3,123	3-21-52	4,963	4,149	4,854	....	....
Ohio 1 Rose	NE NE NE 35-1-40W	3,305	12-17-51	5,270	....	5,042	5,228	....
Deep Rock 1 Clark	SW SW SW 23-1-42W	3,456	7-25-52	5,632	4,586	5,332	5,403	5,565
Atkinson 1 Beaumeister	SE SE NE 31-2-39W	3,266	5-10-55	3,010	....	....	....	....
Hammer 1 Beaumeister	SW SW NW 32-2-39W	3,285	9- 7-54	4,720	3,770	4,510	....	....
Service 1 Beeson	NE NE NW 8-3-38W	3,510	3-31-52	5,392	4,488	5,189	5,375	....
Falcon—Seaboard 1 Zweygardt	SE SE SW 1-3-41W	3,526	2-18-55	5,449	4,495	5,173	5,339	....
Carle and Ungerman 1 Martin	SE SE SE 10-4-41W	3,388	6-18-52	3,075	....	....	....	....
Texas 1 Walz	SW NW NE 3-5-42W	3,547	11- 8-52	5,387	4,421	5,041	5,218	....

was produced for a short time from the basal part of the Pierre Shale and upper part of the Niobrara Formation of Cretaceous age at a depth of about 1,000 feet. Gas also was reported in the Niobrara Formation in the now abandoned Wray field just across the Kansas state line in Yuma County, Colorado. The amount of petroleum so far found in Kansas in rocks of Mesozoic age has been disappointing, however.

Acknowledgments.—We thank the Guy F. Atkinson Company, James D. Bishop, Chief Geologist, for making the core and samples available to the Survey for study. In addition to the core, information obtained from many core analyses, a drilling-time log, and the original sample log were placed at our disposal. The core and samples are being kept by the State Geological Survey at Lawrence for future reference. William A. Cobban of the United States Geological Survey identified the invertebrate megafossils; Richard H. Benson of the University of Kansas checked identifications of the microfossils. The shale samples for micropaleontologic studies were prepared by Glen L. Foster.

TECTONIC ENVIRONMENT

By Daniel F. Merriam

The Hugoton Embayment, which is a large shelflike extension of the Anadarko Basin of Oklahoma, developed in western Kansas, eastern Colorado, and northern Oklahoma during the Paleozoic Era. The embayment is a major structure formed by a series of epeirogenic movements of differential downwarping of the embayment and uparching of marginal areas. The eastern edge of the structure is bounded by the Pratt Anticline, Central Kansas Uplift, and Cambridge Arch. The western limit is formed by the Las Animas Arch in Colorado. The embayment plunges southward, and sediments thicken both toward the axis and southward into the Anadarko Basin. Early history of the Hugoton Embayment is closely associated with development of the Anadarko Basin. During late Pennsylvanian—early Permian time, the Oakley Anticline, an elongate southward-plunging structure, began to develop structurally, and by the end of the Paleozoic it divided the northern part of the embayment into two smaller basinal areas.

In Mesozoic time, the Western Kansas Basin developed in the area of the Hugoton Embayment and became closely associated with the Denver Basin located west and northwest of Kansas in Colorado. Post-Paleozoic structural movement consisted of epeirogenic movement in response to tectonic activity in the Denver Basin and surrounding areas. Evidence for structural movement during the Triassic is meager; it is possible that some structural adjustment occurred along the Oakley Anticline at this time. During Jurassic time, the area was tilted northwestward toward the Denver Basin. Before deposition of Lower Cretaceous sediments, the area possibly was tilted slightly southward.

Little structural movement actually took place during Cretaceous time except for formation of a marginal syncline along the eastern flank of the Las Animas Arch in western Gove County and eastern Thomas County. This syncline developed on the earlier Oakley Anticline and almost completely destroyed it (Lee and Merriam, 1954). Slight movement occurred on the Cambridge Arch along the eastern margin of the basin. Differential movement continued until some time after deposition of Niobrara sediments, possibly until the end of the Cretaceous, when sediments of the area were tilted northwestward toward the Denver Basin and possibly slightly folded. These movements did not alter the general shape of the older Hugoton Embayment, however.

After deposition of the Ogallala Formation (Pliocene), the area was tilted eastward (Merriam and Frye, 1954). This structural movement concluded development of western Kansas and brought beds into their present position.

STRATIGRAPHY

By Daniel F. Merriam

Only a brief description of Mesozoic rocks encountered by the drill in northwestern Kansas is presented here. For further discussions on stratigraphy the reader is referred to Moore and others (1951, 1952), and Prescott (1953); for structure, reference is given to Jewett (1951), and Lee and Merriam (1954).

Inasmuch as the Dakota Formation on the surface in Kansas has not been certainly correlated in detail with the subsurface units identified in the Denver Basin, informal subsurface terminology will be used in this report. This terminology has not been accepted officially by the State Geological Survey and thus is used only as a matter of convenience of classification here. Merriam (1957) has suggested possible correlations of surface and subsurface units, although much additional work, especially on surface outcrops, is necessary before correlations can be verified. The main difference is in the use of *Dakota,** which is used to designate a formation on the surface (Plummer and Romary, 1947), whereas in the subsurface approximately the same unit is here designated by the name *Omadi.* In this report, then *Dakota* is tentatively used to include the Omadi, Kiowa, and Cheyenne formations.

Rocks overlying the Dakota Group have been traced into the subsurface from outcrops, and no difficulties arise in identifying these units, even where concealed. Most units, especially Cretaceous beds, can be traced into the neighboring states of Colorado and Nebraska. Indeed, type sections of some of the Cretaceous beds (for example Niobrara Formation, Carlile Shale, Greenhorn Limestone, and Graneros Shale) are in adjacent states, and these rocks have been traced and their nomenclature extended into Kansas.

Post-Dakota Rock Units

Quaternary

Rocks of Quaternary age occur as a thin veneer over western Kansas. They consist, for the most part, of unconsolidated gravel, sand, and silt, which occur as alluvial deposits in present stream valleys and as a loess mantle on upland surfaces. An excellent summary of Pleistocene deposits of the state may be found in Frye and Leonard (1952).

Tertiary

The Ogallala Formation, mainly Pliocene in age, unconformably underlies Quaternary deposits in northwestern Kansas. The Ogallala is composed of loosely cemented gravel, sand, silt, and volcanic ash. A reference marker bed, the "Algal limestone", occurs at the top of the formation. In Cheyenne County the Ogallala reaches a maximum thickness of about 300 feet in the

* The names *Omadi Formation* and *Dakota Group,* as used in this report, are capitalized as formal names, although they have not been formally accepted by the State Geological Survey of Kansas. They are not to be regarded as informal names in the sense that "Algal limestone" or "Bartlesville sand" is an informal name.

southwestern part (Merriam, 1955a). Further information on beds of this age can be obtained from Frye, Leonard, and Swineford (1956).

Cretaceous

Cretaceous deposits in the state are composed mainly of shale, chalk, limestone, and sandstone. Most of the sediments were deposited under marine conditions, as is evident from the abundance of marine invertebrate and vertebrate fossils. Many thin beds of bentonite are intercalated throughout the post-Dakota strata. All post-Dakota units are Upper Cretaceous (Gulfian) in age and belong to either the Montana or Colorado Groups. The cross section (Fig. 1) shows position of Cretaceous formations relative to each other as well as to underlying formations in Cheyenne County.

Pierre Shale is the uppermost Cretaceous formation present in Kansas. On the surface it has been divided into six units (Elias, 1931) only one of which, the Sharon Springs Shale member, is identifiable with certainty in the subsurface. The formation, part of the Montana Group, is mainly shale containing many concretionary zones. The shale is light to dark gray, soft, micaceous, fissile, slightly calcareous, and fossiliferous. In Cheyenne County the maximum thickness of the formation is about 1,600 feet in the extreme northwestern corner. The beveled Pierre is unconformably overlain by Tertiary and Quaternary deposits.

The Niobrara Formation, uppermost unit of the Colorado Group, conformably underlies Pierre Shale. The Niobrara has been subdivided into the Smoky Hill Chalk (upper) and Fort Hays Chalk (lower) members. Both of these units are traceable in the subsurface. The Smoky Hill is chiefly a chalky (or calcareous) shale, light, medium, or dark gray, mottled, soft, calcareous, and fossiliferous. Thin stringers of bentonite are common. The Fort Hays is a white or light-gray, chalky, porous, soft, fossiliferous limestone containing interbedded soft chalky shale. Maximum thickness of the Niobrara Formation in Cheyenne County is about 600 feet.

The Carlile Shale conformably underlies the Niobrara Formation. This unit, which contains three identifiable members, consists predominantly of shale but contains some sandstone. The

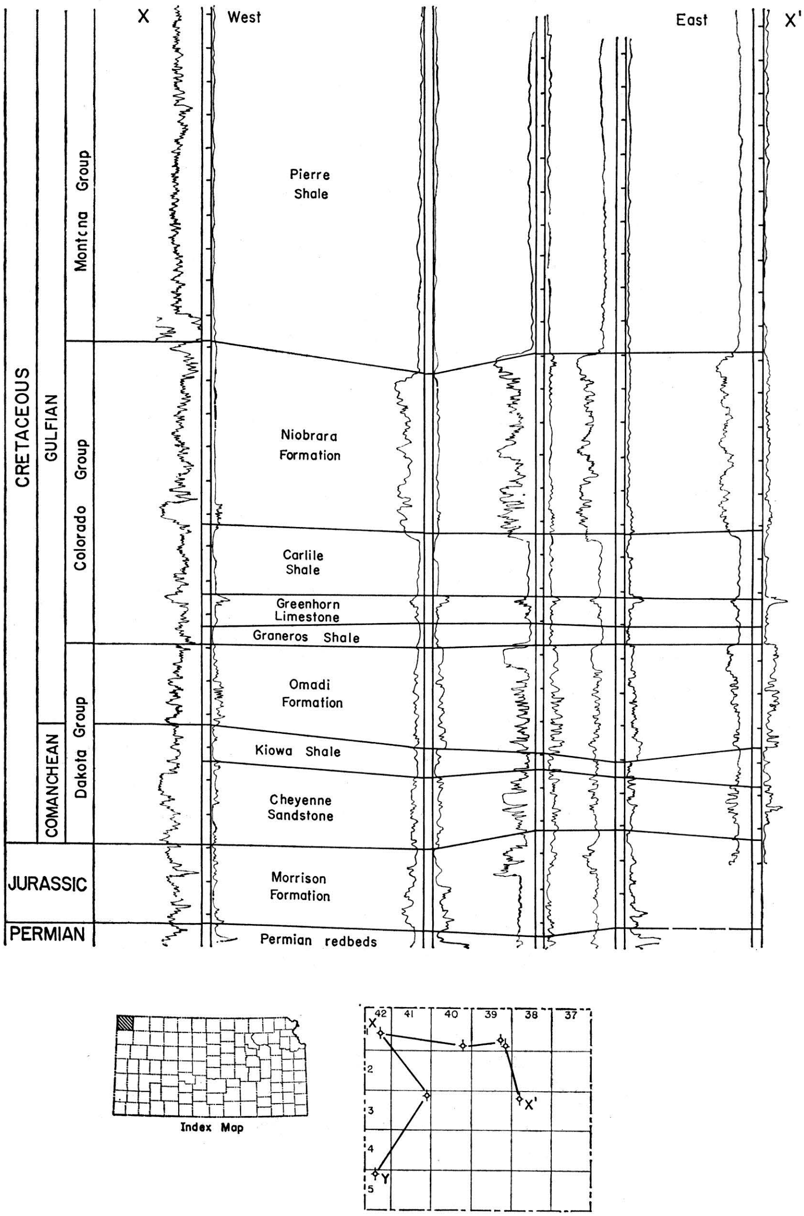
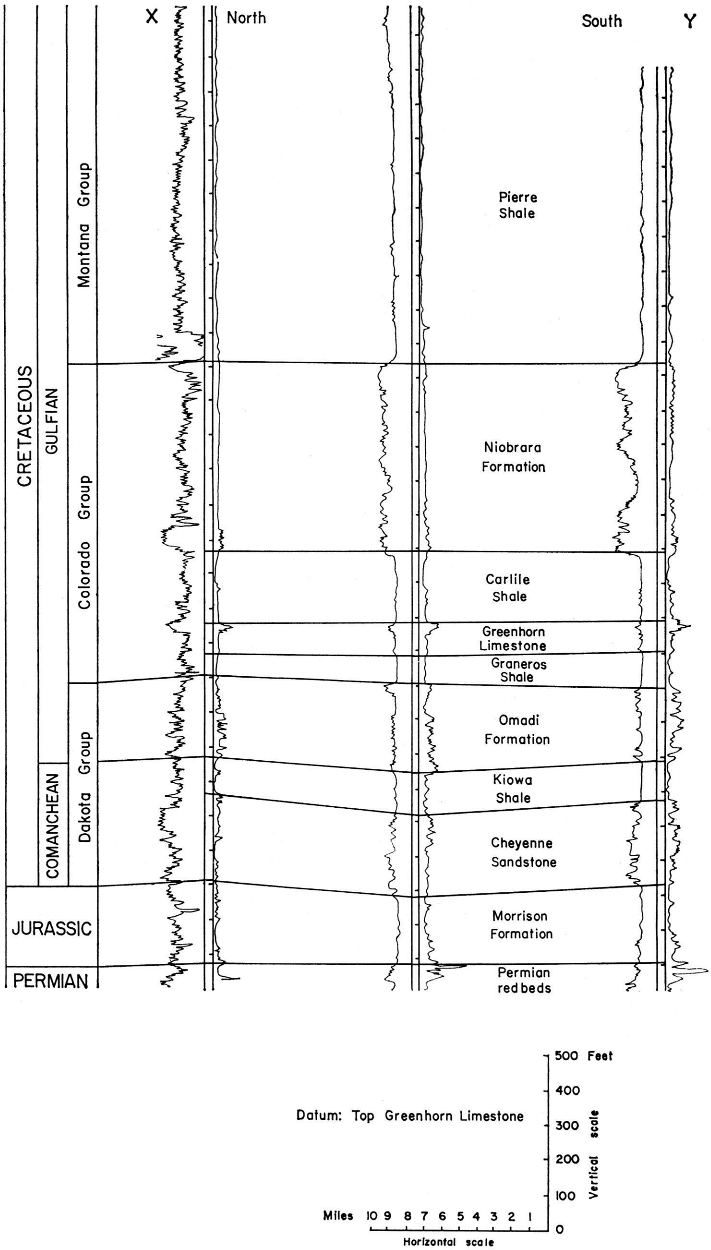


FIG. 1.—Electric-log sections showing stratigraphic relations



of Mesozoic rock units in Cheyenne County, Kansas.

Codell, upper member of this unit, is a brown to gray, fine- to medium-grained, subangular sandstone containing interspersed silt. The middle member is the Blue Hill, which is composed of gray to blue-gray clayey noncalcareous shale. The Fairport, a chalky shale, is the lowermost member of the Carlile. It contains stringers of limestone. Thin layers of bentonite are present near the base of the member. The Carlile is fossiliferous; it has a nearly uniform thickness of about 200 feet.

Conformably underlying Carlile Shale is the Greenhorn Limestone. On the surface the formation is divisible into four members, but no effort has been made to identify these units in the subsurface. The Greenhorn consists chiefly of limestone and limy shale (Bergman, 1949). The limestone is gray to light brown, chalky or crystalline, and fossiliferous; shale is gray to brownish, calcareous, and fossiliferous. A persistent bed in the uppermost part of the formation is known as the Fencepost Limestone. This bed produces an easily identifiable double-pronged kick on electric logs and may be traced over a large area in the Midcontinent and Rocky Mountain regions. In Kansas the Greenhorn unit has a uniform thickness of about 100 feet.

The Graneros Shale is the lowest unit of the Colorado Group and conformably underlies Greenhorn Limestone (Plummer and Romary, 1942). This formation is composed of shale but contains minor amounts of sandstone and thin stringers of bentonite. The Graneros is a medium-gray to black, noncalcareous or slightly calcareous silty shale. Locally it is abundantly fossiliferous. One bentonite bed, termed the "Bentonite marker bed", is traceable over large areas and serves to subdivide the formation. It is blue-gray bentonite, 1 to 2 feet thick in Kansas, and causes an easily identifiable kick on electric logs. In Cheyenne County, thickness of the formation ranges from about 50 to 100 feet. Graneros Shale overlies the Dakota Group disconformably over much of western Kansas.

Dakota Group

The Dakota Group as tentatively defined here includes that sequence of rock strata of Cretaceous age between overlying Graneros Shale and underlying rocks ranging in age from Permian to Jurassic. In the subsurface as on the surface the group is divisible into three formations, but in the subsurface, especially in the northwestern part of the state, units of the group are more consistent and more easily recognized, and lend themselves to lithologic subdivision more readily than on the outcrop. An area of scanty information, which causes untold difficulties in correlation of different units, occurs near the outcrop, where the rocks are covered but so shallow as not to be adequately logged.

Uppermost unit of the group is termed the Omadi Formation (see Condra and Reed, 1943; Boreing, 1953; and Merriam, 1957, for stratigraphic nomenclature pertaining to this formation and its present status in Kansas); middle unit, Kiowa Shale; and lower unit, Cheyenne Sandstone. In turn, the Omadi Formation is subdivided into three members: Gurley Sandstone (upper), Huntsman Shale, and Cruise Sandstone (lower). Sands of the Dakota Group in the Denver Basin have been given letter designations as a matter of practicability. The "D", "G", and "J" sands are in the Omadi Formation; the "M", "O", "R", and "T" sands in the Cheyenne Sandstone. Preliminary investigations indicate that sands also occur at approximately the same stratigraphic positions in Kansas and thus they could and have been referred to by the same letter terminology.

Figure 2D shows the thickness of the Dakota Group, which ranges from about 525 feet in south-central Cheyenne County to about 625 feet in the east-central and west-central parts of the county. Generally, the thickness is variable because of the unconformity at the base of the group.

Omadi Formation is judged to be Upper Cretaceous (Gulfian), whereas Kiowa Shale and Cheyenne Sandstone are believed to be Lower Cretaceous (Comanchean) by the Kansas Geological Survey (Moore and others, 1951).

Many interesting sedimentary structures and rock types were observed in the core. Some of the sedimentary structures closely resemble those pictured by Fentress (1955, p. 181). Plate 1A shows distorted bedding in an alternating sequence of sand and shale of the Gurley member. Large fragments of carbonaceous material are pictured in Plate 1B. Carbonaceous material is common throughout the Omadi Formation, although that pictured is from the Huntsman member. Plate 1C and 1F show conglomeratic sandstone from the Cruise member; the pebbles, which

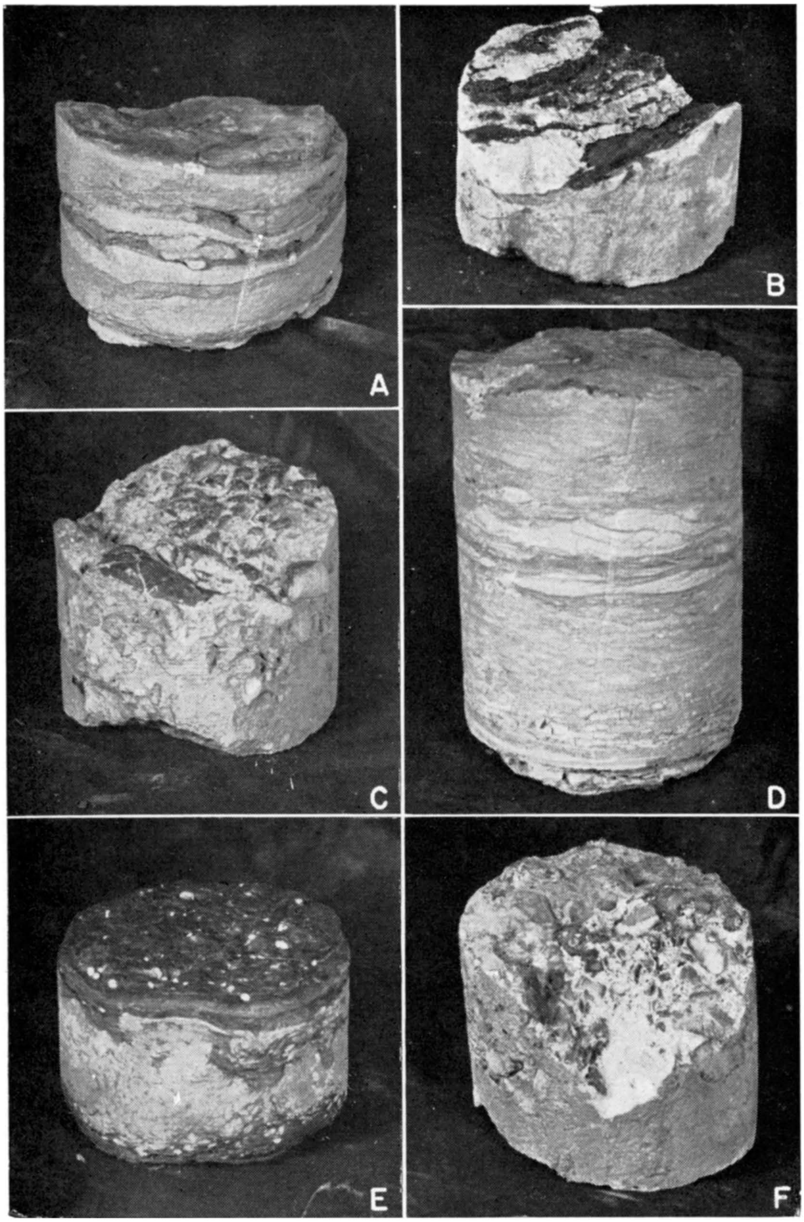


PLATE 1.—Photographs of representative core samples from Guy F. Atkinson No. 1 Beaumeister well. Diameter of core, 3 inches. **A.** Distorted bedding in alternating sequence of sandstone and shale of Gurley member. **B.** Large fragments of carbonaceous material from Huntsman member. **C.** Conglomeratic sandstone of Cruise member. **D.** Sandstone lenses in laminated shale of Cruise member. **E.** Distorted shale laminae in sandstone of Cruise member. **F.** Conglomeratic sandstone containing bone(?) fragments, Cruise member.

are composed mainly of collophane, are rounded and polished. Plate 1D and 1E exhibit the intricate nature of erratic bedding of interbedded sandstone and shale of two samples from the Cruise member. Small rounded masses of white fine-grained sand are observable in the black laminated shale on the upper surface of the core sample on Plate 1E. These "sandballs" are common in parts of the Omadi Formation.

Recent articles on the Denver Basin include the excellent symposium published by the Rocky Mountain Association of Geologists (1954), McCoy (1953), Boreing (1953), Fentress (1955), Finley, Dobbin, and Richardson (1955), and MacQuown and Millikan (1955).

Omadi Formation

The Omadi Formation consists of sandstone, siltstone, conglomerate, shale, and clay. One thin bed of coal is present. Thickness of the formation increases eastward in Cheyenne County (Fig. 2A) to a maximum of about 350 feet. Contacts of the Omadi with adjacent overlying and underlying units are conformable or locally unconformable (Merriam, 1957).

Gurley Sandstone member—The Gurley consists mainly of sandstone but includes some shale and siltstone. In general, sandstones are light to medium gray, fine to coarse grained, slightly micaceous, calcareous, and friable. Shales are medium gray, noncalcareous, and thinly laminated. Siltstones are light gray, micaceous, and noncalcareous, and some are carbonaceous. Shaly streaks are common in both sandstones and siltstones, and sandy streaks are present in the shales.

In Cheyenne County, thickness of the Gurley ranges from about 60 to 100 feet. The member, in general, thins to the east and from preliminary correlations seems not to crop out in Kansas but to be truncated and overstepped by Graneros Shale, which rests on the Huntsman Shale member in the subsurface near the outcrop (Merriam, 1957, pl. 1).

Huntsman Shale member—The Huntsman Shale is composed of shale and sandstone. The shale is medium to dark gray, noncalcareous, clayey or sandy, and contains carbonaceous material. Sandstones are light gray, fine to medium grained, noncalcareous to slightly calcareous, shaly, and carbonaceous.

The Huntsman is the thinnest member of the Omadi; in Cheyenne County its thickness ranges from 10 to 25 feet. Preliminary correlations suggest that this member may correlate with the outcropping Janssen Clay (Merriam, 1957).

Cruise Sandstone member—The Cruise is mainly sandstone, siltstone, and shale, but contains minor amounts of clay, conglomerate, and coal. Sandstones are typically light brown or gray, fine to medium grained, calcareous, and friable; siltstones are light gray, micaceous, carbonaceous, shaly, and hard; and shales are medium gray, noncalcareous, and soft. The clay is light gray to greenish gray and silty, and locally contains siderite "pellets". The conglomerates are composed of rounded, smooth, black pebbles. The coal is lignitic.

The Cruise Sandstone in Cheyenne County ranges in thickness from about 130 to 220 feet. This unit may correspond to the exposed Terra Cotta Clay (Merriam, 1957).

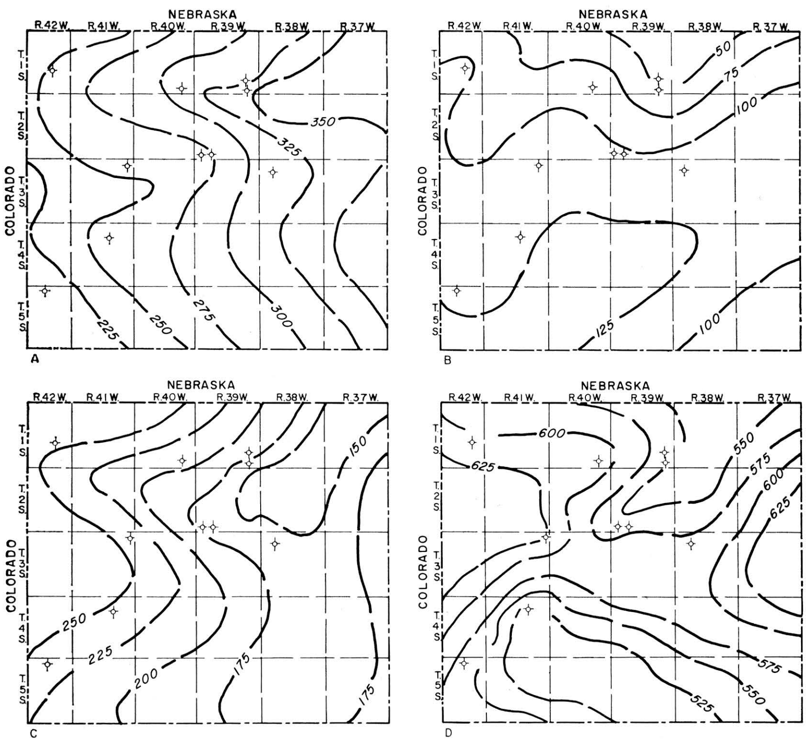


FIG. 2.—Isopachous maps of formations in Dakota Group in Cheyenne County, Kansas. A. Thickness of Omadi Formation. B. Thickness of Kiowa Shale. C. Thickness of Cheyenne Sandstone. D. Total thickness of Dakota Group.

Kiowa Shale

Kiowa Shale consists of shale, some siltstone and sandstone, and minor amounts of limestone. The shale is medium to dark gray, noncalcareous, slightly micaceous and pyritic, soft, and fossiliferous. The siltstone is light gray, slightly calcareous and micaceous, and hard. Sandstones are gray, very fine to fine grained, and slightly calcareous, micaceous, and glauconitic. A thin bed of impure hard limestone occurs near the base of the formation. The Kiowa has not been subdivided in the subsurface.

Thickness of the Kiowa Shale in Cheyenne County ranges from 50 to 125 feet (Fig. 2B). In other parts of the state it attains a maximum thickness of approximately 150 feet. Detailed descriptions of the formation on the outcrop are given by Latta (1946).

Cheyenne Sandstone

Cheyenne Sandstone has no recognized named subdivisions in the subsurface, although several could be made. The formation is composed of sandstone but contains some shale and other minor constituents. Sandstones are light gray or brown, fine to medium grained, glauconitic, micaceous, pyritic, and noncalcareous; shales are medium to dark gray, noncalcareous, and soft. A very thin bed of coal containing amber was found just below the Kiowa-Cheyenne contact.

Thickness of the formation in Cheyenne County (Fig. 2C) ranges from 150 to 250 feet and in general decreases to the east and south. Latta (1946) gives a detailed description of the formation on the outcrop in south-central Kansas.

Pre-Dakota Rock Units

In Cheyenne County, the Cretaceous Dakota Group is underlain by the Jurassic Morrison Formation (Merriam, 1955). These Jurassic deposits attain a thickness of 350 feet in northwestern Kansas and thin toward the east, southeast, and south to a featheredge. They do not crop out in the state. Where the Morrison Formation is not present, the Cretaceous is underlain by rocks of Permian age, mainly redbeds. In extreme southwestern Kansas the Cretaceous rests on the Triassic Dockum (?) Group. The Mesozoic rock sequence as a whole unconformably overlies the Permian, indicating a hiatus of considerable length in the state.

CORE AND SAMPLE DESCRIPTIONS

By Daniel F. Merriam and William R. Atkinson

Although no electric log or radioactivity log was available for the Guy F. Atkinson No. 1 Beaumeister well, other data such as a drillers log, sample log, and drilling-time log were available. The drillers log, which was supplied by the Kansas Geological Society's Well Log Bureau, is brief (Table 2). No tops were given on the log; furthermore, because of the brevity of the log, no tops could be picked. The anhydrite encountered at a depth of 2,880 feet is too shallow to be the Stone Corral (Cimarron anhydrite of subsurface terminology) but possibly is the Blaine.

TABLE 2.—*Drillers log of Guy F. Atkinson No. 1 Beaumeister (SE¼ SE¼ NE¼ sec. 31, T. 2 S., R. 39 W.). Elevation, 3,266 feet RB; total depth, 3,010 feet. H & H Drilling Company, contractor. Casing: 8⅝ in. at 194 feet, cemented with 150 sacks of cement. Production, dry.*

Lithology	Depth to bottom of formation, feet.
Shale and sand	194
Shale	1,370
Shale and sand	1,930
Shale	1,997
Coring	2,484
Shale	2,495
Shale and sand	2,717
Shale and lime	2,800
Coring	2,827
Shale and lime	2,863
Shale	2,880
Anhydrite	2,913
Shale and sand	3,010
Total Depth	

The original sample log prepared by James D. Bishop, Chief Geologist of the Guy F. Atkinson Company, is presented in Table 3 in slightly abbreviated form. From this detailed log it is possible to ascertain the following tops: Pierre Shale, 10 feet; Niobrara Formation, 1,130 feet; Fort Hays Chalk member, 1,620 feet; Carlile Shale, 1,650 feet; Blue Hill Shale member, 1,710 feet; Fairport Shale member, 1,820 feet; Greenhorn Limestone, 1,890 feet; Graneros Shale (estimated), 1,975 feet; Omadi Formation, 2,034 feet; Kiowa Shale, 2,308 feet; Cheyenne Sandstone, 2,419½ feet; Morrison Formation, 2,590 feet; Permian redbeds, 2,895 feet; and the total depth of the well at 3,010 feet, still in Permian redbeds. The Stone Corral was not reached. Lithologi-

TABLE 3.—*Sample log of Guy F. Atkinson Company No. 1 Beaumeister well, examined by James D. Bishop, Chief Geologist, Guy F. Atkinson Company.*

Depth From	Depth To	Description of material
0	5	Silty sandy loam
5	10	Medium to coarse-grained sand
10	40	Yellow, gray to dark-gray, weathered shale
40	260	Gray, slightly calcareous, fissile shale
260	520	Gray to dark-gray, fissile, calcareous shale
520	610	Dark-gray to black, fissile, noncalcareous shale
610	630	Ditto with white bentonite
630	670	Dark-gray to black, fissile, noncalcareous shale
670	850	Ditto; fossil shells and limy concretions
850	1030	Dark-gray to black, noncalcareous shale, some bentonite, fossil fragments, and limy concretions
1030	1130	Brown to dark-gray, slightly calcareous, fossiliferous shale
1130	1200	Brown to gray, very calcareous, slightly fossiliferous shale; some bentonite
1200	1570	Gray speckled white, calcareous, slightly fossiliferous shale; some bentonite
1570	1590	Gray to white, slightly shaly chalk
1590	1620	Gray speckled white, slightly shaly, fossiliferous chalk; some bentonite
1620	1650	White, limy chalk
1650	1710	Gray, fine- to medium-grained, calcareous sand
1710	1730	Gray, chalky shale
1730	1820	Ditto; some bentonite
1820	1870	Ditto; some white, crystalline limestone
1870	1890	Gray to dark-gray, chalky shale
1890	1930	Gray, medium hard, dense to finely crystalline limestone
1930	1997	Dark-gray, very calcareous fossiliferous shale
1997	2021	Gray to dark-gray, calcareous, fossiliferous, fissile shale; thin bentonite beds
2021	2034	Dark-gray to black, noncalcareous, fossiliferous, fissile shale
2034	2484	Core of Dakota Group—see detailed log, Figure 3
2484	2505	Gray to dark-gray, hard, fissile shale; some coarse-grained quartz sandstone
2505	2540	Gray, medium-grained, calcareous sandstone
2540	2550	Gray to dark-gray shale
2550	2560	Gray, hard, pyritic, calcareous sandstone
2560	2585	Gray to dark-gray shale and medium-grained, well-cemented sandstone
2585	2590	Gray, coarse-grained, quartz sandstone
2590	2680	Green and gray, bentonitic shale
2680	2755	Green to gray, bentonitic shale and white to buff, medium-hard, crystalline limestone and dolomite
2755	2775	Green and gray, bentonitic, sandy shale; some white, dense, medium-hard limestone
2775	2795	White to buff, dense, slightly sandy limestone and green and gray, sandy, bentonitic shale
2795	2805	White to buff, dense, finely crystalline, sandy cherty limestone
2805	2860	Gray to green, medium-hard, calcareous shale; stringers of crystalline, cherty limestone
2860	2885	Red-brown sandstone
2885	2915	White gypsum and anhydrite; some medium crystalline limestone and red and gray shale
2915	2925	Green and gray, sandy shale
2925	3010	Brick-red shale, gray sandy shale, and some red to gray medium-grained sandstone
3010		Total depth

cally the rock units encountered in this well are similar to their respective units in other parts of northwestern Kansas and thus are easily recognized.

A gas odor was noted by Bishop at the top of the Niobrara Formation in a zone that possibly is faulted. Stratigraphically this is the same zone that produced minor amounts of gas in Sherman County in the old Goodland field. Also, under fluorescent light some dark-golden-brown oil stains were noted in the Omadi Formation. A few zones in the Omadi beds showed traces of free oil, but when the core was studied several months later, no traces of oil were found.

The drilling-time log is presented in Table 4. Time intervals are 10-foot to a depth of 1,997 feet and then 1-foot to total depth. Pertinent information concerning drilling operations is noted in the remarks column.

TABLE 4.—*Drilling-time log of Guy F. Atkinson Company No. 1 Beaumeister well, SE¼ SE¼ NE¼ sec. 31, T. 2 S., R. 39 W., Cheyenne County, Kansas.*

All measurements from rotary bushing, 5 feet above ground elevation of 3,262 ft.; size of hole, 7⅞ in.; drill pipe: 4½ in.

Depth From	Depth To	Drilling time, minutes	Remarks
		(10-foot time)	
200	300	4-4-3-3-3-3-3-3-3-3	Date 4-29-55; started drilling from
300	400	3-3-3-3-4-4-3-3-3-3	under surface pipe at 7:43 p.m.
400	500	4-3-4-3-3-3-3-6-5-6	
500	600	2-3-2-3-2-3-3-2-2-3	Test slope @ 594 ft.; (½%)
600	700	3-3-3-4-3-4-3-3-3-3	Date 4-30-55
700	800	3-3-2-2-3-3-4-3-3-3	
800	900	3-2-2-3-3-3-3-4-5-5	
900	1000	4-5-4-4-4-3-4-4-5-4	
1000	1100	4-4-4-4-5-5-5-4-5-5	Test slope @ 1061 ft.; (1%)
1100	1200	4-4-3-3-3-3-3-4-3-3	
1200	1300	2-3-2-3-3-3-3-3-3-3	
1300	1400	3-3-4-5-7-7-6-3-3-3	
1400	1500	2-2-2-3-3-3-2-3-2-2	Jetted pits
1500	1600	3-4-4-3-3-3-3-2-3-2	Test slope @ 1590 ft.; (¾%)
1600	1700	3-3-4-5-5-3-2-3-4-5	
1700	1800	5-7-9-9-10-10-11-11-11-11	
1800	1900	10-9-9-9-10-10-10-12-12-12	
1900	1997	10-10-10-11-10-11-10-10-11-10	Cir. 45 min. @ 1997 ft.; (Trip)
		(1-foot time)	
1997	2000	27-24-33	Start core 1 @ 1997 ft.;
2000	2010	28-35-21-21-20-18-19-19-18-18	Vis. 38, wt. 9.2 5-1-55
2010	2020	16-13-14-16-18-20-17-15-16-12	
2020	2030	17-17-15-18-11-12-26-16-14-15	Pulled core for inspection @ 2026 ft.;
2030	2040	13-15-16-12-8-11-3-2-1-1	(core loss 4 ft. 7 in.) Start core 2
2040	2050	2-3-7-6-5-5-5-7-7-7	
2050	2060	8-10-7-6-6-7-6-5-5-4	

TABLE 4.—*Drilling-time log of Guy. F. Atkinson Company No. 1 Beaumeister well, SE¼ SE¼ NE¼ sec. 31, T. 2 S., R. 39 W., Cheyenne County, Kansas.*

All measurements from rotary bushing, 5 feet above ground elevation of 3,262 ft.; size of hole, 7⅞ in.; drill pipe: 4½ in.

Depth From	Depth To	Drilling time, minutes	Remarks
2060	2070	6-6-6-9-7-12-13-18-15-14	End of core 2 @ 2076 ft.; start core 3.
2070	2080	17-17-17-14-17-7-10-3-1-2	Vis. 35, wt. 9.1 5-2-55
2080	2090	2-3-2-1-2-2-2-2-2-3	Pump press. 350
2090	2100	2-2-2-1-2-2-2-2-2-2	
2100	2110	3-2-2-3-2-1-3-4-4-4	
2110	2120	3-4-1-2-3-5-5-7-10-6	
2120	2130	9-8-6-5-2-8-6-1-4-7	End of core 3 @ 2126 ft.; start core 4
2130	2140	6-5-1-3-4-4-6-2-2-4	
2140	2150	1-1-1-3-13-10-2-4-8-7	Vis. 41, wt. 9.1, pump press. 450
2150	2160	4-5-5-6-6-6-4-6-4-5	
2160	2170	5-4-4-5-5-7-7-5-5-4	
2170	2180	5-4-5-6-6-7-9-6-4-4	End of core 4 @ 2176 ft.; start core 5
2180	2190	6-3-3-5-5-6-6-5-7-8	5-3-55
2190	2200	8-8-14-11-15-2-2-2-3-2	
2200	2210	2-9-6-5-9-9-12-11-12-9	Vis. 42, wt. 9.2
2210	2220	6-4-5-7-8-8-8-8-5-5	
2220	2230	6-7-6-6-7-5-6-7-9-12	End of core 5 @ 2226 ft.; start core 6
2230	2240	11-8-5-9-4-4-3-5-2-2	Vis. 38, wt. 9.1, pump press. 450
2240	2250	5-6-4-4-7-5-5-6-6-7	
2250	2260	7-6-7-6-7-5-3-2-3-5	Vis. 41, wt. 9.2, pump press. 350
2260	2270	3-4-4-4-3-3-2-3-3-3	End of core 6 @ 2276 ft.; start core 7
2270	2280	4-5-2-2-2-2-2-2-2-2	
2280	2290	1-2-2-2-2-2-1-2-2-2	5-4-55 Pump press. 350
2290	2300	2-2-2-1-2-1-2-2-2-2	
2300	2310	2-2-2-3-2-5-3-6-12-8	End of core 7 @ 2309.5 ft.; start core 8
2310	2320	30-30-25-22-14-10-7-10-21-27	5-5-55
2320	2330	26-23-24-23-22-20-20-22-17-23	Vis. 44, wt. 8.9, pump press. 450
2330	2340	23-24-20-23-21-14-15-16-14-14	5-6-55
2340	2350	19-19-16-10-9-9-7-9-8-9	
2350	2360	13-12-13-13-16-20-17-14-9-3	End of core 8 @ 2359 ft.; start core 9
2360	2370	4-6-10-7-11-12-6-4-3-14	5-7-55 Vis. 39, wt. 9.1
2370	2380	16-12-12-16-19-16-16-17-19-20	
2380	2390	18-17-12-15-10-13-17-19-16-17	Vis. 37, wt. 8.9
2390	2400	10-17-17-15-10-5-6-12-11-8	
2400	2410	15-8-5-10-13-15-15-14-16-21	End of core 9 @ 2409 ft.; start core 10
2410	2420	14-17-15-12-7-8-8-11-12-9	5-8-55
2420	2430	3-3-2-2-4-4-6-6-3-5	Pulled core 10 @ 2427 ft. (damaged
2430	2440	5-4-3-4-7-10-8-3-4-3	diamond corehead—pyrite)
2440	2450	2-2-5-7-5-4-6-11-14-2	
2450	2460	4-6-5-6-8-5-2-1-2-2	End of core 11 @ 2454 ft.; start core
2460	2470	2-3-3-2-3-1-2-3-4-2	12
2470	2480	5-4-6-4-8-8-11-13-14-12	End of core 12 @ 2484 ft. (stopped
2480	2490	13-16-11-9-2-3-2-3-2-3	coring)
2490	2500	3-3-3-3-4-3-2-3-4-2	5-9-55 (5-ft. samples)
2500	2510	1-2-2-1-2-1-2-3-2-2	Vis. 40, wt. 9.0
2510	2520	2-1-2-1-2-2-1-1-1-2	
2520	2530	1-1-1-1-3-2-2-2-2-2	
2530	2540	2-2-1-2-2-3-3-2-2-2	
2540	2550	2-3-2-2-3-2-1-1-3-2	
2550	2560	2-4-7-1-5-5-5-4-8-7	Slope test (1%)
2560	2570	5-4-4-4-1-1-4-3-3-1	
2570	2580	1-1-1-1-1-1-1-1-1-2	
2580	2590	1-2-4-2-3-3-3-3-3-2	

TABLE 4.—*Drilling-time log of Guy. F. Atkinson Company No. 1 Beaumeister well, SE¼ SE¼ NE¼ sec. 31, T. 2 S., R. 39 W., Cheyenne County, Kansas.*

All measurements from rotary bushing, 5 feet above ground elevation of 3,262 ft.; size of hole, 7⅞ in.; drill pipe: 4½ in.

Depth From	To	Drilling time, minutes	Remarks
2590	2600	2-4-5-3-5-5-3-1-1-1	Vis. 39, wt. 9.0
2600	2610	1-1-1-½-1-1-1-1-1-1	
2610	2620	1-3-5-6-4-5-5-5-3-5	
2620	2630	4-3-3-4-5-3-5-5-4-5	
2630	2640	5-6-4-5-4-2-2-1-5-4	Vis. 38, wt. 9.1
2640	2650	4-3-1-1-3-1-2-1-2-1	
2650	2660	1-2-2-1-6-6-6-1-1-½	
2660	2670	½-½-½-½-½-1-1-3-5-2	
2670	2680	2-1-3-4-2-2-3-2-7-*	* 1 foot kelly correction
2680	2690	12-8-7-8-8-11-10-9-13-14	Vis. 36, wt. 9.3
2690	2700	12-11-11-11-11-15-24-12-25-17	Trip @ 2700 ft. (new bit)
2700	2710	2-4-5-2-3-5-6-4-5-5	
2710	2720	7-9-5-5-3-2-3-4-4-4	
2720	2730	3-3-4-5-3-4-2-3-2-3	
2730	2740	2-2-3-3-3-1-2-5-3-3	
2740	2750	3-5-4-3-2-3-2-2-2-3	
2750	2760	3-2-2-2-2-2-1-3-2-3	
2760	2770	2-2-2-2-1-2-3-2-3-2	
2770	2780	2-3-2-4-2-2-4-2-3-2	Circ. 1 hr. @ 2775 ft.
2780	2790	2-2-2-2-2-3-2-3-2-3	Circ. ½ hr. @ 2790 ft.
2790	2800	2-2-2-2-3-3-2-3-4-2	Circ. 1 hr. @ 2800 ft.
2800	2810	11-8-12-10-8-11-9-11-9-11	5-10-55 Start core 13 @ 2800 ft.
2810	2820	10-10-17-12-10-9-8-12-14-14	Vis. 38, wt. 9.2
2820	2830	15-15-12-13-13-14-12-2-2-2	End of core 13 @ 2827 ft.
2830	2840	4-4-2-3-3-3-3-2-3-3	
2840	2850	3-3-4-4-4-4-4-2-2-4	
2850	2860	4-3-5-5-4-4-2-5-6-4	
2860	2870	3-2-3-3-4-3-2-2-3-2	
2870	2880	1-2-2-2-2-3-3-2-2-7	
2880	2890	8-7-6-2-2-8-7-7-2-3	
2890	2900	2-1-2-6-7-5-9-9-8-10	
2900	2910	8-8-8-8-7-7-8-7-7-7	
2910	2920	7-6-6-4-4-4-3-3-3-3	
2920	2930	3-3-2-2-2-2-4-2-3-3	
2930	2940	2-3-2-3-3-2-3-3-4-2	
2940	2950	2-2-3-2-3-3-4-3-3-7	
2950	2960	8-7-5-4-1-1-1-1-1-1	
2960	2970	½-½-1-½-½-1-½-½-½-½	
2970	2980	½-½-1-1-½-½-½-½-1-½	
2980	2990	½-½-½-½-1-½-½-1-1-½	
2990	3000	1-1-1-1-½-½-1-1-1-1	
3000	3010	1-1-1-½-½-1-½-½-1-1	T.D. 5-10-55 11:00 p.m.

Lithology of the Cretaceous Dakota core is shown in graphic form in Figure 3. Descriptions are supplemented by binocular and petrographic spot descriptions.

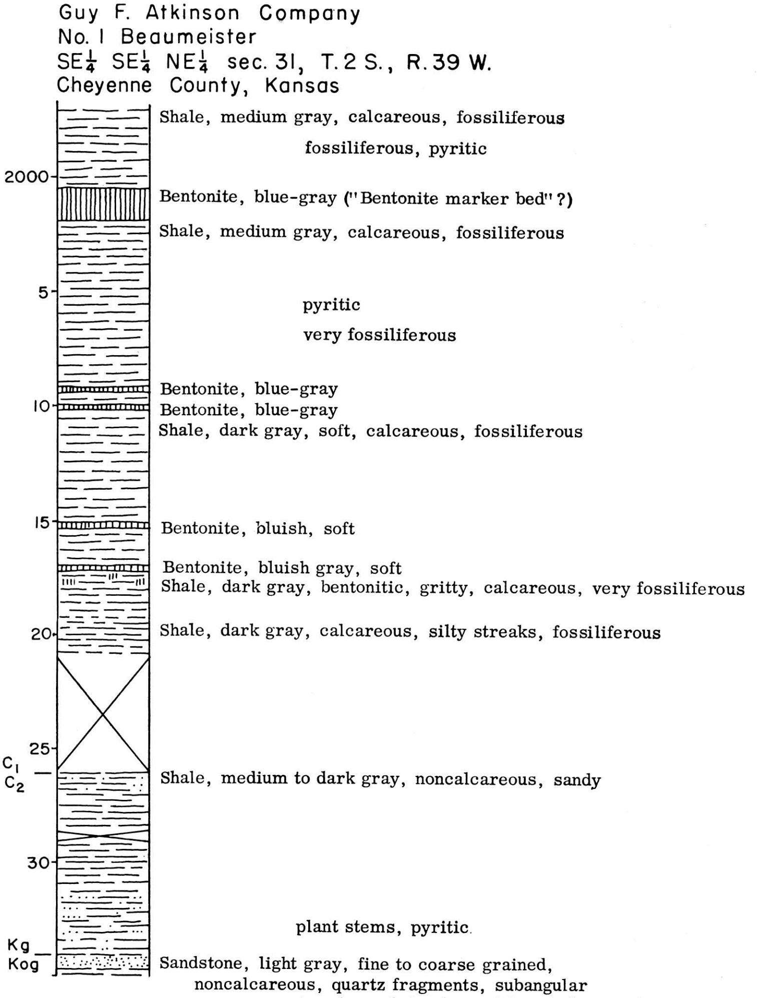


FIG. 3.—Graphic description of Dakota (Cretaceous) core from Guy F. Atkinson No. 1 Beaumeister well.

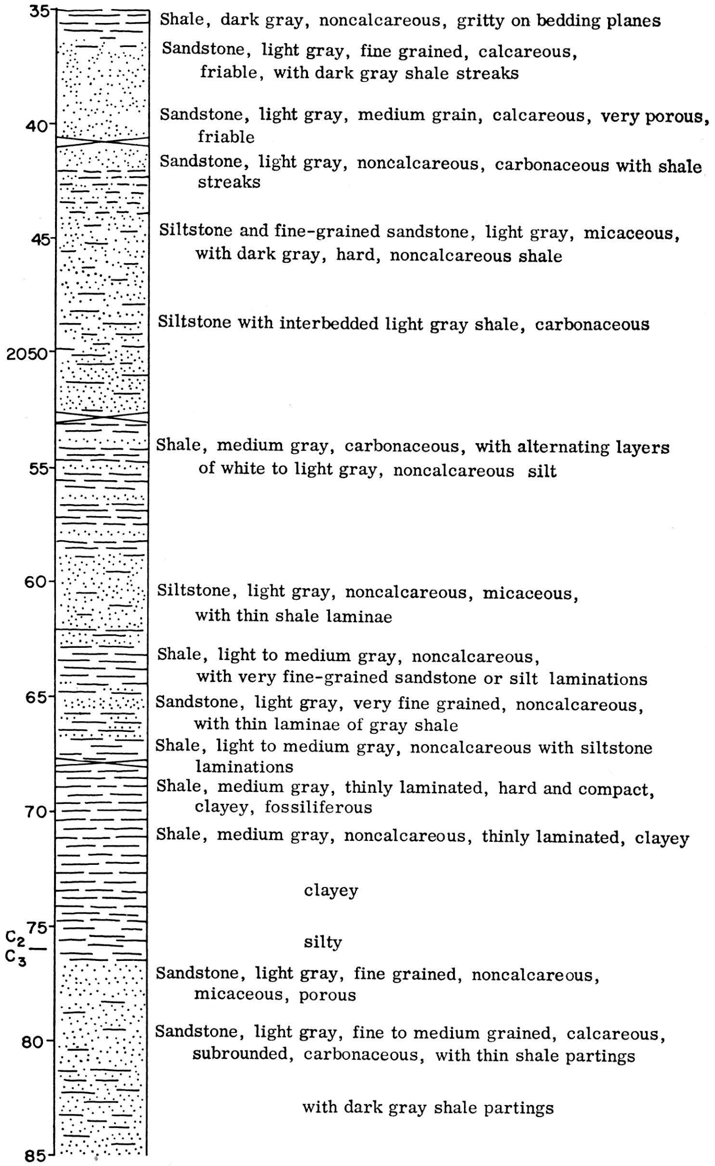


FIG. 3.—Graphic description of Dakota (Cretaceous) core from Guy F. Atkinson No. 1 Beaumeister well *(continued)*.

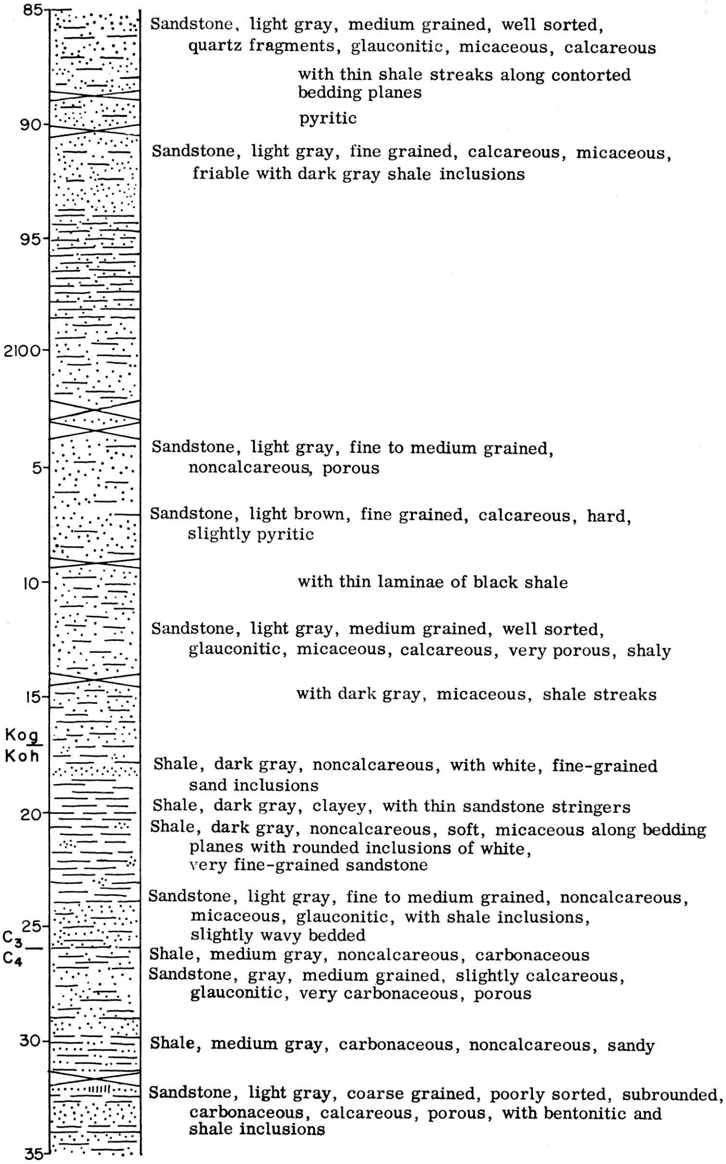


FIG. 3.—Graphic description of Dakota (Cretaceous) core from Guy F. Atkinson No. 1 Beaumeister well *(continued)*.

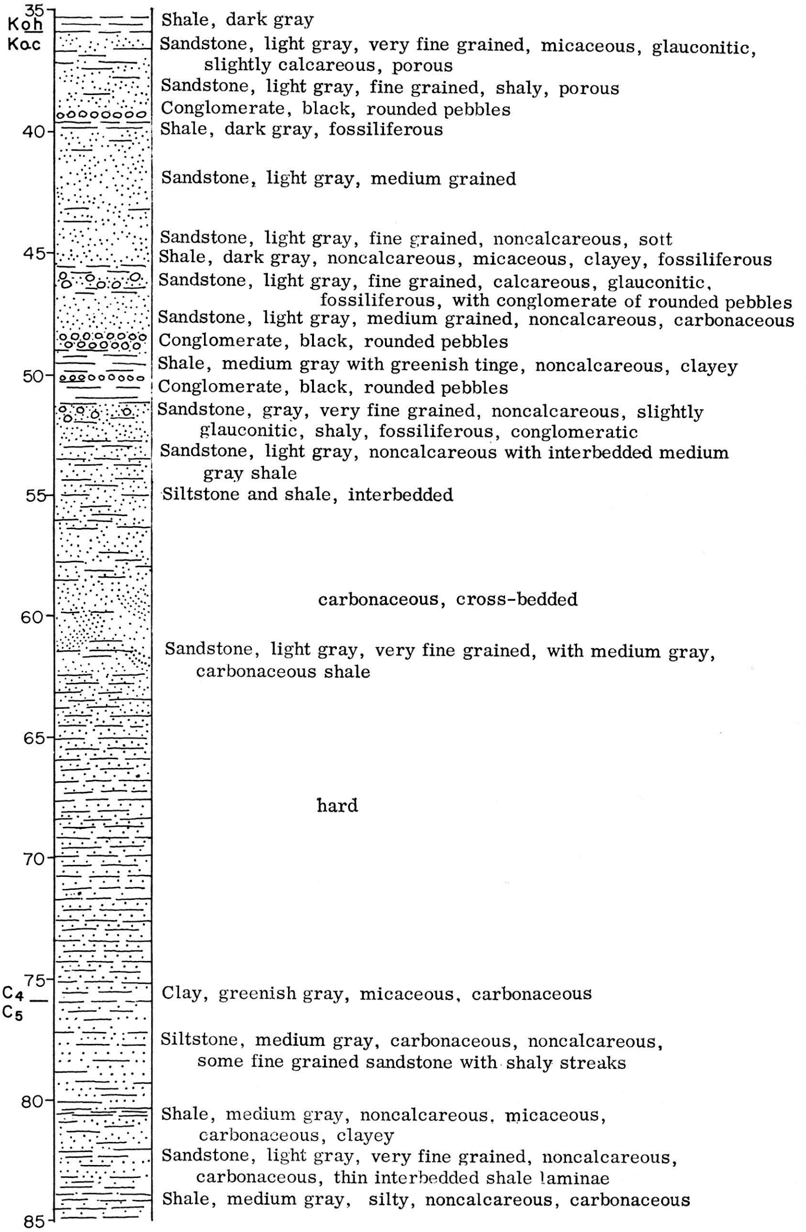


FIG. 3.—Graphic description of Dakota (Cretaceous) core from Guy F. Atkinson No. 1 Beaumeister well *(continued)*.

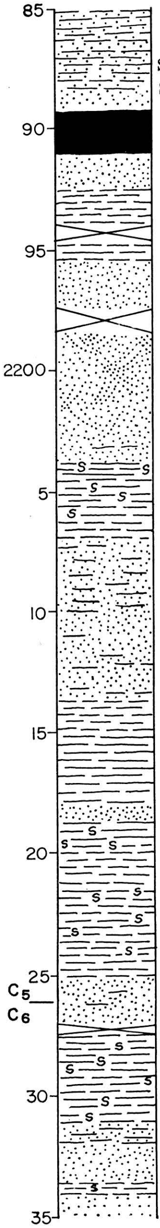


FIG. 3.—Graphic description of Dakota (Cretaceous) core from Guy F. Atkinson No. 1 Beaumeister well *(continued)*.

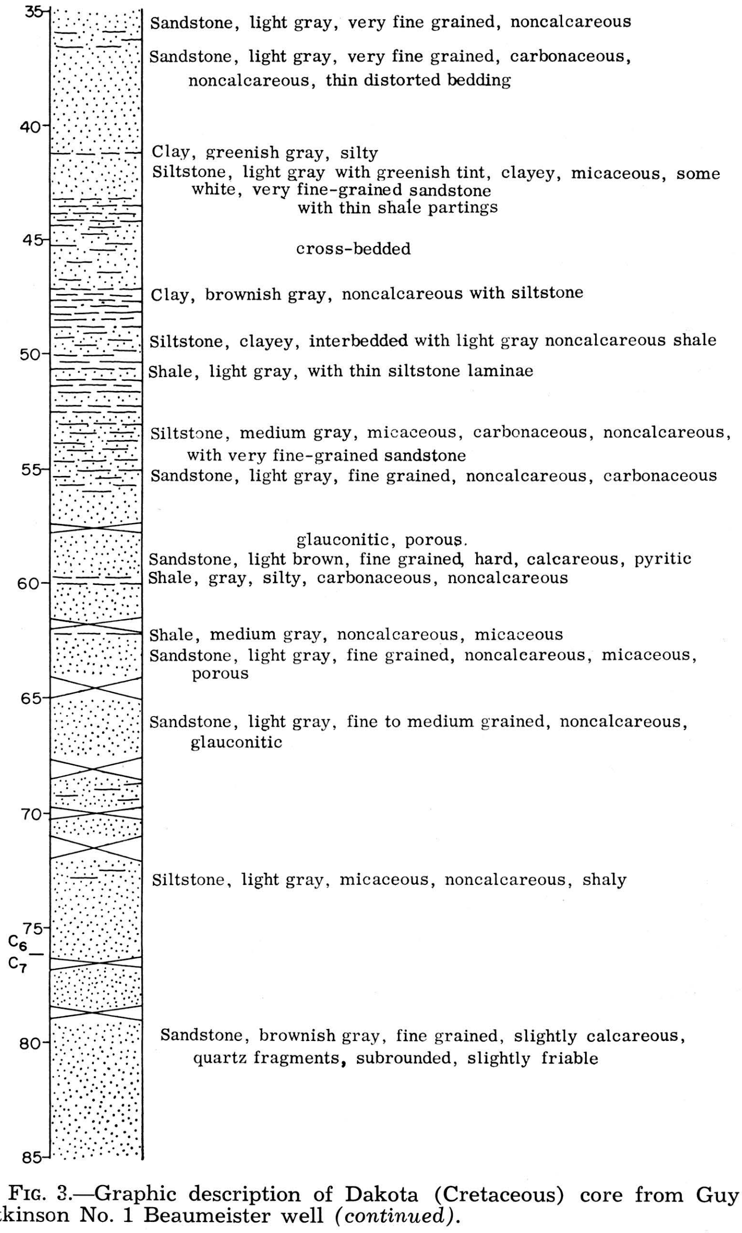


FIG. 3.—Graphic description of Dakota (Cretaceous) core from Guy F. Atkinson No. 1 Beaumeister well *(continued)*.

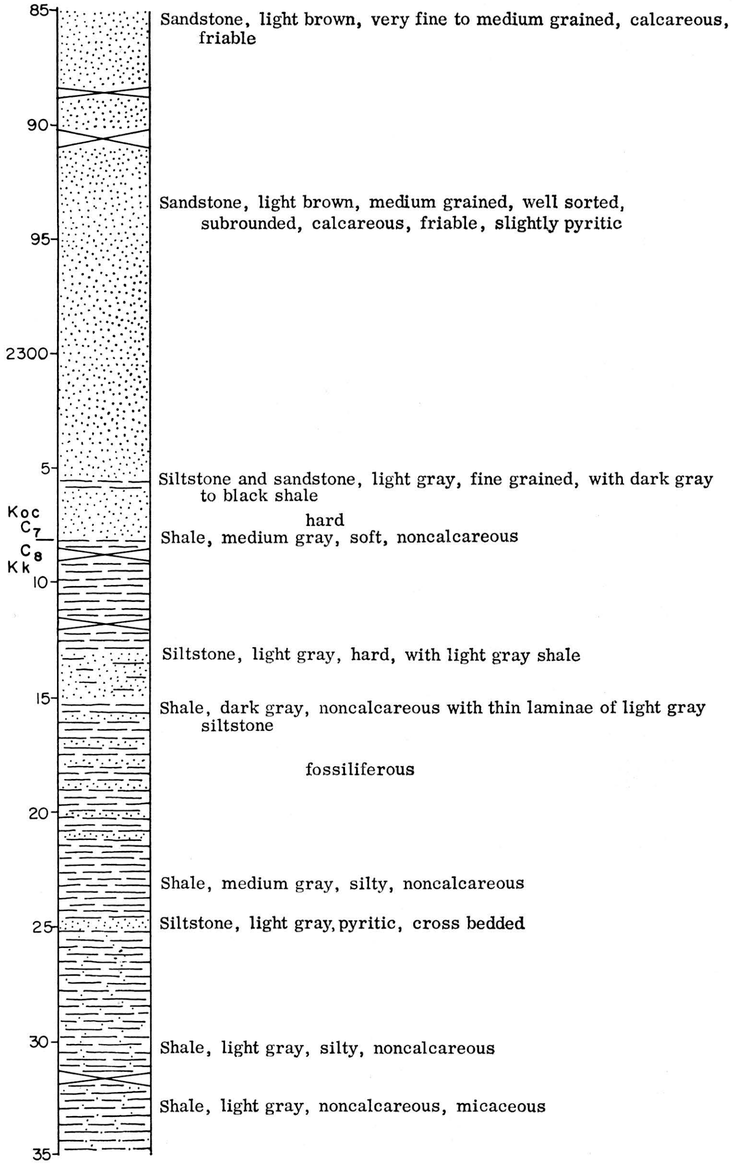


FIG. 3.—Graphic description of Dakota (Cretaceous) core from Guy F. Atkinson No. 1 Beaumeister well *(continued)*.

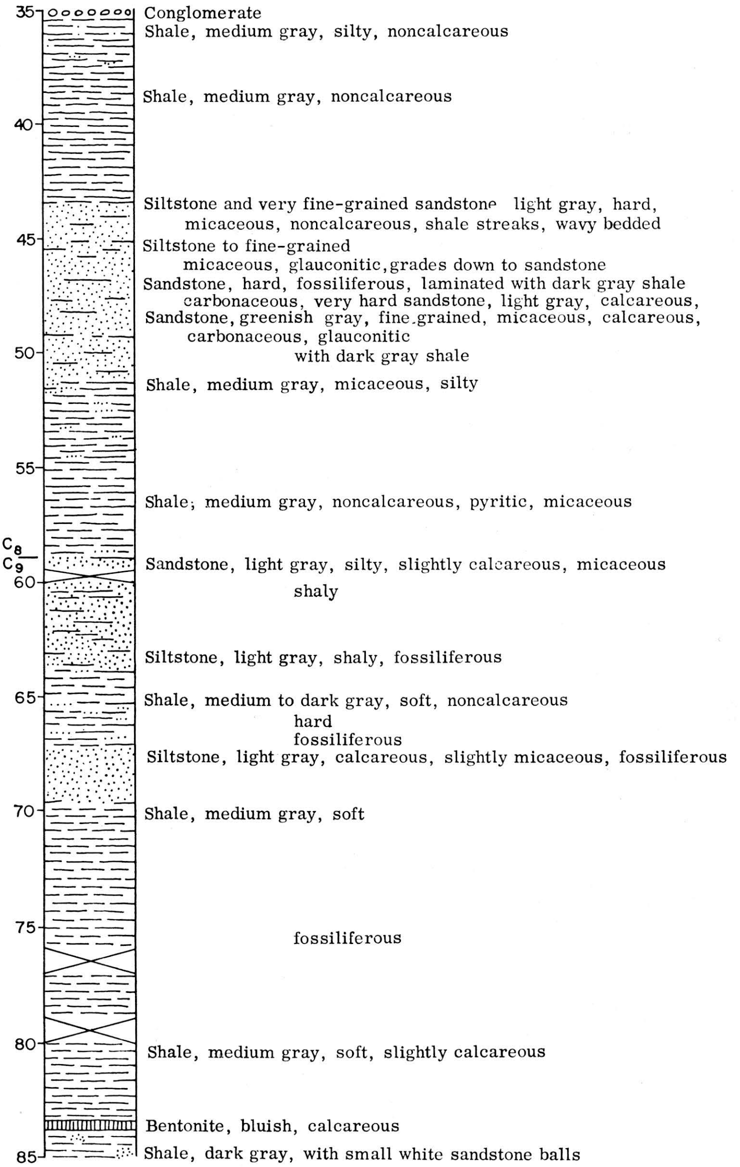


FIG. 3.—Graphic description of Dakota (Cretaceous) core from Guy F. Atkinson No. 1 Beaumeister well *(continued)*.

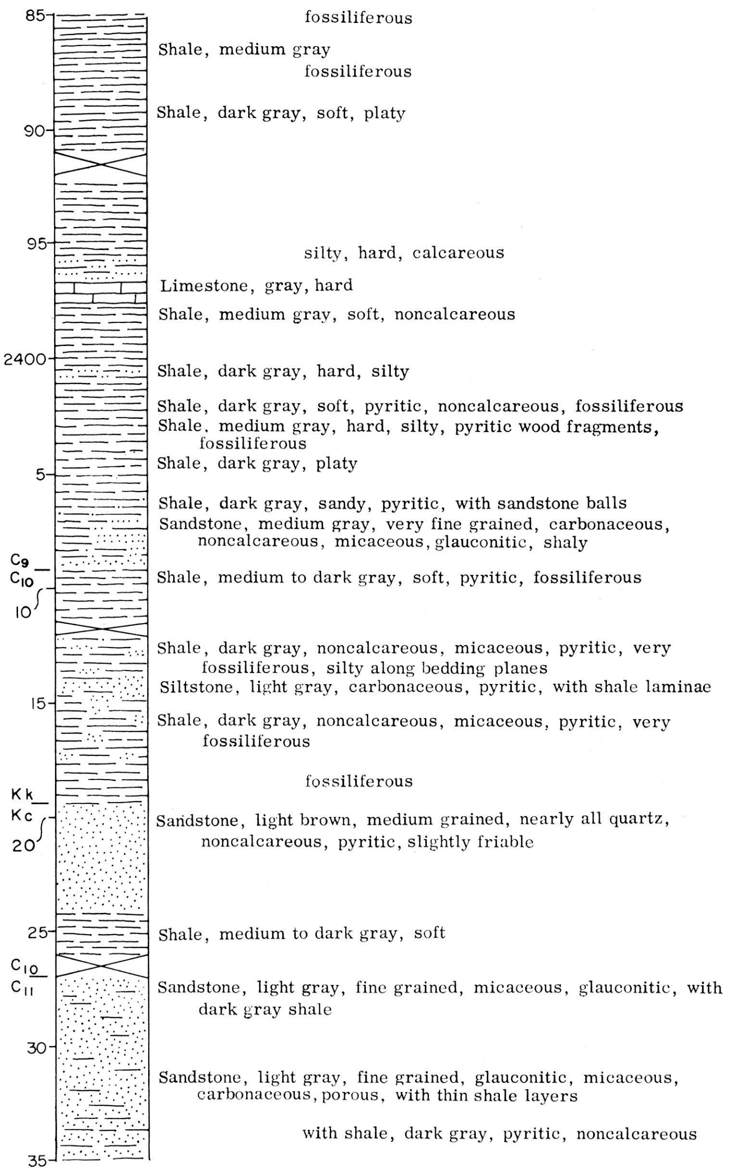


FIG. 3.—Graphic description of Dakota (Cretaceous) core from Guy F. Atkinson No. 1 Beaumeister well *(continued)*.

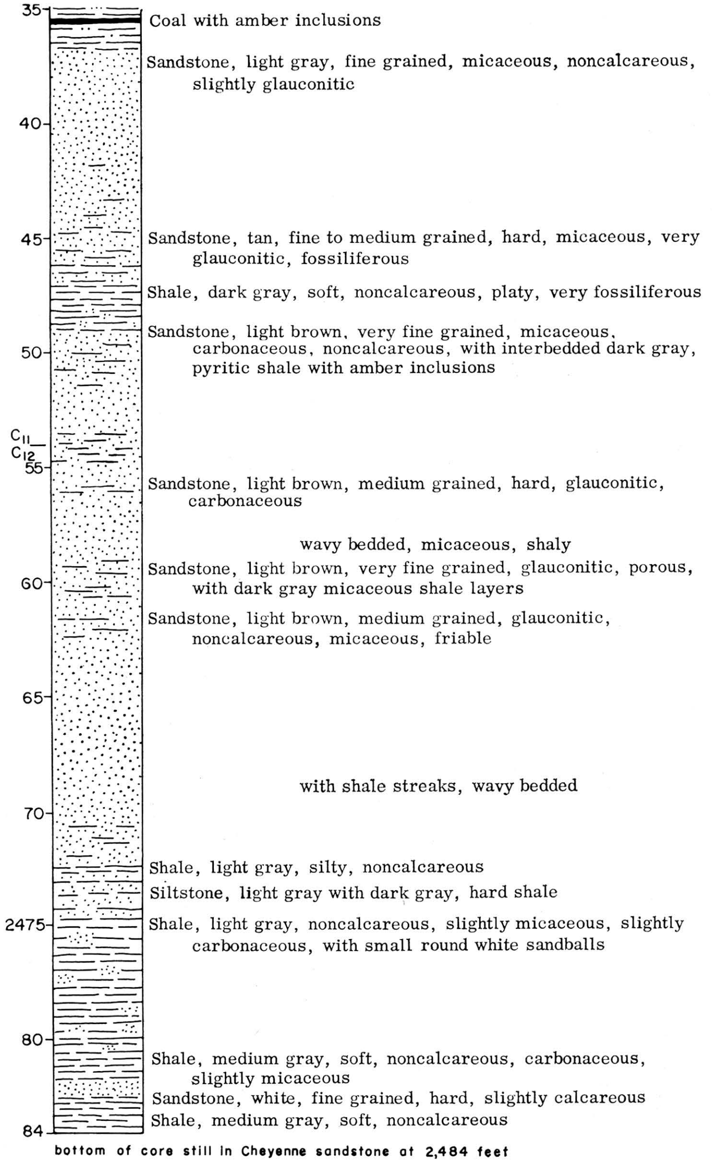


FIG. 3.—Graphic description of Dakota (Cretaceous) core from Guy F. Atkinson No. 1 Beaumeister well *(concluded)*.

Paleontology

Megafossils

The following is a summary by William A. Cobban of the megafossils he identified from the core (written communication, July 6, 1956).

"The fossils from the cores of the Guy F. Atkinson No. 1 Beaumeister well in sec. 31, T. 2 S., R. 39 W., are all marine species. The presence of *Inoceramus* and *"Corbula"* in much of the core suggests moderately shallow water. The brachiopod *Lingula* occurs in marine and brackish-water deposits, but the associated fossils in the Kiowa cores show it to be marine there. The few fossils from the Omadi Formation, although indicating a marine environment, cannot be used for correlation."

Table 5 includes identification of fossils, their depth, and remarks made by Cobban.

TABLE 5.—*Description of megafossils from the Guy F. Atkinson No. 1 Beaumeister well.*

Depth	
	Fossils from Graneros Shale
1998½	Medium-dark-gray calcareous shale. Foraminifera: Pelagic species Pelecypods: *Inoceramus prefragilis* Stephenson *Ostrea* sp. Remarks: The *Inoceramus* was described from the Woodbine Formation of Texas by Stephenson (U.S. Geol. Survey Prof. Paper 242, p. 64). I believe Stephenson's species is identical with *Inoceramus pictus* Sowerby from the Upper Cenomanian of England.
2007	Medium-dark-gray noncalcareous shale. Pelecypod: *Inoceramus arvanus* Stephenson Remarks: Another Woodbine species (U. S. Geol. Survey Prof. Paper 242, p. 65). *Inoceramus* is strictly a marine form.
2011	Medium-dark-gray calcareous shale. Pelecypod: *Inoceramus arvanus* Stephenson Cephalopod: Fragment of an ammonite, possibly *Euomphaloceras*
2011½	Medium-dark-gray slightly calcareous shale. Pelecypod: *Inoceramus arvanus* Stephenson Vertebrate: Fragment of fish jaw
	Fossils from Omadi Formation
2145½	Light-gray fine-grained argillaceous sandstone containing black-coated, brown phosphatic (?) pebbles. Brachiopod: *Lingula* n. sp. Remarks: The presence of this brachiopod suggests either a brackish-water or near-shore marine environment.
2246	Light-gray very fine grained sandstone. Pelecypod: *Laternula* n. sp. Remarks: A marine form.
2285	Medium-dark-gray noncalcareous shale. Pelecypod: *Inoceramus* sp. Remarks: A marine environment is indicated by the presence of this genus.

Fossils from Kiowa Shale

2317½	Gray siltstone with dark shale partings. Brachiopod: Discinoid species
2363	Gray siltstone and darker shale. Pelecypod: *Gryphaea?* sp.
2367	Medium-gray siltstone with darker shale streaks. Pelecypod: *Anomia* sp.
2375	Medium-dark-gray noncalcareous shale. Brachiopod: Discinoid species
2401	Medium-dark-gray noncalcareous shale. Pelecypod: *"Corbula"* sp.
2411	Medium-dark-gray shale. Pelecypod: *"Corbula"* sp.
2412	Medium-dark-gray shale. Brachiopod: *Lingula* sp.
2413	Medium-dark-gray shale. Brachiopod: *Lingula* sp. Pelecypods: *Cardium kansasense* Meek *"Corbula"* sp.
2414	Medium-gray shale. Pelecypod: *Cardium kansasense* Meek
2415	Medium-gray shale. Brachiopod: *Lingula* sp. Pelecypod: *Yoldia microdonta* Meek
2418	Medium-gray shale. Brachiopod: *Lingula* sp. Pelecypod: *Yoldia microdonta* Meek
2420	Medium-gray shale. Brachiopod: *Lingula* sp. Pelecypod: *Cardium kansasense* Meek

Fossils from Cheyenne Sandstone

2448	Medium-dark-gray shale. Pelecypods: *Cardium kansasense* Meek *Ursirivus?* sp.

Microfossils

Thirty-seven shale samples were taken from the core to be examined for microfossils (Table 6). Eighteen of the samples were barren, but most of the other samples contained either fragments of fish teeth or scales. Many of the samples contained fragments of megafossil shells that were not identifiable. Small forams (*Globigerina* and *Globigerenella*) were found in the samples of Graneros Shale, and poorly preserved ostracodes (probably *Bairdia* and *Cytherella*) in one sample in lower Kiowa Shale. Of special interest is the abundance of plant spores in several samples in the Graneros Shale and Omadi Formation.

TABLE 6.—*Microfossils from Guy F. Atkinson No. 1 Beaumeister well, Cheyenne County, Kansas.*

Depth

Graneros Shale

1998—*Globigerina, Globigerenella,* fish teeth, and shell fragments
2002—*Globigerenella* and shell fragments
2007—Fish scales, teeth fragments, shell fragments, and spores
2010—Fish scales, teeth fragments, and shell fragments
2016—Fish scales, teeth fragments, shell fragments, and spores
2020—Fish teeth
2029—Fish teeth
2033—Fish teeth

Omadi Formation

2068—nothing
2073—nothing
2119—nothing
2123 nothing
2140—Fish teeth and shell fragments
2146—Spores and a small pyritized pelecypod
2149—Fish scales
2196—nothing

Kiowa Shale

2308½—nothing
2312—nothing
2321—nothing
2324—nothing
2335—Fish scales
2337—nothing
2341—nothing
2343—Shell fragments
2351—nothing
2356—nothing
2366—Fish scales
2376—nothing
2385—nothing
2390—Shell material
2400—Shell material
2413—Shell material
2420—Poorly preserved ostracodes (*Bairdia* (?) and *Cytherella* (?)) and shell material

Cheyenne Sandstone

2471—nothing
2474—nothing
2479—nothing
2484—*Valvulineria* and small subcylindrical tubes (worm castings?)

PETROGRAPHIC, X-RAY, DIFFERENTIAL THERMAL, AND FIRING ANALYSIS OF CORE

By P. C. Franks and Norman Plummer

General

Following are descriptions of selected samples taken from the core. The samples were studied by petrographic and x-ray examination, differential thermal analysis, and firing tests to provide lithologic checks of the megascopic core logging and to provide data on clay-mineral composition of the various stratigraphic units.

Description of lamination is based on the system of McKee and Weir (1953 p. 383). Thus *laminated* refers to strata 2 millimeters to 1 centimeter thick and *thin-laminated* to strata less than 2 millimeters thick.

Petrographic Descriptions

All the following petrographic descriptions are based on thin-section studies. Measurements cited in the descriptions are, therefore, those made in the plane of the thin section. All percentage compositions cited are estimates based on visual inspection of both hand samples and thin sections. Likewise, roundness of detrital grains was estimated by use of charts published by Krumbein (1941).

In many samples it was impossible to estimate original roundness of the detrital grains because the grains had been extensively modified by overgrowths and sutures. Commonly the overgrowths are not delineated by changes in kind or amount of inclusions.

X-Ray Data

X-ray diffraction data were obtained by use of a General Electric XRD-3 proportional counter diffractometer. Patterns were run at a scanning rate of 2 degrees 2θ per minute and at 0.2 degree 2θ per minute where more detail was needed for interpretation. A 1° beam slit, 0.2° detector slit, and nickel-filtered copper radiation were used. The unit was operated at 50 kv and 15 ma.

Oriented clay particles having equivalent spherical diameters of 2 microns or less were studied. Samples were prepared by settling the clay from a water suspension onto glass slides. The slides were then air-dried and diffraction patterns were obtained. Depending on clay-mineral composition, the slides were treated with glycerol and heated to 450° and 575°C. Some samples containing 14-angstrom minerals other than montmorillonite were treated by boiling in hydrochloric acid and in ammonium chloride for determination of chlorite and vermiculite.

Estimates of the percentage of each clay mineral in the samples were made from the diffractometer patterns and are based in part on the method outlined by Murray (1954). The 001 reflection of glycerated montmorillonite was arbitrarily assigned the same reflecting power as the 001 illite reflection. The estimates are not intended to be accurate but only to serve as a means of comparison between samples (Table 7).

The term "degraded illite", as used in this report, refers to mixed-layer clay whose weak reflections between 10 and 13Å are apparent as skew shoulders on 001 illite reflections at 10Å as shown, for example, in Figure 4, sample 2034, pattern A, and in Figure 6, sample 2176, pattern A. On treatment with glycerol, it was found that the reflections between 10 and 13Å shifted to 14Å and that in many samples a weak reflection also appeared at about 28Å as shown in Figure 4, sample 2034, pattern B, and in Figure 6, sample 2176, pattern B. Some samples of air-dried degraded illite had a suggestion of a reflection between 24 and 26Å. On glyceration, the 24Å reflection shifted to 28 or 29Å as shown in Figure 6, sample 2191, patterns A and B.

Many of the clay samples studied gave weak but distinct reflections between 11 and 13Å. Some of the samples also had weak reflections at about 24Å. On treatment with glycerol, as in the case of the degraded illite, the reflections shifted to 14Å and 28 or 29Å, respectively (Fig. 4, sample 2074, patterns A and B; Fig. 8, sample 2341, patterns A and B). In accordance with work by Weaver (1956, p. 217) these reflections, as well as those from the degraded illite, are attributed to irregularly interstratified mixed-layer clay that is composed of approximately equal amounts of illite and montmorillonite.

Differential Thermal Analysis

The differential thermal analysis apparatus used to obtain the curves described in this report consists of a program controller, recorders, and preamplifiers. The unit is similar to that described by Kerr and Kulp (1948)) and was obtained from Leeds and Northrup Company. Furnace temperatures are recorded on a Micromax, and differential temperatures on a Speedomax. The furnace is a platinum-wound tube enclosed in suitable insulation. The sample holder is made of sintered alumina. Both furnace and sample holder were fabricated in the ceramic laboratory of the State Geological Survey.

A mixture of alumina and calcined kaolin was used as the inert reference, and the furnace thermocouple was placed between the sample and the inert reference. Accuracy of the furnace temperature and its correlation with the differential thermal record were checked by the alpha to beta quartz transformation at 573°C.

The samples were heated at a uniform rate of 10°C per minute, and all the curves were recorded at the same amplification. The curves shown in this report were reproduced from tracings of the originals. No corrections were made for base-line drift, nor were minor irregularities smoothed out.

Interpretation of curves produced by the differential thermal analysis of clay materials is severely limited by several factors. The fact that the various clay minerals show endothermic and exothermic reactions at approximately identical temperatures is the chief source of confusion. For example, the kaolin group, the illite group, mixed-layer clays, and some of the montmorillonoids show a major endothermic reaction producing a peak between 500° and 620°C. A further limitation to accurate interpretation of the curves is the greatly varying size of the areas enclosed by the curves produced by the various clay minerals. Rocks containing only one clay mineral, or in which one clay mineral greatly predominates, can be identified with considerable accuracy, and under some conditions fairly close estimates of quantity can be made.

Carbonaceous material, pyrite and marcasite, and calcite and dolomite add to uncertainty in interpretation of differential thermal analysis curves. All of these materials produce large peak areas when present in comparatively small amounts. Carbonaceous materials and the iron sulfide minerals give strong exothermic reactions beginning at temperatures as low as 200° and extending as high as 700°C. Carbonaceous material seriously interferes with the endothermic peaks of the clay minerals in the 500° to 620°C region, and in some samples may permit only a small endothermic swing on a larger exothermic peak. The differential thermal method also is sensitive to calcite and dolomite. Traces of calcite as small as 1 percent and of dolomite as small as 0.3 percent can be detected in the absence of conflicting peaks (Mackenzie, 1957, p. 329). The peak temperatures for calcite vary from 840° to 940°C in a diluted sample. This endothermic peak may be confused with the higher endothermic peaks for illite, montmorillonite, or even chlorite.

Firing Tests

Pieces broken from several core samples were fired slowly in an oxidizing atmosphere to about 1000°C. The fired color and the relative hardness of the samples so treated are recorded in Table 8. In a series of tests on samples of Kiowa Shale, Dakota Formation clays, and Graneros Shale it was found (Plummer and Romary, 1947) that the fired color of clay samples is a good empirical criterion for approximate determination of the clay-mineral content and of stratigraphic units.

As the result of firing a large number of clay and shale samples of known clay-mineral composition, it has been found that any clay material that fires white or buff contains a fairly high percentage of kaolinite unless the material is calcareous, or in rare samples, contains a high percentage of iron-free montmorillonite. No confusion need arise from the exceptions, however, because the presence of calcite is easily detected in the raw sample, and montmorillonite shrinks excessively on firing and becomes almost glasslike. Illite, chlorite, and most montmorillonite fire to colors ranging from salmon or light orange pink to dark brown, or brownish red, owing to the presence of iron. Of course the various iron compounds that may be present with kaolinite can produce pink or reddish colors in the fired material, but such compounds are fairly conspicuous in the raw sample, and the color produced on firing tends to be a fairly clear red or pink resulting from various dilutions of the color produced by hematite. The iron in illite, montmorillonite, and chlorite usually produces orange-pink to brown or brownish red shades.

The colors of fired samples given in Table 8 are the conventional names used by brick manufacturers. These colors were compared to the Soil Color Name Charts, a selected group of colors from the Munsell color standards. The buffs are close to the Munsell very pale brown (10 YR 8/4), although the notation ranges from 10 YR 7/4 to 8/4. The "very pale brown" is between white and light gray on the left of the names chart and yellow on the right of the names chart, and is much closer to white than the color commonly thought of as brown. The salmon used as a color name in Table 8 ranges from pink (5 YR 7/4) to reddish yellow (7.5 YR 7/6). The red of the tables ranges from light reddish brown (2.5 YR 6/4) through light red (2.5 YR 6/6) to red (2.5 YR 5/8).

Descriptions of Samples

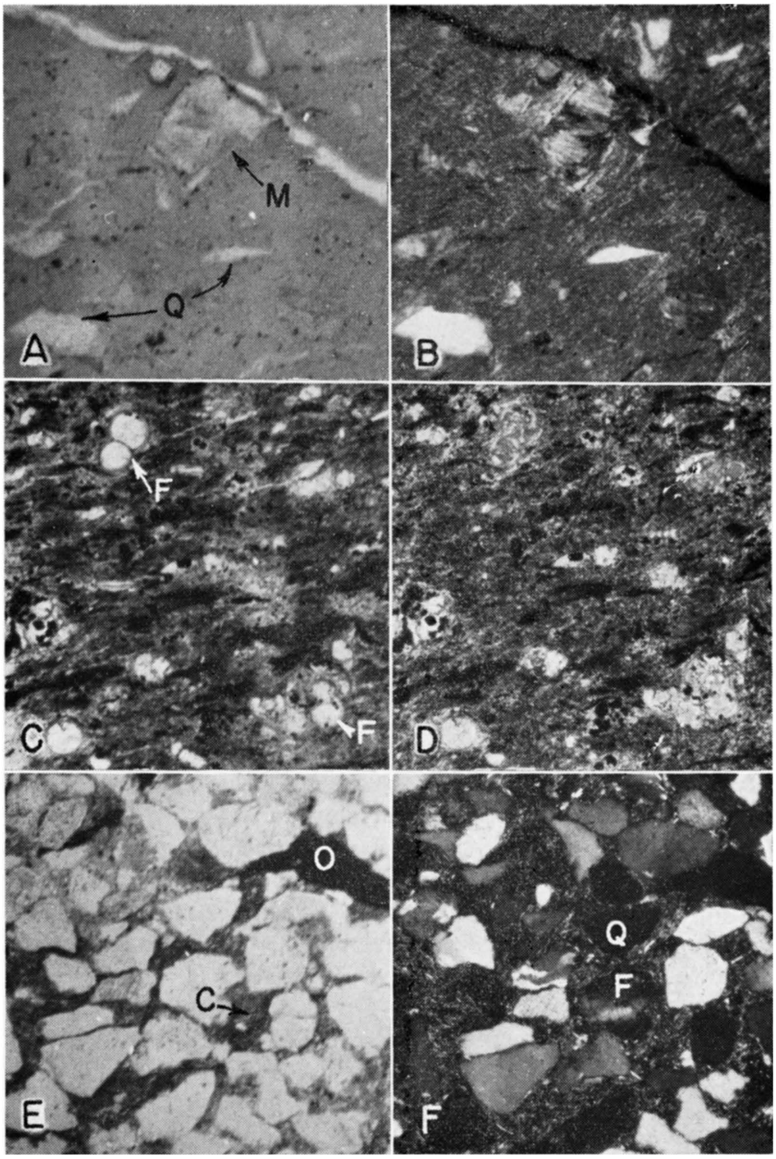
Graneros Shale

Sample from depth of 2001 feet

Megascopic description.—The rock is a very light gray claystone that has conchoidal to blocky fracture. Where the sample has been worn by coring it displays markedly parallel thin laminae. The sample swells in water and is bentonite.

Petrographic description.—In thin section (Pl. 2 A, B), it can be seen that the bentonite is composed of montmorillonite showing orientation along wavy laminae that are subparallel to bedding. Locally, the montmorillonite is segregated into coarse wormlike books that amount to about 5 percent of the rock and measure 0.1 to 0.3 millimeter in length. The rock is vertically jointed and shows distinct bedding. There is gradation in grain size and color from the centers to the margins of the joint blocks; centers of the joint blocks are in part coarser grained than the margins and are brown in transmitted light, whereas the margins are uniformly very fine grained and light brown. Some areas in the block centers are white under reflected light, whereas the rest of the rock is gray to light brown.

Plate 2.—Photomicrographs of thin sections, x 65. **A.** Sample 2001, bentonite, plane polarized light. Montmorillonite book, M, and quartz grains, Q, embedded in fine-grained montmorillonite. Black grains are pyrite. **B.** Sample 2001, bentonite, crossed nicols. Note composite structure of montmorillonite book. **C.** Sample 2017, calcareous mudstone, plane polarized light. Circular bodies, F, are fossilized foraminifera. Black specks and stringers include carbonaceous matter and pyrite. **D.** Sample 2017, cal-



careous mudstone, crossed nicols. Light-gray areas, C, are calcite. **E.** Sample 2095, sandstone, plane polarized light. Detrital grains, mostly quartz, embedded in clay matrix, C, that also contains organic matter, O. **F.** Sample 2095, sandstone, crossed nicols. Q, quartz; F, feldspar; and M, metaquartzite. Note irregular shape of most grains and sutured margins shown by some.

In addition to montmorillonite, the thin section contains about 5 percent small angular fragments of quartz and plagioclase that range in length from 0.07 to 0.18 millimeter. A small percentage of pyrite is present in the rock as irregular patches and minute blebs ranging in diameter from 0.05 to 1 millimeter. Pyrite also occurs as veinlets measuring about 0.05 millimeter in length.

X-ray data.—In the fraction finer than 2 microns, the sample is composed completely of sodium montmorillonite as shown by a 12.6Å basal spacing of the air-dried sample (Grim, 1953, p. 57). On glyceration the basal spacing expanded to 18.0Å, and collapsed to 9.8Å on heating to 450°C (Fig. 4).

Differential thermal analysis.—Differential thermal curves indicate (Fig. 5) that the only clay mineral present in the bentonite is sodium montmorillonite. The single absorbed-water peak at 145°C is exceptionally strong. The first dehydration peak at 697°C is fairly strong, and the second at 885°C is fairly weak. There is only a suggestion of an exothermic peak at 925°C. The small percentage of pyrite in the sample produced small but sharp exothermic peaks at 477° and 537°C.

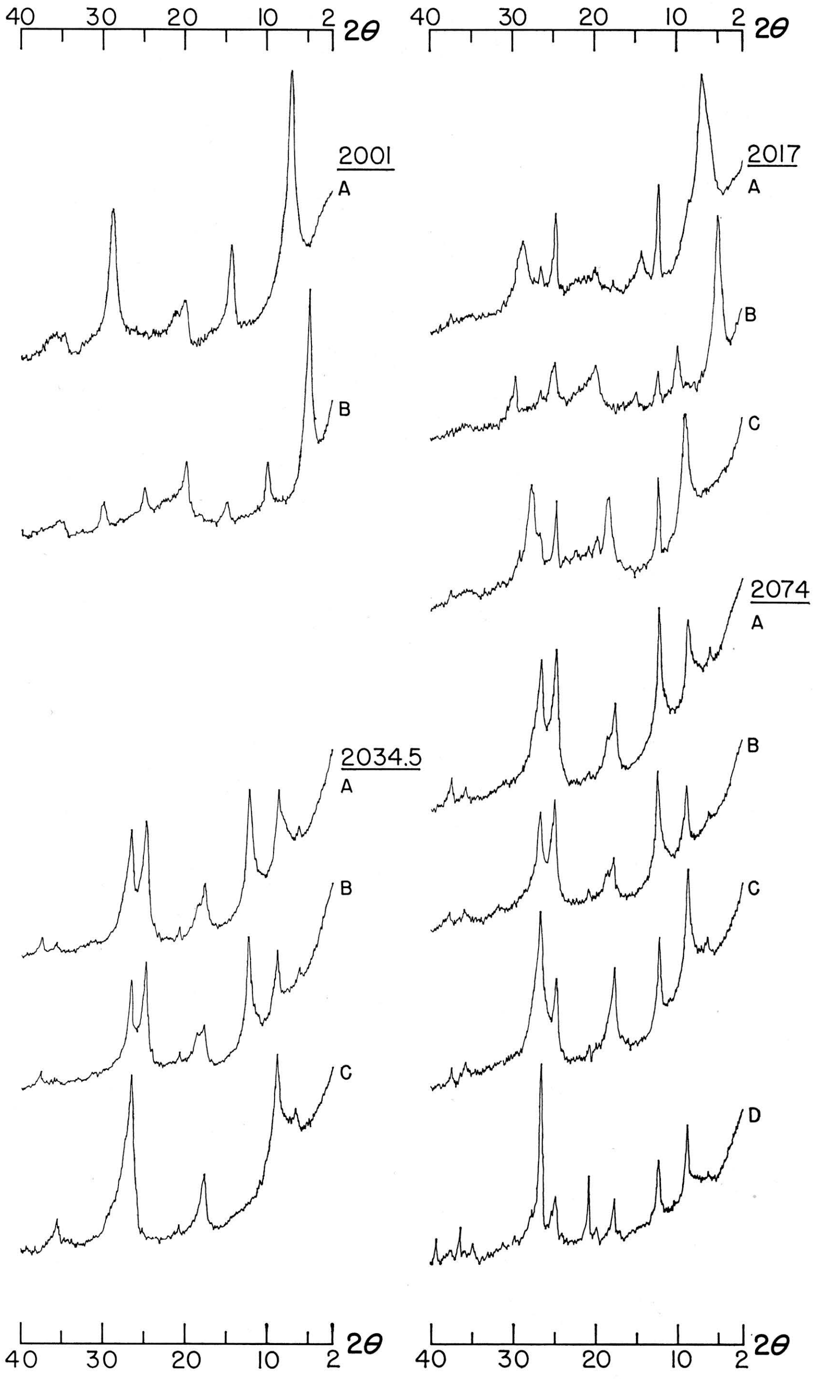
Sample from depth of 2017 feet

Megascopic description.—The rock consists of interlaminated medium-gray claystone and light-gray calcareous mudstone.

Petrographic description.—Two distinct rock types are apparent in thin section: one is claystone; the other, calcareous mudstone, is composed mainly of clay and calcite.

The claystone is composed mainly of montmorillonite and shows good preferred orientation parallel to bedding. The clay is light brown in transmitted light. Embedded in the claystone are rounded books of montmorillonite (?) that transect the lamination of the rock, but that have not disturbed the orientation of the surrounding clay flakes. The books amount to about 15 percent of the claystone and range in diameter from 0.05 to 0.3

FIG. 4.—Diffractometer patterns of fraction finer than 2 microns from selected claystone and mudstone samples. Sample 2001: sodium bentonite, Graneros Shale; A, air-dried; B, glycerated. Sample 2017: interlaminated sodium bentonite and calcareous mudstone, Graneros Shale; A, air-dried; B, glycerated; C, heated to 575°C. Sample 2034.5: mudstone, Omadi Formation (Gurley member); A, air-dried; B, glycerated; C, heated to 575°C. Sample 2074: mudstone, Omadi Formation (Gurley member); A, air-dried; B, glycerated; C, heated to 450°C; D, boiled in hydrochloric acid and air-dried.


40 30 20 10 2 2θ
2001
A
B
2034.5
A
B
C
2017
A
B
C
2074
A
B
C
D
40 30 20 10 2 2θ

millimeter. They are dominantly clear in transmitted light but are transected by pleochroic brown material (X and Y=dark brown and Z=light brown) that forms distinct bands parallel to the layering of the books.

Pyrite, which amounts to about 7 percent of the claystone, occurs as minute euhedral or subhedral grains measuring less than 0.01 millimeter in diameter and as irregular aggregates measuring as much as 0.15 millimeter in diameter. The claystone also contains trace amounts of quartz as angular fragments ranging in length from 0.05 to 0.15 millimeter.

The calcareous part of the rock consists of approximately equal amounts of clay and calcite (Pl. 2 C, D). The clay is mainly montmorillonite and has good preferred orientation parallel to bedding. Trace amounts of clay also are present as books identical to those described above.

The calcite is seen as finely divided grains ranging in diameter from 1 to 10 microns. In addition to finely divided calcite, irregular patches of optically continuous calcite that measure as much as 0.2 millimeter in length approximate 10 to 15 percent of the calcareous mudstone. Optically continuous calcite also fills numerous foraminiferal tests. The calcite filling approximates 10 or 15 percent of the calcareous mudstone.

Pyrite similar to that in the claystone amounts to about 10 percent of the calcareous mudstone. Trace amounts of quartz also are present as small, angular, sutured grains.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 70 percent montmorillonite and 15 percent each kaolinite and illite. The basal spacing of air-dried montmorillonite was 12.6Å. The montmorillonite basal spacing expanded to 18Å on treatment with glycerol and collapsed to 9.8Å on heating to 450°C (Fig. 4). It is a sodium montmorillonite (Grim, 1953, p. 57). Minor amounts of calcite also are present in the -2 micron fraction.

Differential thermal analysis.—Montmorillonite is the only clay mineral definitely indicated by the differential thermal analysis curves (Fig. 5). The single strong peak at 132°C indicates a sodium montmorillonite. The second endothermic montmorillonite peak at 675°C is fairly short and broad; its small size may be due in part to the extremely strong exothermic reaction (caused by both pyrite and organic matter), which reaches a

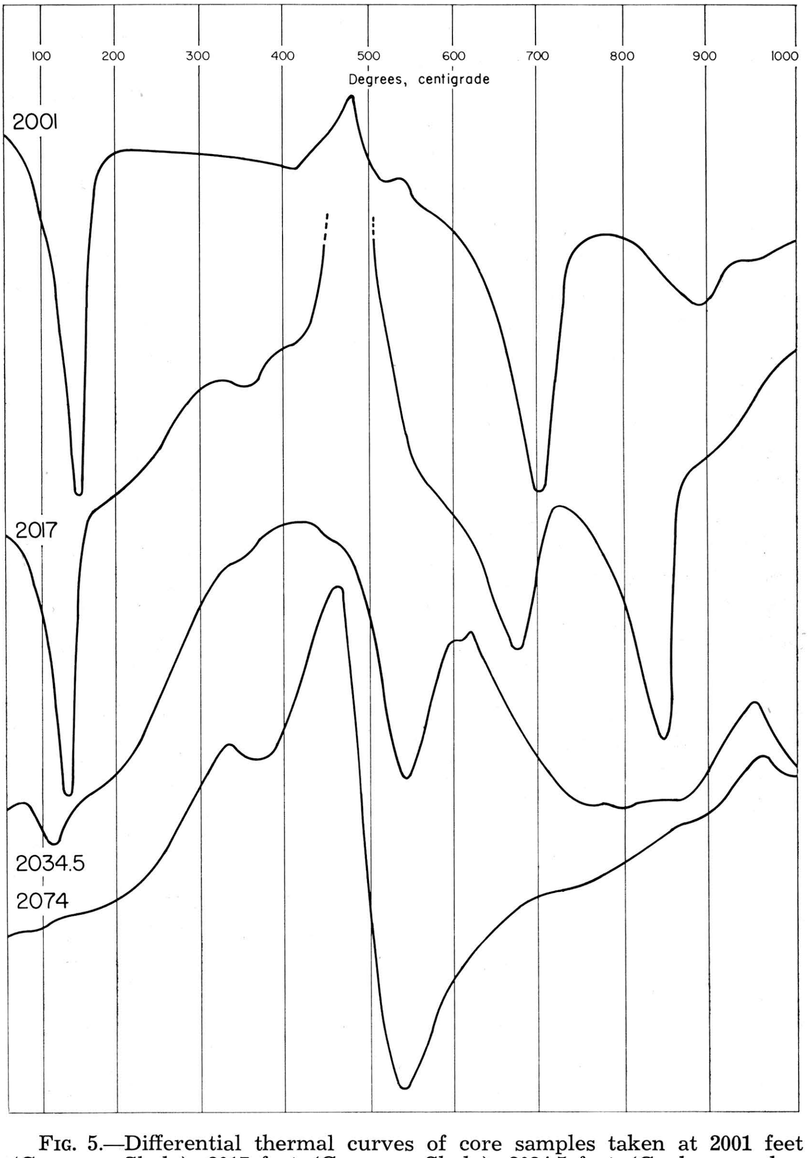


FIG. 5.—Differential thermal curves of core samples taken at 2001 feet (Graneros Shale), 2017 feet (Graneros Shale), 2034.5 feet (Gurley member of Omadi Formation), and 2074 feet (Gurley member of Omadi Formation).

peak at 475°C. Kaolinite and illite, known from x-ray to be present, would tend to broaden and lower the second endothermic peak for montmorillonite. The third endothermic montmorillonite peak at 874°C is unusually strong and doubtless was produced by both montmorillonite and calcite. The usual exothermic reaction at or above 900°C is very weak.

Omadi Formation—Gurley Member

Sample from depth of 2034.5 feet

Megascopic description.—The rock is a medium- to dark-gray thin-laminated mudstone that has slight fissility. Sparse minute mica flakes are apparent on the laminae. Pyrite is present as crystalline aggregates measuring less than 3 millimeters in diameter.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 60 percent partly degraded illite, 30 percent kaolinite, and 10 percent chlorite (Fig. 4). Minor amounts of quartz also are present in the -2 micron fraction.

Differential thermal analysis.—Pyrite and carbonaceous material dominate the differential thermal record of this sample (Fig. 5) from about 200°C to 700°C. An endothermic peak at 543°C and a very small one at 605°C are superimposed on the broad exothermic peaks produced by pyrite and carbonaceous material. The moderately sharp endothermic peak at 543°C reflects the presence of degraded illite and kaolinite. The 605°C inflection probably is caused by a variation in the intensity of the large exothermic reaction. The very small absorbed-water peak at 110°C indicates that very little montmorillonite can be present. Very small deflections to the endothermic side of the record at 750° and 790°C may be caused by the presence of chlorite. The high-temperature endothermic peak at 850°C is extremely weak, but the exothermic reaction at 950°C is fairly strong, probably owing to the presence of kaolinite.

Sample from depth of 2039 feet

Megascopic description.—The rock is a medium-gray, fine- to medium-fine-grained sandstone in which irregularly spaced mudstone films impart a wavy lamination to the rock. The sample contains trace amounts of mica as small flakes, and abundant interstitial clay. Sparse concentrations of minute grains of pyrite locally give the rock a mottled appearance.

Petrographic description.—In thin section, the rock is seen to be composed mainly of subangular to subrounded grains of quartz that are embedded in a clay matrix. The detrital grains measure 0.02 to 0.40 millimeter on their long axes; most range from 0.15 to 0.25 millimeter in length. The detrital grains show only slight tendency for orientation of their long axes parallel to bedding. Bedding is indicated in thin section by alignment of the interstitial clay and its concentration into thin layers.

Detrital quartz amounts to about 84 percent of the rock and occurs as subangular to subrounded grains that show abundant silica overgrowths as well as sutured margins. The overgrowths locally are delineated from the original detrital quartz grains by lines of inclusions. Apatite, rutile-like needles, "dust planes", and fluid bubbles are present as inclusions in the quartz. A few of the quartz grains show a mosaic pattern under crossed nicols and probably are detrital metaquartzite.

Other detrital grains include chert, feldspar, and mica. Grains of detrital chert that is both fine and coarse grained amount to about 2 percent of the rock and hold abundant small inclusions of clay. The detrital feldspar includes orthoclase, microcline, and plagioclase and amounts to about 1 percent of the rock. Muscovite is present in trace amounts as slender books measuring as much as 0.4 millimeter in length. The books have shredded ends and most are bent.

Trace amounts of tourmaline, zircon, staurolite, and phyllite fragments are present as detrital grains. The tourmaline, which is both brown and blue green and is strongly pleochroic, occurs as subangular grains. The zircon is clear and well rounded. The staurolite occurs as light-yellow-brown subrounded grains. The phyllite fragments are well rounded, measure about 0.2 millimeter in length, and are composed of various amounts of sericite and anhedral quartz.

The matrix is composed mainly of clay but locally contains minor amounts of calcite and pyrite. The clay, which fills pore spaces and occurs as thin films surrounding the detrital grains, amounts to about 7 percent of the rock. The clay is brown in transmitted light, strongly birefringent, and oriented subparallel to the bedding. Calcite is present as anhedral networks between the detrital grains and has replaced the margins of the detrital grains. It amounts to about 1 percent of the rock. Pyrite, which amounts to as much as 3 percent of the rock, has replaced both the matrix and parts of the detrital grains and occurs as minute subhedral grains and anhedral patches.

Glauconite is present in trace amounts as rounded masses measuring as much as 0.2 millimeter along their long axes. Rounded grains of leucoxene as much as 0.1 millimeter in length also are present in trace amounts.

Estimated percentage composition:

Constituent	*Percent*	*Constituent*	*Percent*
Quartz	84	Phyllite fragments	Tr
Chert	2	Clay	7
Feldspar	1	Calcite	1
Muscovite	Tr	Pyrite	3
Tourmaline	Tr	Glauconite	Tr
Zircon	Tr	Leucoxene	Tr
Staurolite	Tr		

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 45 percent partly degraded illite, 35 percent kaolinite, and 20 percent chlorite. Minor amounts of quartz, feldspar, and calcite also are present.

Sample from depth of 2074 feet

Megascopic description.—The rock is a medium-gray, slightly silty, thin-laminated mudstone showing slickensides and slight fissility.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include approximately 55 percent illite that is partly degraded, 15 percent kaolinite, 20 percent chlorite, and 5 percent each montmorillonite and mixed-layer clay (Fig. 4). The mixed-layer clay has basal reflections between 11 and 13Å and at about 25Å. On treatment with glycerol, the basal reflections shift to 14 and 29Å respectively. Also present are minor amounts of quartz.

Differential thermal analysis.—The only peak of any size produced on differential thermal analysis of this sample (Fig. 5) was a moderately broad peak at 535°C indicating mixed-layer clay or degraded illite. The endothermic peak at 890°C is very weak. The exothermic peak at 955°C is small but definite. The strong exothermic reaction between about 200° and 500°C, which produces peaks at 327° and 460°C, is caused by the presence of relatively large amounts of pyrite and organic material in the sample. The weak exothermic deflection at 745° could be attributed to chlorite, but this interpretation is not positive, inasmuch as similar peaks appear in the thermograms of samples containing no indication of chlorite on analysis by x-ray. A small quartz peak at 567°C is superimposed on the large endothermic clay peak. This alpha to beta quartz inversion temperature recorded is about 6° below the actual inversion temperature and may indicate a temporary lag at the junction of the control thermocouple.

Sample from depth of 2082 feet

Megascopic description.—The rock is a light-brownish-gray thin-bedded to thin-laminated fine-grained sandstone. Wavy films of dark-gray mudstone occupy the bedding planes. Small flakes of muscovite are disseminated through the rock and scattered on bedding surfaces.

Petrographic description.—In thin section, the rock is seen to be composed mainly of subangular to subrounded grains of quartz that are embedded in a clay matrix. The detrital grains measure 0.02 to 0.35 millimeter on their long axes; most measure 0.1 to 0.2 millimeter in length. The detrital grains show slight tendency for preferred orientation of their long axes subparallel to bedding. Bedding is indicated by local concentration of interstitial clay and carbonaceous matter into thin bands.

Detrital quartz amounts to about 83 percent of the rock and occurs as subangular and subrounded grains. The quartz grains show abundant silica overgrowths, some of which are delineated from the rest of the grain by lines of inclusions. In addition, some of the grains have sutured margins. "Dust planes", apatite, tourmaline (?), chlorite (?), and fluid bubbles are present as inclusions in the quartz grains. A few of the quartz grains show a mosaic pattern under crossed nicols and probably are detrital metaquartzite.

Other detrital grains include feldspar, chert, mica, and tourmaline. Feldspar amounts to about 3 percent of the rock and includes plagioclase, microcline, and orthoclase, and shows differing degrees of argillic alteration. About 2 percent of the rock consists of grains of detrital fine-grained chert that is clouded by small inclusions of clay or organic matter. Muscovite, which constitutes about 2 percent of the rock, is present as slender books having shredded ends. Many books are bent and measure as much as 0.7 millimeter in length. Much of the muscovite is concentrated in layers that contain abundant interstitial clay. Trace amounts of detrital tourmaline also are present. The tourmaline grains are subrounded, pleochroic, and clear or brownish green.

Phyllite fragments approximate 2 percent of the rock. They are composed of mica, chlorite, and anhedral quartz, and measure as much as 0.2 millimeter in length.

The matrix is composed mainly of clay but locally includes minor amounts of chert, calcite, and pyrite. The clay, which constitutes about 5 percent of the rock, occurs as thin films separating the detrital grains. It is brownish green in transmitted light and its birefringence is typical of intermixed illite and kaolinite. Locally, small books of kaolinite are present in pore spaces. Secondary chert, which amounts to about 1 percent of the rock, occupies pore space and is clouded by small particles of clay or organic matter. Calcite is present in trace amounts as optically continuous patches that replace both detrital grains and matrix. Pyrite, also present in trace amounts, replaces both detrital grains and matrix and encrusts particles of carbonaceous matter.

Carbonaceous matter is present as elongate irregular particles that are interstitial to the detrital grains and also are incorporated in the layers containing abundant clay. Individual particles are partly pyritized and measure as much as 0.7 millimeter in length. Carbonaceous matter amounts to less than 1 percent of the rock.

Trace amounts of glauconite are present as rounded masses that are interstitial to the detrital grains and measure as much as 0.25 millimeter along their long axes.

Estimated percentage composition:

Constituent	*Percent*	*Constituent*	*Percent*
Quartz	83	Clay	5
Chert	2	Secondary chert	1
Feldspar	3	Calcite	Tr
Muscovite	2	Pyrite	Tr
Tourmaline	Tr	Carbonaceous matter	<1
Phyllite fragments	2	Glauconite	Tr

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 40 percent kaolinite, 40 percent partly degraded illite, 10 percent chlorite, and 10 percent montmorillonite. Also present are traces of quartz, feldspar, and calcite.

Sample from depth of 2095 feet

Megascopic description.—The rock is a light-gray fine-grained sandstone that has abundant irregularly spaced, contorted medium- to dark-gray thin mudstone laminae. Sparse flakes of mica are apparent in the hand sample.

Petrographic description.—In thin section (Pl. 2 E, F), the rock is seen to be composed mainly of fine-grained detrital quartz and about 15 percent interstitial clay as matrix. The detrital grains range in length from 0.02 to 0.3 millimeter; most are 0.1 to 0.2 millimeter along their long axes. The detrital grains are subrounded to subangular. The clay matrix is brown in transmitted light and may contain organic matter.

Quartz amounts to about 72 percent of the rock. Most of the quartz is detrital, but trace amounts occur as overgrowths on detrital grains and as irregular patches in the matrix. Overgrowths on quartz grains generally are limited to areas of least abundant interstitial clay. Locally some quartz grains have sutured borders and are partly replaced by calcite. Most of the quartz shows uniform extinction, but some grains have a mosaic pattern under crossed nicols and probably are detrital metaquartzite. Inclusions in the detrital quartz include rutile-like needles, small subhedral crystals of apatite, sphene (?), zircon, "dust planes", and spherical fluid inclusions.

Detrital feldspar amounts to about 5 percent of the rock and includes plagioclase, microcline, and orthoclase. The feldspar grains are subrounded to subangular and show differing degrees of argillic alteration. Chert, in subrounded to subangular grains, constitutes about 3 percent of the rock.

Rounded phyllite fragments, present in traces, are composed of well-oriented sericite flakes and various amounts of anhedral quartz, and measure as much as 0.2 millimeter in length.

Interstitial to the detrital grains is an argillic matrix that amounts to about 15 percent of the rock. The matrix is brown in transmitted light and is irregularly distributed through the rock as contorted stringers and blebs. It is composed mainly of illite that is oriented subparallel to the laminae of the rock. Included in the matrix are trace amounts of calcite and quartz that form irregular patches. Irregularly distributed through the matrix are trace amounts of chlorite (?) and about 1 percent well-crystallized illite that is segregated as clear books and patches. Subhedral books of muscovite, which amount to about 1 percent of the rocks, also are present in the matrix. The books range in length from 0.05 to 0.3 millimeter and locally are bent around quartz grains.

Magnetite or ilmenite (?), or both, as irregular patches and blebs, appear as replacements of the detrital grains and the matrix. They amount to about 2 percent of the rock. Limonite or hematite, or both, in similar patches amount to about 1 percent of the rock. Leucoxene is present in traces as small blebs scattered through the rock.

Estimated percentage composition:

Constituent	*Percent*	*Constituent*	*Percent*
Quartz	72	Chlorite (?)	Tr
Feldspar	5	Illite books and patches	1
Chert	3	Muscovite	1
Phyllite fragments	Tr	Magnetite or ilmenite (?), or both	2
Clay	15	Limonite or hematite, or both	1
Calcite	Tr	Leucoxene	Tr

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 50 percent illite that is partly degraded, 30 percent kaolinite, and 20 percent chlorite (Fig. 10). Also present are minor amounts of quartz and feldspar.

Differential thermal analysis.—The differential thermal curve (Fig. 11) for the fraction finer than 2 microns from this sandstone sample shows a fairly strong endothermic peak at 555°C and a definite exothermic peak at 957°C, both of which are characteristic of kaolinite. A fairly large percentage of degraded illite in the sample is definitely indicated by the double absorbed-water peak at 95° and 105°C, and by a slight broadening at the 555°C peak. The small 740°C endothermic swing could be ascribed to chlorite if similar peaks were not present on the curves for samples not containing chlorite. The large exothermic swing producing peaks at 325° and 415°C was produced by carbonaceous matter and perhaps pyrite as well.

Omadi Formation—Huntsman Member

Sample from depth of 2118 feet

Megascopic description.—The core sample is dark-gray to very dark gray thin-laminated mudstone that has good fissility parallel to the laminae. Stringers and blebs of very light gray micaceous siltstone parallel the lamination. Sparse specks of carbonaceous matter are apparent in the sample.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include approximately 60 percent illite that is partly degraded, 25 percent kaolinite, and 15 percent chlorite. The degraded illite has a superlattice reflection at about 27Å in the air-dried samples. On glyceration, the reflection shifted to about 30Å. Also present are minor amounts of quartz.

Omadi Formation—Cruise Member

Sample from depth of 2146 feet

Megascopic description.—The rock is light- to medium-gray conglomeratic sandstone that grades downward to conglomerate. The conglomeratic sandstone is mainly fine grained but contains smooth well-rounded pebbles that measure as much as 2.5 centimeters in length. The conglomerate is composed of pebbles that are well rounded, measure as much as 3 centimeters in length, and are embedded in a matrix of very fine grained to coarse-grained sandstone. The pebbles in both the conglomerate and the conglomeratic sandstone have black exterior shells and dark-gray to light-brown interiors. The conglomeratic sandstone has irregularly spaced wavy laminae. Bedding in the conglomerate is indistinct. Both rock types contain abundant interstitial clay, sparse muscovite flakes, and angular black fragments. The black fragments, which are thin, somewhat curved, and marked with slender arcuate striae, range in length from about 1 to 10 millimeters and are less than ½ millimeter thick. They may be shell fragments from phosphatic bivalved organisms. Sparse fragments of light- to dark-gray fossilized bone(?) also are apparent in the core sample.

Petrographic description.—The sandstone and conglomerate are composed mainly of detrital quartz grains embedded in a brown clay matrix. The detrital grains range in long diameter from 0.02 to 0.56 millimeter and are poorly sorted. Incorporated in the rock are large rounded masses of collophane, the thin

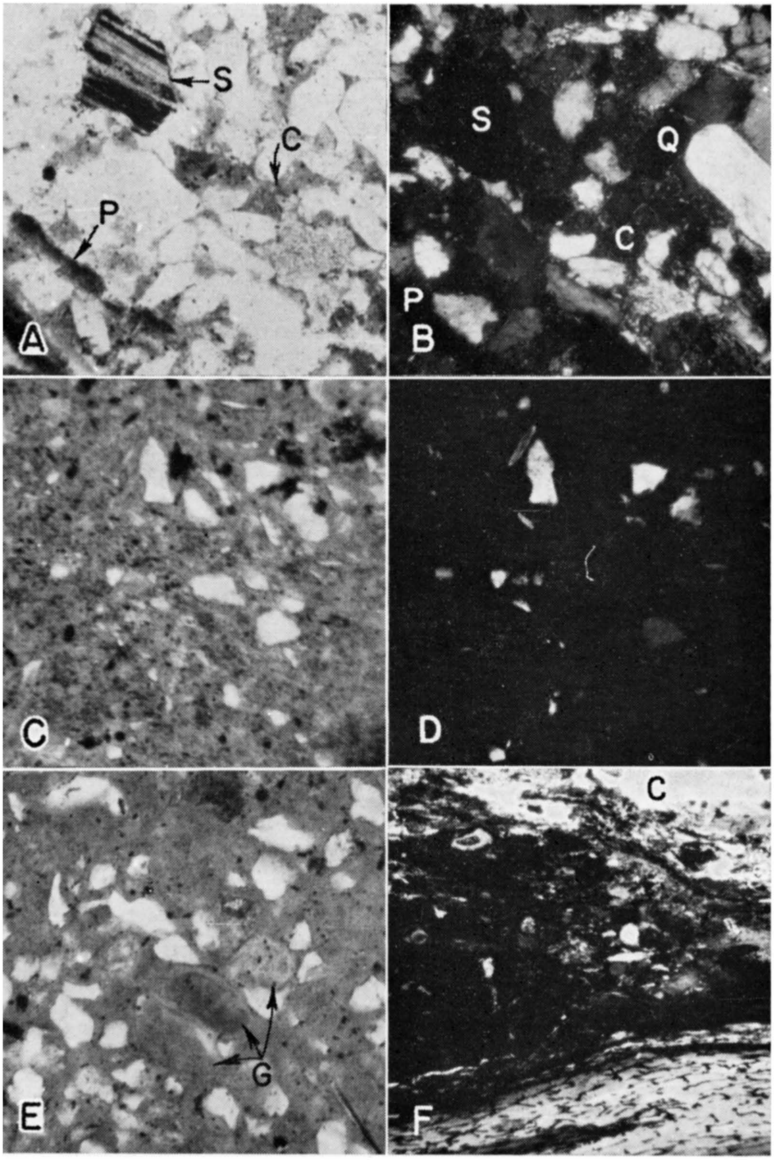


PLATE 3.—Photomicrographs of thin sections, x 65. **A.** Sample 2146, conglomeratic sandstone, plane polarized light. Quartz grains embedded in matrix of clay, C, and collophane, P. Large striped grain, S, composed of collophane and apatite may be shell fragment. **B.** Sample 2146, conglomeratic sandstone, crossed nicols. C, clay, P, collophane, S, shell(?) fragment, and Q, quartz. **C.** Sample 2146, collophane pebble, plane polarized light. Clear grains are quartz; black specks include hematite and pyrite. **D.** Sample 2146,

borders of which are black and dark brown in transmitted light. Also present are rectangular and gently curved fragments of interlayered collophane and birefringent apatite. Other fragments, which may be fossilized bone, are composed mainly of collophane and birefringent apatite (Pl. 3 A, B).

The detrital quartz grains are subangular to subrounded and have sutured margins and silica overgrowths. The overgrowths are not delineated from the original detrital grains by lines of inclusions. Some of the quartz grains show mosaic patterns under crossed nicols and probably are detrital metaquartzite. Present as inclusions in the quartz grains are fluid bubbles, "dust planes", and sparse rutile-like needles.

Sparse chert and even lesser amounts of feldspar are present as detrital grains in the rock. The chert is both fine and coarse grained. Margins of the grains commonly are uneven and indistinct; they seem to have been modified by secondary solution or by deposition of silica, or by both. The feldspar includes microcline, plagioclase, and orthoclase, whose grains show differing degrees of argillic alteration.

Other detrital minerals include trace amounts of tourmaline and muscovite. The muscovite is present as slender shredded books that are bent about other detrital grains and that measure as much as 0.2 millimeter in length. The tourmaline is subangular and strongly pleochroic. Some grains are blue, some brown, and some are both blue and brown.

Small rounded fragments of quartz-sericite phyllite also are present in trace amounts. The fragments are as much as 0.15 millimeter long.

The pebbles are translucent and light brown in transmitted light. X-ray and optical data show that the light-brown material is collophane. The borders of the pebbles are partly opaque owing to pyrolusite (?) and have a submetallic steel-gray color under reflected light. Included in the pebbles are abundant angular grains of quartz, chert, and feldspar, and rounded masses of glauconite (Pl. 3 C, D, E). The included detrital grains range in length from 0.05 to 0.1 millimeter, and the rounded masses of

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collophane pebble, crossed nicols. **E.** Sample 2146, collophane pebble, plane polarized light. Round patches, G, glauconite; light-gray grains quartz; black specks, hematite and pyrite. **F.** Sample 2189, coal, plane polarized light. Rock composed of clay, C, and translucent and opaque attritus. Note black spicules in translucent attritus at bottom of photograph. Bright round spots and round spots showing light margins and dark centers are resin globules.

glauconite are as much as 0.2 millimeter long. Also included in the pebbles are irregular blebs of pyrolusite (?).

Numerous shell(?) fragments are irregularly distributed; most are subrectangular and curved. They range in thickness from 0.05 to 0.2 millimeter and are composed of alternate layers of apatite and collophane. Some of the collophane is opaque and seems to contain pyrolusite(?). Fragments of bone(?) are sparse. They too are composed mainly of collophane but also contain minor amounts of anisotropic apatite. The haversian canals (?) are partly filled with pyrolusite (?) and pyrite.

The matrix is composed mainly of strongly birefringent brown clay (illite) that seems to be poorly oriented. Also present in the matrix is abundant glauconite, as irregular blebs that grade imperceptibly into the rest of the matrix and as discrete round masses as much as 0.25 millimeter in length. Pyrite and limonite are present in traces as anhedral blebs in the matrix. Locally, adjacent to the phosphate pebbles, the matrix is composed of collophane and pyrolusite(?). The distribution and interstitial occurrence of collophane in the matrix indicate that there may have been secondary deposition of collophane.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 40 percent illite that is partly degraded, 30 percent kaolinite, 20 percent chlorite, and 10 percent mixed-layer clay. The mixed-layer clay has reflections between 11 and 13Å and at 26Å. On treatment with glycerol, the reflections shifted to 14 and 31Å respectively. Trace amounts of quartz also are apparent.

The black pebbles were studied by x-ray diffraction. They were ground to pass a 74-micron sieve, and diffractograms were made. The diffractograms show reflections for apatite, lesser amounts of quartz, and minor amounts of feldspar. The apatite has reflections at 1.723 and 1.783Å that indicate that it is carbonate-fluorapatite (Silverman, Fuyat, and Weiser, 1951, p. 6). Optical data indicate that the mineral is collophane, an isotropic form of apatite.

Sample from depth of 2166 feet

Megascopic description.—The rock consists of alternating thin laminae of medium-gray mudstone and light-gray siltstone; abundant minute mica flakes and sparse carbonaceous specks are disseminated on the laminae. Locally the siltstone laminae have been deformed into wavy layers and small elongate pods that transect bedding at angles as great as 40°.

Petrographic description.—In thin section, the rock is seen to be composed mainly of silt and clay particles that are segregated into distinct laminae. The siltstone laminae locally contain as much as 30 percent interstitial organic matter and clay, whereas the mudstone laminae locally contain as much as 30 percent quartz and are brownish green in transmitted light. The laminae range in thickness from 0.02 to 3 millimeters and locally are deformed so that scroll-like projections of silt penetrate the mudstone. Clay flakes in the mudstone are aligned subparallel to the siltstone laminae.

Quartz constitutes about 57 percent of the rock. It occurs as subangular silt-sized detrital grains in the siltstone laminae and in lesser amount in the mudstone laminae. Long axes of the quartz grains measure 0.15 to 1.5 millimeters, but most grains are 0.15 to 0.55 millimeter long. The quartz grains contain inclusions of apatite (?), zircon, "dust planes", and fluid bubbles. The matrix of the siltstone laminae is composed mainly of small flakes of illite as much as 0.1 millimeter long.

The mudstone laminae are composed mostly of strongly birefringent flakes of clay (illite?). The flakes are about 0.03 millimeter in length and are aligned subparallel to the laminae. Total clay content of the rock is estimated to be 27 percent.

Disseminated flakes of muscovite, ranging in length from 0.05 to 0.5 millimeter, amount to about 4 percent of the rock. Trace amounts of green biotite or chlorite, or both, are present mainly in mudstone laminae. Traces of leucoxene occur in the siltstone laminae.

Organic matter, probably macerated coal, although scattered through the thin section, is concentrated mainly in the mudstone laminae. It appears as small irregular particles and as flakes or films as much as 2 millimeters long. Most of the organic matter

Estimated percentage composition:

Constituent	*Percent*	*Constituent*	*Percent*
Quartz	57	Biotite, chlorite, or both	Tr
Clay	27	Leucoxene	Tr
Muscovite	4	Organic matter	11

is opaque, but some appears translucent red brown. Organic matter amounts to about 11 percent of the thin section.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include 60 percent illite that is partly degraded, 25 percent kaolinite, and 15 percent chlorite. Also present are minor amounts of quartz.

Sample from depth of 2176 feet

Megascopic description.—The rock is a medium-gray, somewhat silty, thin-laminated mudstone having very little fissility. Diffuse limonitic stains parallel the laminae. Sparse minute mica flakes and specks of carbonaceous matter are apparent on bedding planes.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 60 percent partly degraded illite and 20 percent each of kaolinite and chlorite (Fig. 6). The rock also contains minor amounts of quartz in the fraction finer than 2 microns.

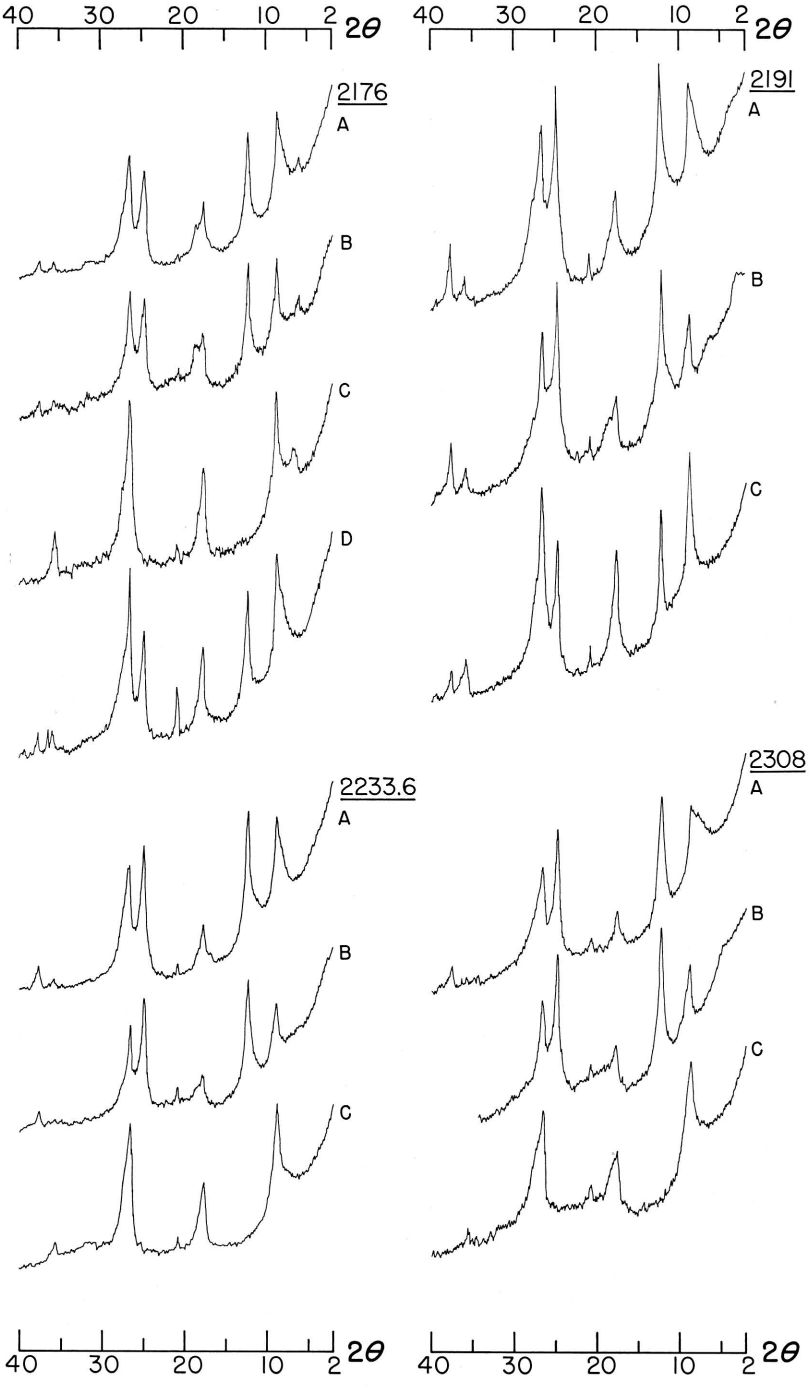
Differential thermal analysis.—A small endothermic peak below 100°C, a fairly large, broad endothermic peak at 540°C, and a small endothermic peak at 967°C indicate that the dominant clay mineral in this sample is mixed-layer clay or degraded illite (Fig. 7). In addition, organic material produced a broad exothermic curve from 200° to about 500°C showing peaks at 332° and 465°C. A very small quartz peak at 573°C is superimposed on the large 540°C endothermic peak.

Sample from depth of 2189 feet

Megascopic description.—The rock is a dark-gray to black subbituminous coal showing dull luster and thin wavy laminae. Small lenses and wisps of light- to medium-gray clay parallel the bedding. Scattered areas having woody texture show on bedding planes. The coal has conchoidal fracture and abundant randomly oriented slickensides as well as incipient cubical fractures.

Petrographic description.—In thin section (Pl. 3 F) the coal

FIG. 6.—Diffractometer patterns of fraction finer than 2 microns from selected mudstone samples. Sample 2176: mudstone; A, air-dried; B, glycerated; C, heated to 575°C; D, boiled in hydrochloric acid and air-dried. Sample 2191: argillaceous siltstone; A, air-dried; B, glycerated; C, heated to 450°C. Sample 2233.5: mudstone; A, air-dried; B, glycerated; C, heated to 575°C. Sample 2308: mudstone; A, air-dried; B, glycerated; C, heated to 575°C. All samples from Cruise member, Omadi Formation.



40 30 20 10 2 2θ
2176
A
B
C
D
2191
A
B
C
2233.6
A
B
C
2308
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is seen to be composed mainly of macerated carbonaceous matter and clay. The clay has faint birefringence and forms discrete blebs, lenses, and layers that are almost free of carbonaceous

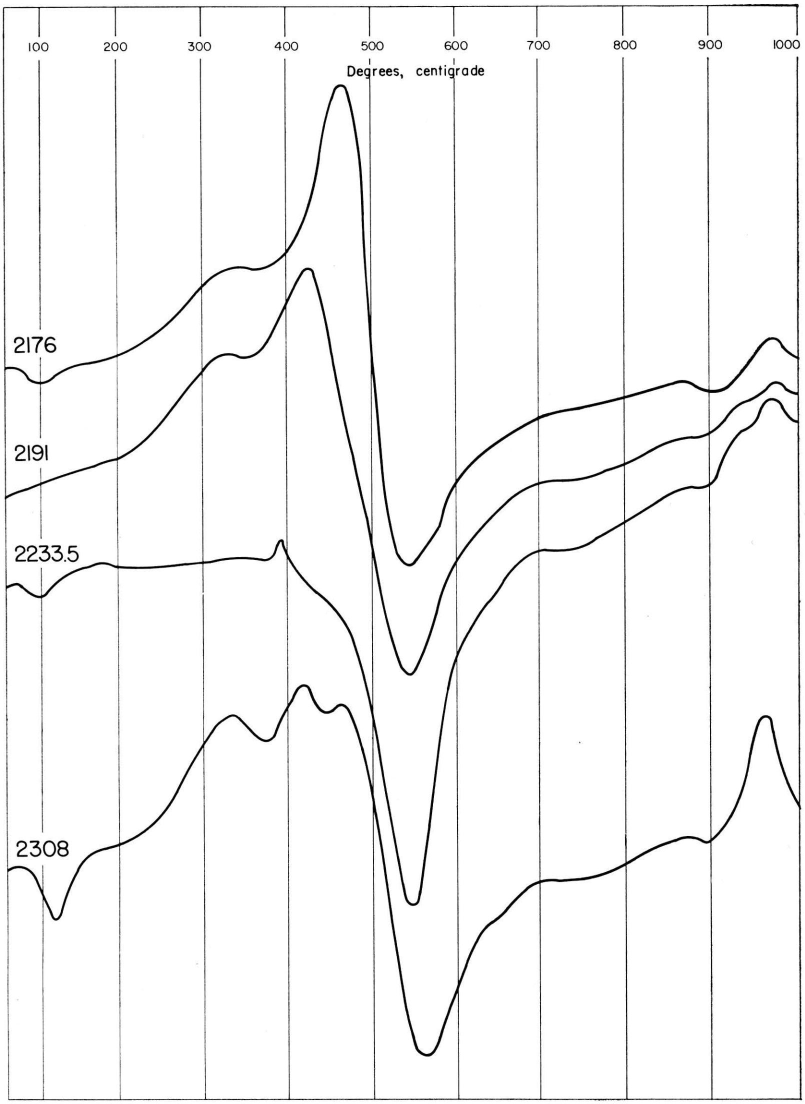


FIG. 7.—Differential thermal curves of core samples taken at 2,176 feet, 2,191 feet, 2,233.5 feet, and 2,308 feet. All samples from Cruise member of Omadi Formation.

matter and in which the clay mineral is oriented parallel to the bedding. Clay also forms a poorly oriented groundmass that includes abundant finely divided carbonaceous matter. Color of the clay in transmitted light depends upon the content of carbonaceous matter and ranges from very light brown to dark brown. Trace amounts of quartz as anhedral grains measuring as much as 0.1 millimeter in diameter also are apparent in thin sections of the coal.

The coaly material is macerated and includes resistant translucent and opaque attritus, abundant resin globules, and sparse fusain. The resin globules, which measure as much as 0.15 millimeter in diameter, contain minute tubular structures about 2 microns in diameter. The tubular structures may be fungus hypha (Robert W. Baxter, oral communication, March 1957).

Other structures observed in the coal include elongate translucent layers or bands that are bounded by opaque attritus and contain numerous opaque branching curved spicular carbonaceous particles. The bands measure as much as 0.4 millimeter in width, and the included spicular particles measure as much as 1 millimeter in length and 5 microns in diameter. Under crossed nicols, the translucent material assumes a rippled sheen similar to that exhibited by mica books. Birefringence may be partly masked by brown coloration, but seems to be first order gray. Extinction is parallel to the length of the layers and bands. The translucent material is slightly pleochroic from light brown to brown, and it probably is an aggregate of well-oriented clay.

X-ray data.—In the fraction finer than 2 microns, the mineral constituents of the coal include a kaolin mineral, mixed-layer clay, and trace amounts of quartz. The kaolin mineral has a broad 001 peak at 7Å and seemingly is poorly crystallized. The mixed-layer clay has a broad diffraction band that extends from 10 to 15Å. On treatment with glycerol, the broad band is resolved into two small peaks at 10.1 and 14.7Å. On heating to 450°C, the reflection at 14.7Å disappears and the reflection at 10.1Å is intensified somewhat. Percentages of clay components estimated from the diffractogram of the glycerated sample are 40 percent kaolin and 60 percent mixed-layer clay.

Sample from depth of 2191 feet

Megascopic description.—The rock is a light- to medium-gray argillaceous siltstone or very fine grained sandstone that contains abundant carbonaceous matter as fragments and films and as small veinlets steeply inclined to locally distinct bedding.

Petrographic description.—In thin section (Pl. 4 A, B), the rock is seen to be composed mainly of silt-sized quartz grains embedded in a matrix of clay. Bedding is indistinct in thin section except where delineated by alignment of carbonaceous flakes and mineral matter. Bedding commonly is deformed: arcuate silty lenses and silty blebs merge with horizontal and gently inclined planar bedding.

Detrital quartz approximates 60 percent of the rock; the grains are subangular to subrounded and measure 0.01 to 0.25 millimeter along their long axes. The grain size distribution is bimodal; maxima lie between 0.01 and 0.05 millimeter, and between 0.1 and 0.2 millimeter. Other detrital minerals include traces of orthoclase (?) and plagioclase.

Clay matrix amounts to about 30 percent of the rock and is comopsed mainly of coarsely crystalline illite (?) whose flakes measure as much as 0.05 millimeter in length. Trace amounts of muscovite also are present in the matrix as books that range in length from 0.05 to 0.15 millimeter. The matrix shows two distinct directions of orientation of the clay and muscovite flakes, which are inclined between 30° and 45° to the axis of coring. Because of the preferred orientation of the constituent flakes, the matrix appears as a rhomboidal plexus under crossed nicols.

Allochthonous coalified matter amounts to about 10 percent of the rock. The coal is composed mainly of opaque and translucent attritus, which forms stringers parallel to the bedding as well as nearly vertical anastomosing veinlets. The apparent opaqueness of much of the coalified material seemingly is due to the thickness of the thin section. Locally the translucent attritus includes resin globules that measure as much as 0.12 millimeter in diameter. In addition to attritus, abundant carbonaceous matter has impregnated the siltstone matrix and imparted a brown color to it.

Examination of the hand sample indicates that the coalified material is lignite or subbituminous coal and that in addition to attritus the rock contains small amounts of fusain as stringers and films along bedding surfaces.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include approximately 65 percent illite that is partly

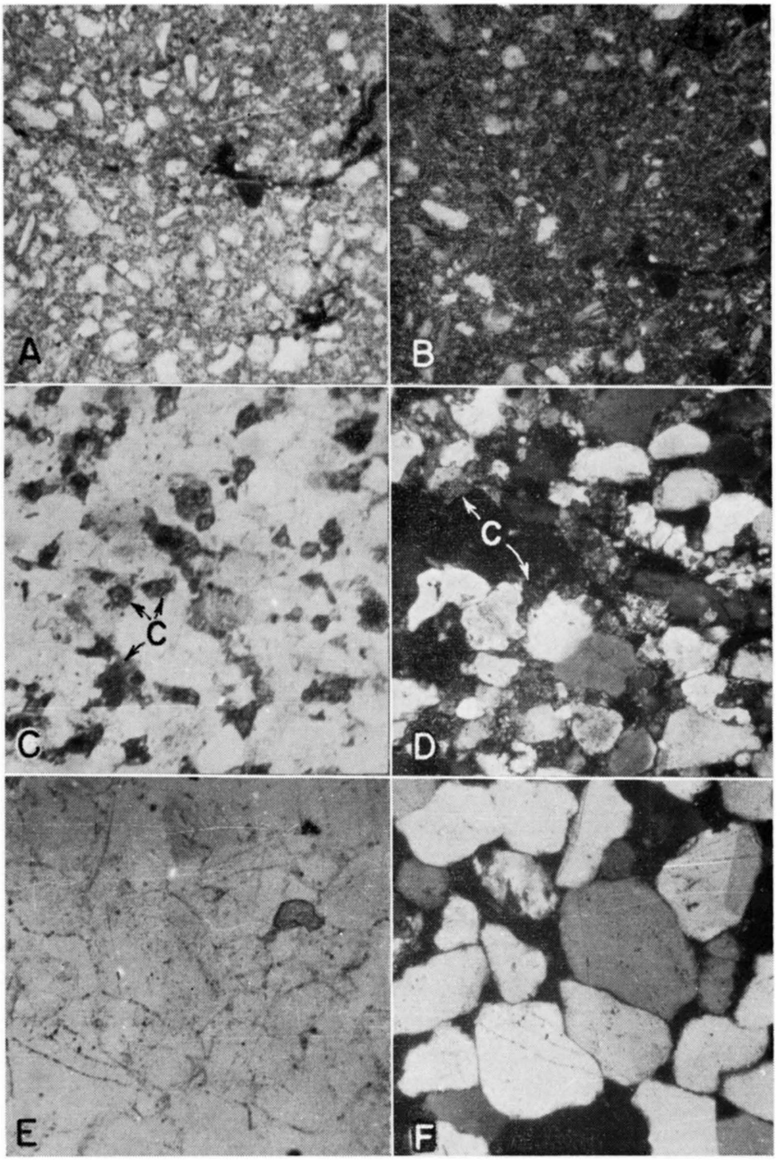


PLATE 4.—Photomicrographs of thin sections, x 65. **A.** Sample 2191, siltstone, plane polarized light. Quartz grains embedded in clay matrix. Black material is organic matter. **B.** Sample 2191, siltstone, crossed nicols. **C.** Sample 2259, sandstone, plane polarized light. Quartz grains cemented mainly by calcite, C. **D.** Sample 2259, sandstone, crossed nicols. C, calcite. **E.** Sample 2421, sandstone, plane polarized light. Dark grain is tourmaline. **F.** Sample 2421, sandstone, crossed nicols.

degraded and 35 percent kaolinite. The x-ray patterns (Fig. 6) also show a weak reflection at 25Å. On glyceration, the 25Å reflection shifts to 29Å, a second order reflection appears at 14Å, and the shoulder on the illite 001 reflection disappears. Also present are minor amounts of quartz.

Differential thermal analysis.—The differential thermal curve for this sample is similar to that for the sample at 2,176 feet (Fig. 7). The endothermic peak at 542°C for this sample is somewhat larger and sharper than the corresponding peak for the sample from 2,176 feet, and reflects the slightly smaller percentage of degraded illite and greater percentage of kaolinite indicated by the x-ray data for this sample. The thermal curve for this sample also shows a weak endothermic reaction at 900°C and a small exothermic peak at 975°C. An absorbed-water peak, such as is present on previously discussed curves, is not shown by this one. The exothermic reactions for carbonaceous matter, which produce peaks at 323° and 425°C, are strong, but the area under the peaks is somewhat less than for samples taken above a depth of 2,191 feet. It is probable that pyrite and marcasite, present in previously discussed samples, have increased the exothermic reaction in the range between 323° and 425°C; under the circumstances it is impossible to separate the reactions due to carbonaceous matter from those due to iron sulfides.

Sample from depth of 2193 feet

Megascopic description.—The rock is a light- to medium-gray mudstone containing coalified material as films and irregular fragments. The mudstone has indistinct deformed bedding and numerous randomly oriented slickensides. It is locally silty, and the silty parts form indistinct irregular patches within the mudstone.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 65 percent partly degraded illite and 35 percent kaolinite. Minor amounts of quartz also are present.

Sample from depth of 2206 feet

Megascopic description.—The rock is a light-gray to light-greenish-gray mudstone that has no obvious lamination and has conchoidal fracture. Sparse carbonaceous stringers and one fern-leaf imprint were observed in the sample. Numerous brown subspherical grains of siderite are apparent. The grains are about

0.5 millimeter in diameter and their surfaces are irregular, owing to crystal growth.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 70 percent illite that is partly degraded and 30 percent kaolinite. The degraded illite has a superlattice reflection at about 24Å, which shifts to about 30Å on glyceration. Also present in the -2 micron fraction are minor amounts of quartz and calcite.

Sample from depth of 2226 feet

Megascopic description.—The rock is a light-gray to light-greenish-gray mudstone that has no obvious lamination. It is somewhat silty and breaks with a conchoidal fracture. Sparse subspherical brown grains of siderite are visible in the sample. Individual grains are about 0.5 millimeter in diameter, and their surfaces are irregular, owing to crystal growth.

X-ray data.—In the -2 micron fraction, the clay minerals include approximately 65 percent partly degraded illite, 25 percent kaolinite, and 10 percent chlorite. The degraded illite has a superlattice reflection at about 25Å, which shifts to about 30Å on treatment with glycerol. Also present in the fraction finer than 2 microns are minor amounts of quartz.

Sample from depth of 2233.5 feet

Megascopic description.—The rock is a light-gray mudstone having sparse irregular siltstone laminae, conchoidal fracture, and numerous slickensides, but no apparent fissility.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 65 percent illite that is partly degraded and about 35 percent kaolinite (Fig. 6). Minor amounts of quartz also are present.

Differential thermal analysis.—A fairly large endothermic peak at 550°C dominates the differential thermal record of this sample (Fig. 7). Although the peak temperature is low, the shape of the peak is characteristic of kaolinite. The partly degraded illite indicated by x-ray data probably accounts for the slight broadening of the 550°C peak and for the small endothermic peak at 900°C. The small exothermic peak at 970°C is more or less normal for a mixture of these two clay minerals. A very broad exothermic shift below 400°C probably was produced by a small amount of organic matter. The small exothermic peak at 392°C indicates a minute amount of pyrite.

Sample from depth of 2239 feet

Megascopic description.—The rock is a light-gray fine-grained sandstone showing indistinct wavy bedding. It contains abundant interstitial clay and abundant carbonaceous matter as thin seams, films, and fragments. Sparse mica flakes are disseminated through the rock.

Petrographic description.—In thin section, the rock is seen to be composed mainly of subangular to subrounded detrital quartz grains embedded in a clay matrix. Wavy bedding is indicated by variations in amount of interstitial clay, by stringers of interstitial carbonaceous matter, and by diverse subparallel orientation of the long axes of detrital grains. The detrital grains measure 0.02 to 0.20 millimeter long.

Detrital quartz, which amounts to about 80 percent of the rock, is present as subangular and subrounded grains that have abundant silica overgrowths. The overgrowths locally are delineated by lines of inclusions, but most commonly they are not. Some of the quartz grains have sutured margins. Present as inclusions in the quartz grains are brownish-green tourmaline, apatite, chlorite (?), "dust planes", fluid bubbles, and rutile-like needles. Some grains have a mosaic texture under crossed nicols and probably are detrital metaquartzite.

Other detrital minerals include about 2 percent feldspar, 1 percent chert, and trace amounts of muscovite and tourmaline. The feldspar includes microcline, orthoclase, and plagioclase. Some feldspar grains show signs of secondary growth. Muscovite is present as slender books having shredded ends. The books measure as much as 0.3 millimeter in length and are bent around the detrital grains. The tourmaline is present as subangular, somewhat prismatic, gray-blue and brown grains.

The clay matrix approximates 11 percent of the rock but locally amounts to as much as 15 percent. The matrix is brown in transmitted light where abundant carbonaceous matter is present; elsewhere it is light green. The birefringence and green tinge indicate that the clay is mainly illite. The clay fills voids and forms thin films surrounding detrital grains; it lacks preferred orientation.

Carbonaceous matter approximates 5 percent of the rock and occurs as irregular stringers that are interstitial to the detrital grains and extend parallel to bedding, and as irregular blebs as as much as 0.3 millimeter long. Pyrite, which amounts to less than 1 percent of the rock, is present as small irregular patches and stringers in the carbonaceous matter.

Estimated percentage composition:

Constituent	*Percent*	*Constituent*	*Percent*
Quartz	80	Tourmaline	Tr
Feldspar	2	Clay	11
Chert	1	Carbonaceous matter	5
Muscovite	Tr	Pyrite	Tr

X-ray data.—In the fraction finer than 2 microns, the clay minerals include 55 percent illite that is partly degraded, 40 percent kaolinite, and 5 percent montmorillonite. Also present in the -2 micron fraction are minor amounts of quartz.

Sample from depth of 2254 feet

Megascopic description.—The rock is a medium-gray mudstone containing abundant thin sandy siltstone laminae. The laminae are wavy and locally contorted and have little fissility. Traces of carbon are apparent as specks on bedding planes.

Petrographic description.—In thin section, lenses and layers of siltstone and mudstone are inclined at differing angles, partly truncating and partly paralleling one another. The rock is composed of almost equal amounts of mudstone and siltstone.

The mudstone is composed mostly of brown strongly birefringent clay that has fair orientation parallel to the lenses and stringers. Included in the mudstone are books of illite, which measure about 0.01 millimeter in length and approximate 3 percent of the rock. Small grains of silt-sized quartz (0.02 to 0.05 millimeter in diameter) amount to 5 or 10 percent of the mudstone. The quartz grains are subangular to angular, in part corroded, and some show overgrowths of silica. Traces of shredded muscovite are present as flakes measuring as much as 0.05 millimeter in length. Traces of carbonaceous(?) matter are apparent as black specks measuring as much as 0.1 millimeter in length.

The layers and stringers of sandy siltstone are composed mainly of quartz grains ranging from 0.01 to 0.10 millimeter long. The grains are angular and subangular and have been modified in part both by silica overgrowths and by suturing. Interstitial to the quartz grains are small flakes of light-green faintly pleochroic illite, which amount to about 20 percent of the rock and measure as much as 0.01 millimeter in length. In addition to quartz and clay, the siltstone layers contain trace amounts of feldspar (orthoclase?) and mica. The mica occurs as small shreds measuring as much as 0.25 millimeter in length.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include 60 percent partly degraded illite, 30 percent kaolinite, and 10 percent chlorite. Minor amounts of quartz also are present.

Sample from depth of 2259 feet

Megascopic description.—The rock is a light-brownish-gray medium-fine-grained sandstone that has indistinct cross-lamination. Locally it contains abundant muscovite flakes and specks of interstitial argillic material. Blebs of pyrite that measure as much as 5 millimeters in diameter locally are apparent.

Petrographic description.—In thin section (Pl. 4 C, D), the sandstone is seen to be composed mainly of subangular to subrounded detrital quartz grains cemented by calcite, silica, and clay. The detrital grains are 0.02 to 0.30 millimeter long, but most grains measure 0.1 to 0.2 millimeter. Bedding is indicated by some segregation of detrital grains according to size, by distribution of interstitial clay in layers, and by diverse subparallel orientation of the long axes of detrital grains.

Quartz amounts to about 85 percent of the rock. The detrital quartz grains have abundant silica overgrowths that commonly are delineated from the original detrital grains by lines of inclusions. The silica overgrowths commonly interlock to cement the rock. Initial roundness of the quartz grains is estimated to be 0.4 to 0.6. Trace amounts of detrital quartz show mosaic patterns under crossed nicols and probably are grains of metaquartzite. "Dust planes", fluid bubbles, and sparse rutile-like needles are present as inclusions in the quartz grains.

Other detrital minerals include chert, feldspar, muscovite, tourmaline, and staurolite. The chert, which amounts to about 1 percent of the rock, is fine grained and clouded by particles of clay. The feldspar includes microcline, orthoclase, and plagioclase, and amounts to about 2 percent of the rock. Muscovite approximates 1 percent of the rock. Locally it is concentrated along bedding planes but is otherwise present only in trace amounts. It occurs as slender books as much as 1 millimeter long, locally bent around the detrital grains. Pleochroic green tourmaline and yellow-brown staurolite are present in trace amounts as subrounded grains.

Phyllite or schist fragments, or both, approximate 2 percent of the rock. They are composed of anhedral quartz and sericite flakes that show diverse orientation.

In addition to siliceous cement, the rock contains about 7 percent yellow-brown calcite, as distinct rhombohedra and as aggregates of rhombohedral grains. The aggregates are 0.02 to 0.2 millimeter in diameter. Locally the calcite seems to have formed at the expense of clay matrix and quartz grains.

The clay matrix amounts to about 2 percent of the rock. It is composed of coarse clay flakes measuring as much as 0.01 millimeter in length, which occupy pore space and are diversely oriented. Birefringence indicates that the clay may include both illite and kaolinite.

Trace amounts of glauconite occur as rounded patches that are interstitial to detrital grains and measure as much as 0.2 millimeter in diameter. Pyrite was observed in the hand sample, but none was found in thin section.

Estimated percentage composition:

Constituent	*Percent*	*Constituent*	*Percent*
Quartz	85	Phyllite or schist fragments, or both	2
Chert	1	Calcite	7
Feldspar	2	Clay	2
Muscovite	1	Glauconite	Tr
Tourmaline	Tr	Pyrite	Tr
Staurolite	Tr		

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 45 percent partly degraded illite, 40 percent kaolinite, 7 percent each chlorite and mixed-layer clay, and 1 percent montmorillonite (Fig. 10). The mixed-layer clay has a basal reflection between 11 and 13Å; on treatment with glycerol, the basal reflection shifts to 14Å and a weak reflection appears at 28Å. Also present in this size fraction are minor amounts of quartz and calcite.

Differential thermal analysis.—The endothermic peaks at 95°, 527°, and 940°C indicate degraded illite or mixed-layer clay, although the curves (Fig. 11) are not clearly diagnostic. Both the 95° and 527°C peaks are abnormally low, whereas the 940°C peak is high. It is probable that the fairly large percentage of kaolinite, confirmed as present by x-ray data, produced the fairly sharp point on the 527°C peak. The high-temperature exothermic reaction does not form a peak but drifts in the exothermic direction. Carbonaceous material and pyrite produced a definite and strong exothermic reaction that produced small peaks at 270°, 308°, and 388°C. The minor amount of calcite detected by the x-ray in the fraction finer than 2 microns should have produced a small endothermic deflection but did not. This sample sintered and shrank in the sample well—a fact that may account for the decided base line drift in an exothermic direction.

Sample from depth of 2280 feet

Megascopic description.—The rock is a light-brownish-gray, medium-fine-grained friable sandstone. Sparse mica flakes and light-yellow argillic specks are discernible in the sample. No bedding is apparent.

Petrographic description.—The thin section is composed mainly of subangular to subrounded grains of quartz, feldspar, and chert embedded in a matrix of clay minerals and chert. Slight tendency toward subparallel orientation of long axes of detrital grains is suggestive of bedding.

Detrital quartz amounts to about 84 percent of the rock and occurs as subangular and subrounded grains measuring 0.02 to 0.4 millimeter long; most grains are 0.2 to 0.3 millimeter long. Quartz grains show sparse local overgrowths that do not surround the grains. Some overgrowths are delineated from the original quartz grains by inclusions of the matrix. Many grains have sutured outlines that indicate secondary solution of quartz. "Dust planes", rutile-like needles, apatite, tourmaline or staurolite, or both, chlorite(?), and fluid bubbles are present as inclusions in the quartz grains. Some quartz grains show a mosaic pattern under crossed nicols and probably are detrital metaquartzite.

Other detrital grains include feldspar, chert, and mica. The feldspar, including plagioclase, microcline, and orthoclase, amounts to about 3 percent of the rock and shows differing degrees of argillic alteration. Grains of detrital chert amount to about 1 percent of the rock. Macerated muscovite and biotite in flakes as long as 0.7 millimeter occur in trace amounts. Also present in trace amounts are rounded grains of pleochroic blue-green tourmaline, yellow-brown staurolite, and clear zircon.

The matrix is composed mostly of clay, which approximates 7 percent of the rock. The clay is mainly brownish-green illite and occurs as interstitial flakes as much as 0.02 millimeter long. Aggregates of cryptocrystalline silica and clay also are present in the matrix. Locally, irregular patches of sutured quartz seem to have replaced clay. The quartz and cryptocrystalline silica in the matrix approximate 3 percent of the rock. Traces of calcite have replaced clay matrix locally. Barite(?), clouded with small specks of carbonaceous matter, forms about 1 percent of the rock as minute grains that line and fill voids interstitial to the quartz grains.

Present as secondary minerals are trace amounts of leucoxene and pyrite. The pyrite appears as small irregular replacements of the matrix and of detrital grains. The leucoxene appears as small irregular and rounded blebs 0.07 to 0.15 millimeter in length.

Estimated percentage composition:

Constituent	*Percent*	*Constituent*	*Percent*
Quartz	84	Clay	7
Feldspar	3	Secondary silica	3
Chert	1	Barite	1
Muscovite and biotite	Tr	Calcite	Tr
Zircon	Tr	Pyrite	Tr
Tourmaline	Tr	Leucoxene	Tr
Staurolite	Tr		

Sample from depth of 2304 feet

Megascopic description.—The rock is a light-brown, medium-fine-grained sandstone containing abundant pyrite blebs surrounded by small nodular aggregates of calcite cement, which give the rock a warty appearance where worn by the core barrel. Sparse small flakes of mica are apparent in the hand sample. No bedding was observed.

Petrographic description.—In thin section, the rock is seen to be composed mainly of subangular and subrounded quartz grains, locally cemented by calcite and lesser amounts of pyrite, but more commonly by clay and silica. Size of the detrital grains ranges from 0.05 to 0.40 millimeter in long diameter; most grains are 0.15 to 0.30 millimeter in long diameter. Bedding is not apparent in thin section.

Quartz constitutes about 86 percent of the rock. The quartz grains have abundant silica overgrowths, some of which are delineated by lines of inclusions. Locally the overgrowths interlock to cement the rock. Many of the quartz grains have sutured margins, particularly where the rock contains abundant calcite and pyrite. Some of the quartz grains reveal a mosaic pattern under crossed nicols and are thought to be particles of metaquartzite. Present as inclusions in the quartz grains are chlorite (?), rutile-like needles, apatite, fluid bubbles, and "dust planes".

Other detrital minerals include chert, feldspar, muscovite, and tourmaline. Detrital chert amounts to about 2 percent of the rock; feldspar constitutes about 1 percent and includes microcline, orthoclase, and plagioclase; muscovite is present in trace amounts as slender books measuring as much as 0.3 millimeter long. Trace amounts of subangular green tourmaline also are present.

Detrital grains of phyllite or schist, or both, amount to about 1 percent of the rock. They are composed of parallel sericite and muscovite flakes, but contain various amounts of quartz.

Irregularly distributed patches of clay, calcite, and pyrite constitute the matrix. The clay is interstitial, diversely oriented, and amounts to about 4 percent of the rock. Its birefringence indicates that it may be mainly illite and kaolinite. Calcite, constituting 4 percent of the rock, in optically continuous rounded patches as much as 10 millimeters in diameter is irregularly distributed in horizontal zones. Most of the calcite is interstitial to the detrital grains, but locally it has formed at their expense. Pyrite, which amounts to about 1 percent of the rock, forms anhedral blebs and stringers within the rounded patches of calcite. It is mainly interstitial to the detrital grains that are incorporated in the patches of calcite but locally has replaced them.

Trace amounts of glauconite and leucoxene also are present. The glauconite occurs as rounded interstitial patches as much as 0.3 millimeter long. Leucoxene is present as subrounded grains as much as 0.2 millimeter in diameter.

Estimated percentage composition:

Constituent	*Percent*	*Constituent*	*Percent*
Quartz	86	Clay matrix	4
Chert	2	Calcite	4
Feldspar	1	Pyrite	1
Muscovite	Tr	Glauconite	Tr
Tourmaline	Tr	Leucoxene	Tr
Phyllite or schist, or both	1		

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 30 percent kaolinite, 30 percent partly degraded illite, 25 percent chlorite, 10 percent mixed-layer clay, and 5 percent montmorillonite. The mixed-layer clay has basal reflections between 11 and 13Å. On treatment with glycerol, the basal reflections shift to 14Å, and a weak reflection appears as a shoulder on the trace at 28Å. Minor amounts of quartz and calcite also are present.

Kiowa Shale

Sample from depth of 2308 feet

Megascopic description.—This sample is a medium-gray horizontally thin-laminated mudstone.

Petrographic description.—In thin section, the rock shows both even and somewhat wavy horizontal lamination and is composed mainly of strongly birefringent clay (illite?) well oriented parallel to the bedding. In plane-polarized light, the thin section is light to dark brown.

Small books of faintly pleochroic light-green illite are scattered through the section, making up 1 to 2 percent of the rock. The books measure 0.01 to 0.05 millimeter in length. Angular to subangular grains of quartz, which measure 0.01 to 0.08 millimeter in length, constitute 5 to 10 percent of the rock. Most of the grains are oriented subparallel to the lamination of the rock, and many show delicate suturing.

Small fragments of black carbonaceous matter, which are disseminated through the thin section and measure as much as 0.05 millimeter in length, amount to about 3 percent of the rock. Traces of very finely divided pyrite encrust some of the black fragments.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 70 percent partly degraded illite and 30 percent kaolinite (Fig. 6). Also present are trace amounts of quartz.

Differential thermal analysis.—Endothermic peaks were produced by the clay minerals in this sample at 115° and 895°C (Fig. 7). All peaks are relatively small. The 560°C peak was probably subdued to some extent by the strong exothermic reaction from about 200° to some point above 500°C. Although the dominant mineral is degraded illite, it is likely that kaolinite produced most of the 560°C endothermic peak and the 960°C exothermic reaction. Small peaks on the broad exothermic swing below 500°C could have been produced by either pyrite or carbonaceous matter.

Sample from depth of 2341 feet

Megascopic description.—The rock is a medium-gray silty mudstone that has blocky fracture and sparse slickensides. Bedding is not apparent in the sample.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 65 percent illite that is partly degraded, 20 percent kaolinite, and 5 percent each of chlorite, montmorillonite, and mixed-layer clay. The mixed-layer clay has distinct but weak reflections between 11 and 12Å and may have a weak reflection at about 25Å (Fig. 8). On treatment with glycerol, the reflections between 11 and 12Å shift to 14Å, and a shoulder is apparent at 28 or 29Å. Also present are minor amounts of quartz.

Differential thermal analysis.—The differential thermal record (Fig. 9) for this sample is characterized by a strong exothermic reaction to carbonaceous matter and pyrite, which produced peaks at 320°, 422°, and 445°C, and by a decided base line drift to the exothermic side above 550°C. The base line drift probably was caused by the sintering and shrinking of the sample from the wall of the sample holder. The 120° absorbed-water peak, the broad 550° peak, and the small 882°C endothermic peaks are characteristic of degraded illite or mixed-layer clay but certainly could not be diagnosed without the aid of x-ray data. The 940°C exothermic peak indicates a small percentage of kaolinite. The apparent endothermic peak at 740°C does not fit the clay minerals present in the sample and may represent only a swing back to base line at the end of an extended exothermic reaction produced by carbonaceous matter.

Sample from depth of 2397 feet

Megascopic description.—The rock is a light-gray aphanitic limestone containing numerous clay-lined cavities ranging in length from about 1 millimeter to 1 centimeter. Locally the rock shows fibrous structure. It contains no fossils. Etched surfaces show irregularly lobate rounded patches of calcite 1 to 5 millimeters long, which stand in relief. Cupric nitrate and cobalt nitrate staining techniques show that the rock contains no dolomite or aragonite.

Petrographic description.—In thin section, the rock shows an indistinct irregular mosaic of calcite. Patches of calcite are locally separated by films of unidentified clay and contain very fine grained calcite as irregular blebs about 0.01 millimeter in

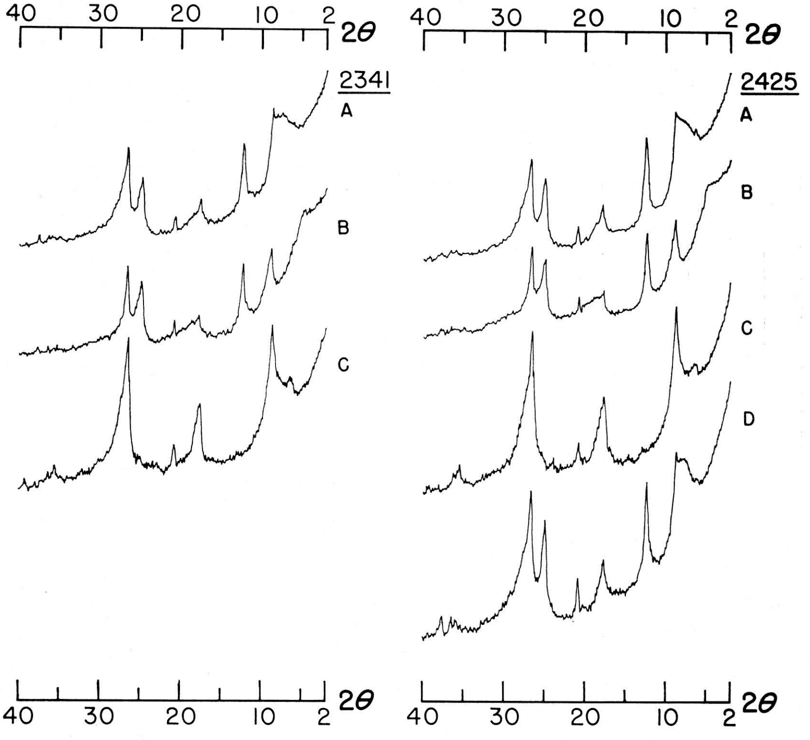


FIG. 8.—Diffractometer patterns of fraction finer than 2 microns from selected mudstone samples. Sample 2341: mudstone, Kiowa Shale; A, air-dried; B, glycerated; C, heated to 575°C. Sample 2425: mudstone, Cheyenne Sandstone; A, air-dried; B, glycerated; C, heated to 575°C; D, boiled in hydrochloric acid and air-dried.

diameter as well as fibrous calcite showing both radial and parallel alignment of fibers. Trace amounts of quartz are present as sutured grains about 0.05 millimeter long.

Cheyenne Sandstone

Sample from depth of 2421 feet

Megascopic description.—The rock is a light-gray-brown fine-to medium-grained friable sandstone having only faint traces of bedding.

Petrographic description.—In thin section (Pl. 4 E, F), the rock is seen to be composed mainly of subrounded to subangular quartz grains; amounts of detrital chert and feldspar are minor. The matrix is mainly clay. Bedding is not apparent in the thin section.

Quartz constitutes approximately 92 percent of the rock. Grains range from 0.05 to 0.5 millimeter in length, but most are 0.20 to 0.35 millimeter long. About 5 percent of the quartz grains

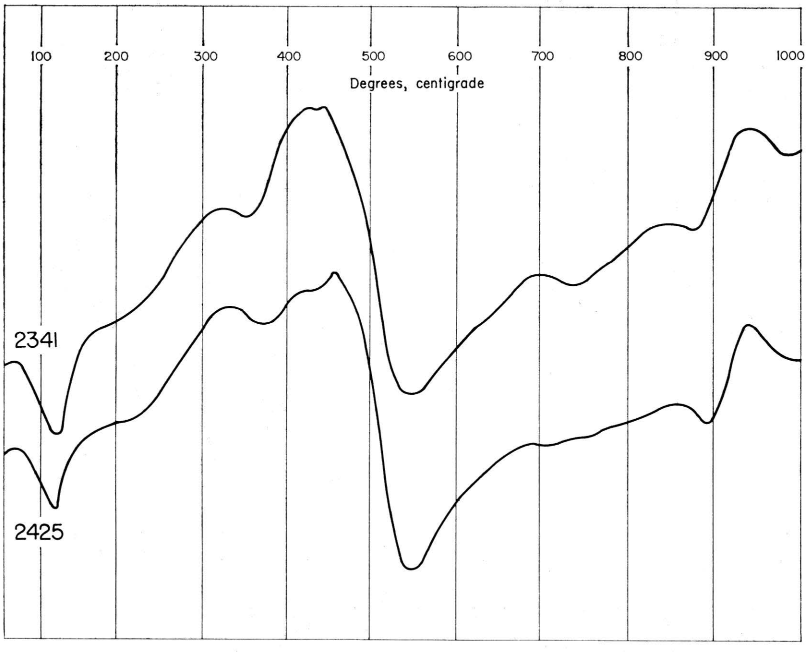


FIG. 9.—Differential thermal curves of core samples taken at 2,341 feet (Kiowa Shale) and 2,425 feet (Cheyenne Sandstone).

show local overgrowths not completely surrounding the original subrounded grains. Most of the overgrowths are not delineated from the rest of the quartz grain by inclusions of matrix. Roundness is estimated to have been 0.4 to 0.6 prior to development of the overgrowths. A few of the quartz grains have sutured outlines. "Dust planes", apatite, fluid bubbles, and tourmaline or staurolite, or both, are present as inclusions in the quartz grains. Rutilated inclusions are sparse. Some of the quartz grains show mosaic patterns on extinction and probably are detrital metaquartzite.

The section contains 1 percent detrital chert and about 1 percent feldspar, including orthoclase, microcline, and plagioclase(?). Also among the detrital minerals are trace amounts of subrounded pleochroic blue-green tourmaline and rounded zircon.

The matrix, about 4 percent of the rock, is composed mainly of clay as minute brown flakes that barely separate the detrital grains. X-ray data show that the clay is approximately 45 percent montmorillonite. Also present in the matrix is about 1 percent barite(?) as minute crystals in the voids between quartz grains.

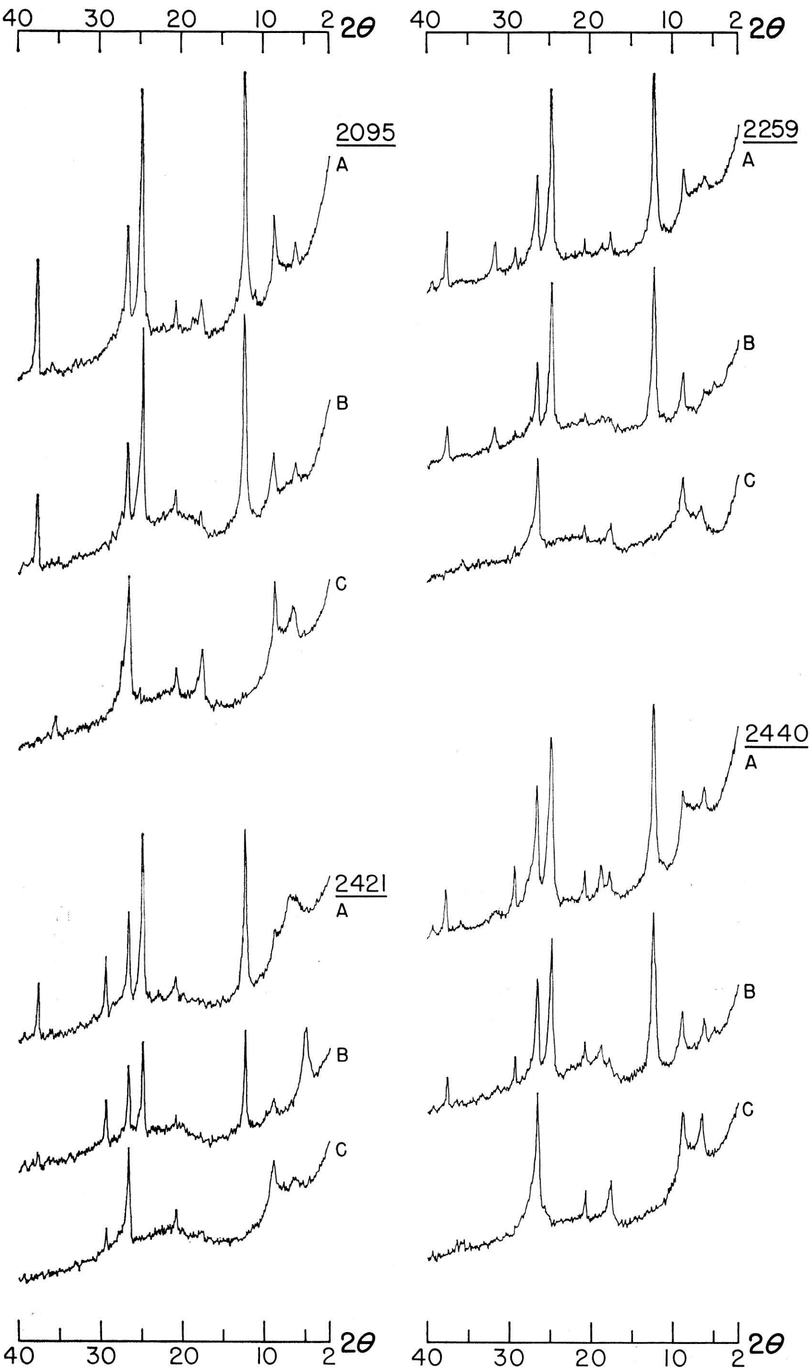
Leucoxene occurs in trace amounts as rounded and irregular grains 0.02 to 0.14 millimeter long.

Estimated percentage composition:

Constituent	*Percent*	*Constituent*	*Percent*
Quartz	92	Zircon	Tr
Chert	1	Clay	4
Feldspar	1	Barite (?)	1
Tourmaline	Tr	Leucoxene	Tr

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 15 percent illite, 25 percent kaolinite, 15 percent chlorite, and 45 percent montmorillonite (Fig. 10). Also present are minor amounts of quartz and calcite.

Differential thermal analysis.—The differential thermal record (Fig. 11) of the fraction finer than 2 microns is dominated by the strong exothermic reactions in the temperature range of pyrite, marcasite, and carbonaceous matter, although none of these constituents were found by petrographic examination. The exothermic swing starts below 200°C and continues almost to


40
30
20
10
2
2θ
2095
A
B
C
2259
A
B
C
2421
A
B
C
2440
A
B
C

500°C. It probably extends as high as 700°C but is partly neutralized by the endothermic reaction from the clay minerals. The absorbed-water peak at 100°C is comparably strong, but the second endothermic reaction, reaching a peak at 576°C, is small and there is a faint indication of an endothermic peak at 695°C. Seemingly the general endothermic swing from about 500° to about 800°C was produced by a gradual loss of water from the clay minerals. There is no clear indication of a high-temperature endothermic peak or the usual exothermic reaction at 900°C or higher. The 100°C peak indicates montmorillonite, as does the minute 695°C endothermic deflection. The 576°C endothermic peak normally indicates degraded illite or mixed-layer clay.

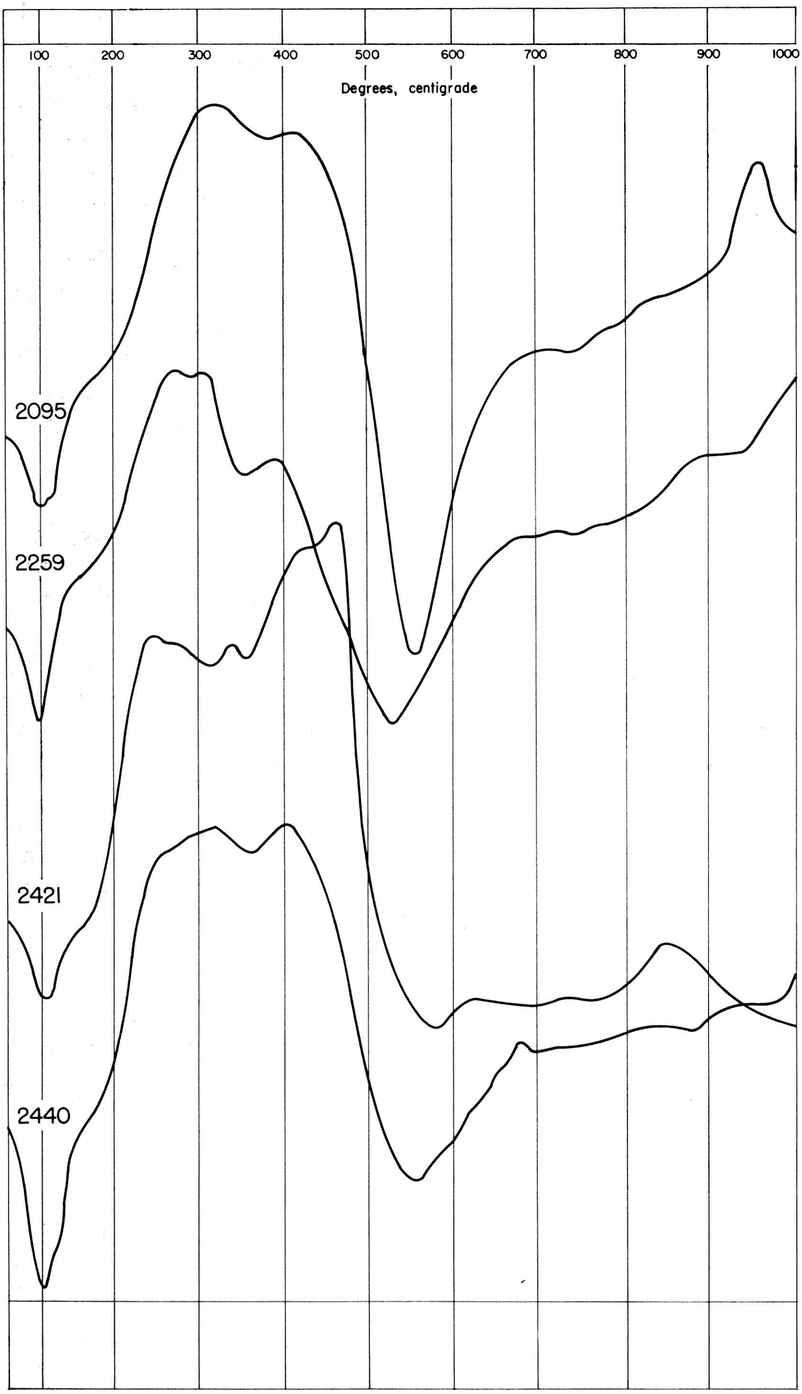
Sample from depth of 2425 feet

Megascopic description.—The rock is a dark-gray wavy-laminated mudstone that contains sparse siltstone laminae. Sparse minute mica flakes are apparent on bedding surfaces. The rock exhibits blocky fracture and slight fissility.

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 65 percent partly degraded illite, 20 percent kaolinite, and 15 percent chlorite and montmorillonite (Fig. 8). Also present are minor amounts of quartz.

Differential thermal analysis.—With the exception of slight differences in size and shape of the peaks and some variation in peak temperatures, the differential thermal record for this sample is similar to that of the sample taken at 2,341 feet (Fig. 9, 2425 and 2341). Both the endothermic peak at 544°C and the exothermic peak at 940°C indicate a slightly larger ratio of kaolinite to degraded illite than the same peaks produced by the sample from 2,341 feet. The exothermic reactions to carbonaceous matter and pyrite are fairly strong. The endothermic peak at 740°C is missing from the record of this sample, indicating that all the carbonaceous matter had been oxidized below that temperature.

FIG. 10.—Diffractometer patterns of fraction finer than 2 microns from selected sandstone samples. Sample 2095: sandstone, Omadi Formation (Gurley member); A, air-dried; B, glycerated; C, heated to 575°C. Sample 2259: sandstone, Omadi Formation (Cruise member); A, air-dried; B, glycerated; C, heated to 575°C. Sample 2421: sandstone, Cheyenne Sandstone; A, air-dried; B, glycerated; C, heated to 575°C. Sample 2440: sandstone, Cheyenne Sandstone; A, air-dried; B, glycerated; C, heated to 575°C.



100
200
300
400
500
600
700
800
900
1000
Degrees, centigrade
2095
2259
2421
2440

Sample from depth of 2440 feet

Megascopic description.—The rock is a light-brownish-gray fine-grained sandstone that shows faint traces of bedding. Apparent in the hand sample are trace amounts of muscovite flakes, opaque grains, and green grains that include glauconite and fragments of reworked schistose or phyllitic rock.

Petrographic description.—In thin section, the rock is seen to be composed mainly of subangular to subrounded grains of quartz in a clay matrix. The detrital grains are 0.05 to 0.35 millimeter long, but most are 0.13 to 0.21 millimeter long. Estimated original roundness of the detrital grains is 0.4 to 0.6, but the grains have been extensively modified by overgrowths and corrosion. Bedding is suggested in the thin section by partial segregation of the finer detrital grains into irregularly spaced subparallel stringers that contain more interstitial clay that the rest of the rock.

Quartz approximates 84 percent of the rock. About 70 percent of the quartz grains show overgrowths, which commonly are delineated by inclusions of the clay matrix along the juncture between the detrital grain and the overgrowth. Many grains show both overgowths and suturing. About 2 percent of the quartz is metaquartzite, as is indicated by the mosaic pattern under crossed nicols. Present as inclusions in the quartz grains are "dust planes", apatite, and rutilated needles, but most grains are relatively free of inclusions.

Detrital chert amounts to about 1 percent of the rock. Both fine- and coarse-grained chert are present. Detrital feldspar includes microcline, plagioclase, and orthoclase in amounts ranging from traces to 1 percent. Traces of detrital muscovite consist of macerated and bent books as much as 0.3 millimeter long.

Also present in the rock are rounded detrital aggregates, 0.08 to 0.20 millimeter long, composed of fine-grained mica and quartz. The mica, probably biotite, is green parallel to X and Y axes and light green parallel to Z. The quartz forms blebs and stringers commonly penetrated by the mica flakes. The fragments consti-

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FIG. 11.—Differential thermal curves of fraction finer than 2 microns, sandstone core samples taken at 2,095 feet (Gurley member of Omadi Formation), 2,259 feet (Cruise member of Omadi Formation), 2,421 feet (Cheyenne Sandstone), and 2,440 (Cheyenne Sandstone).

tute about 2 percent of the rock and are probably reworked schist or phyllite, or both.

Heavy minerals include trace amounts of rounded and subrounded zircon, light-yellow-brown pleochroic staurolite, pleochroic blue to blue-green and clear tourmaline, and sphene that is partly altered to leucoxene.

The matrix is composed mainly of strongly birefringent clay (illite?), which constitutes about 5 percent of the rock and in most places forms films that barely separate the detrital grains. Elsewhere the clay occurs in subparallel stringers together with fine-grained detrital quartz. A small amount of calcite as irregular blebs partly replaces quartz grains and matrix. Traces of microcrystalline barite (?) speckled with minute flecks of carbonaceous matter are interstitial to the detrital grains. Irregular stringers and blebs of chert also occur in trace amounts in the matrix.

Leucoxene, which amounts to about 2 percent of the rock, is present as rounded irregular grains 0.02 to 0.15 millimeter long. Glauconite, which constitutes about 3 percent of the rock, is present as rounded and irregularly rounded grains ranging in length from 0.19 to 0.23 millimeter.

Estimated percentage composition:

Constituent	*Percent*	*Constituent*	*Percent*
Quartz	84	Tourmaline	Tr
Chert	1	Sphene	Tr
Feldspar	1	Clay	5
Muscovite	Tr	Calcite	Tr
Schist or phyllite fragments	2	Barite (?)	Tr
Staurolite	Tr	Leucoxene	2
Zircon	Tr	Glauconite	3

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 35 percent illite that is partly degraded, 30 percent kaolinite, 25 percent chlorite, and 10 percent montmorillonite (Fig. 10). Also present are minor amounts of quartz, feldspar, and calcite.

Differential thermal analysis.—The differential thermal curve for this sample (Fig. 11) is fairly typical for a clay containing a large proportion of illite and a small amount of montmorillonite or chlorite. The fairly large proportion of kaolinite shown by the x-ray data is not definitely indicated by the curves. The large absorbed-water peak at 105°C is indicative of montmorillonite but perhaps also equally indicative of a degraded illite or mixed-layer clay. The small endothermic peak at 700°C probably was produced by chlorite, and the small endothermic peak at 875°C could be attributed to mortmorillonite, illite, chlorite, or calcite. The small exothermic peak at 917°C could have been produced by any of the common clay minerals. The large exothermic deflection marked by peaks at 316° and 405°C was produced by the oxidation of carbonaceous material.

Sample from depth of 2473 feet

Megascopic description.—The rock is a light-gray to brownish-gray very fine grained to fine-grained sandstone showing indistinct subhorizontal laminae 2 to 10 millimeters thick. Small amounts of carbonaceous matter occur as sparse films and specks locally on the laminae, and muscovite flakes as large as 1 millimeter in diameter are concentrated along the laminae. Abundant specks of interstitial white material are apparent in the sample. The rock is indurated and effervesces slightly with dilute hydrochloric acid.

Petrographic description.—The thin section is composed mainly of subangular to subrounded quartz grains and includes lesser amounts of detrital chert and feldspar. The matrix is mainly clay but contains some calcite and chert. Stringers of clay and subparallel alignment of the detrital grains readily define the bedding. The detrital grains range from 0.024 to 0.35 millimeter in length, but most are 0.1 to 0.2 millimeter long.

Quartz amounts to about 83 percent of the rock. About 60 percent of the quartz grains show obvious overgrowths, some of which are delineated by inclusions of clay at the contact between the grains and the overgrowths. Suturing has modified some of the grains, and many grains show overgrowths that have been modified by later suturing. Present as inclusions in the quartz grains are "dust planes", zircon, rutile-like needles, fluid bubbles, and minute irregular dark-green, almost opaque shreds. A few quartz grains show a mosaic texture under crossed nicols and are thought to be detrital metaquartzite.

Chert amounts to about 5 percent of the rock and occurs in roughly equal amounts as detrital grains and as matrix. It is commonly clouded by included clay particles. Detrital feldspar, including orthoclase, microcline, and plagioclase, is present in amounts ranging from traces to about 1 percent. The grains commonly are clouded by argillic alteration. Rounded fragments of phyllite ranging from 0.1 to 0.2 millimeter in length approximate 3 percent of the rock. They are composed of various proportions of fine-grained mica, quartz, and chlorite, and show subparallel orientation of the micaceous flakes.

Muscovite as shredded and bent books ranging in length from 0.2 to 0.6 millimeter constitutes a trace to 2 percent of the rock.

Other detrital minerals include trace amounts of rounded grains of magnetite or ilmenite, or both, and subangular to subrounded grains of garnet, brown and blue-green tourmaline, and yellow-brown staurolite. Leucoxene, as rounded and irregular grains 0.05 to 0.15 millimeter in diameter, makes up about 2 percent of the rock.

The matrix approximates 7 percent of the rock and consists mainly of small flakes of illite that occupy voids and form films between the detrital grains and between the small grains of secondary chert also present in the matrix. Calcite in trace amounts occurs as both optically continuous and cloudy patches in the matrix and as replacement of the margins of detrital grains. Trace amounts of pyrite as small irregular blebs replace other parts of the matrix.

Traces of carbonaceous matter locally appear as irregular masses elongate parallel to the bedding, which they thus help to define. Glauconite is present in trace amounts as rounded green grains about 0.1 millimeter in diameter.

Estimated percentage composition:

Constituent	*Percent*	*Constituent*	*Percent*
Quartz	83	Tourmaline	Tr
Feldspar	1	Staurolite	Tr
Chert	5	Clay	4
Phyllite fragments	3	Pyrite	Tr
Muscovite	1	Calcite	Tr
Leucoxene	2	Carbonaceous matter	Tr
Magnetite or ilmenite, or both	Tr	Glauconite	Tr
Garnet	Tr		

X-ray data.—In the fraction finer than 2 microns, the clay minerals include about 35 percent each illite and kaolinite, 25 percent chlorite, and 5 percent montmorillonite. Also present are minor amounts of quartz, feldspar, and calcite.

Summary

The petrographic, x-ray, differential-thermal-analysis, and firing-test studies of the Cretaceous rocks in the Guy F. Atkinson No. 1 Beaumeister well show only minor differences between similar rock types, from the base of the Graneros Shale to the base of the Cretaceous. The only truly distinctive rock types found in the Dakota Group are the phosphatic conglomeratic sandstone of the Cruise Sandstone member of the Omadi Formation, the coal near the top of the Cruise, and the limestone from the Kiowa Shale.

Petrographic studies show that the sandstone samples examined are essentially similar, both in composition and grain size. The Cheyenne Sandstone, however, commonly has less clay matrix and less silt-sized quartz and seems to be better sorted than sandstone from the Omadi Formation. No diagnostic mineral assemblages were noted. Almost all sandstone examined contained some glauconite, leucoxene, fragments of schist or phyllite, and detrital tourmaline in addition to grains of quartz, feldspar, and chert. Some samples contained trace amounts of zircon and staurolite, but the absence of these minerals in other samples probably reflects the small size of the samples examined.

Variations in clay mineralogy determined by x-ray diffraction are shown in Table 7. The table indicates that the clay minerals of the Graneros Shale include considerably more montmorillonite than the clay minerals of the Daktota Group. Relative proportions of illite and kaolinite in sandstone samples from the Dakota Group seem to be virtually uniform except at the top of the Cheyenne Sandstone, where montmorillonite seems to have formed at the expense of illite. It is suggested that erosion and weathering of the topmost parts of the Cheyenne Sandstone prior to deposition of the Kiowa Shale converted much of the illite to a montmorillonite-like clay.

Clay-mineral composition of mudstone and claystone samples from the Dakota Group also is almost uniform, but differences are to be noted in the thick mudstone sequence in the Cruise Sandstone member of the Omadi Formation. Samples of mudstone between depths of 2,190 and 2,234 feet contain little or no chlorite and montmorillonite (Table 7). The paucity of montmorillonite may reflect the low permeability of the unit and accordingly the absence of circulating ground water that could have decomposed illite to produce montmorillonite-like clay. In this respect, it should be noted that low-temperature endothermic water peaks in the differential thermal analysis curves of samples from the same sequence are weak in comparison with those from mudstone samples from other parts of the Dakota Group. The coal in the Cruise member contains mainly kaolinite and mixed-layer clay, a composition totally unlike other rocks in the Dakota Group.

Differential-thermal-analysis curves for samples from the Dakota Group show minor variations, but there are no consistent features common to any one of the stratigraphic units that distinguish it from the others. As noted above, however, absorbed-water peaks of mudstone samples between depths of 2,190 and 2,234 feet are weak in comparison with those of samples from

TABLE 7.—*Clay-mineral composition of selected core samples.*

				Percentage of clay minerals in samples				
		Depth (feet)	Lithology	Illite	Kaolinite	Chlorite	Montmor-illonite	Mixed layer
GRANEROS SHALE		2,001	Bentonite				100	
		2,017	Claystone	15	15		70	
OMADI FORMATION	Gurley member	2,034.5	Mudstone	60	30	10		
		2,039	Sandstone	45	35	20		
		2,074	Mudstone	55	15	20	5	5
		2,082	Sandstone	40	40	10	10	
		2,095	Sandstone	50	30	20		
	Huntsman member	2,118	Mudstone	60	25	15		
	Cruise member	2,146	Sandstone	40	30		20	10
		2,166	Mudstone	60	25	15		
		2,176	Mudstone	60	20	20		
		2,189	Coal		40			60
		2,191	Siltstone	65	35			
		2,193	Mudstone	65	35			
		2,206	Mudstone	70	30			
		2,226	Mudstone	65	25	10		
		2,233.5	Mudstone	70	30			
		2,239	Sandstone	55	40		5	
		2,254	Mudstone	60	30	10		
		2,259	Sandstone	45	40	7	1	7
		2,304	Sandstone	30	30	25	5	10
KIOWA SHALE		2,308	Mudstone	70	30			
		2,341	Mudstone	65	20	5	5	5
CHEYENNE SANDSTONE		2,421	Sandstone	15	25	15	45	
		2,425	Mudstone	65	20	—15—		
		2,440	Sandstone	35	30	25	10	
		2,473	Sandstone	35	35	25	5	

the other stratigraphic units. The curves obtained for the two Graneros Shale samples are distinctly different from the others in that the peaks are chiefly characteristic of montmorillonite only.

Fired colors of claystone and mudstone samples (Table 8) allow easy recognition of the mudstone sequences in the Cruise Sandstone member of the Omadi Formation. The samples fire to some shade of buff, whereas claystone and mudstone samples from the Cheyenne Sandstone, Kiowa Shale, other parts of the Omadi Formation, and Graneros Shale fire to darker, reddish colors, with the exception of the sample of calcareous Graneros Shale taken at 2,009 feet, which fired buff.

The presence of subspherical grains of siderite in mudstone

TABLE 8.—*Color and hardness of selected core samples after heating to 1000° C.*

Unit	Member	Depth (feet)	Unfired samples: Lithology	Unfired samples: Color	Fired samples: Color	Fired samples: Hardness as to steel
GRANEROS SHALE		1,997	Claystone	Very dark gray	Light pink buff	Harder
		2,001	Bentonite	Very light gray	Light rose	do
		2,009	Claystone (calcareous)	Dark gray	Buff	do
OMADI FORMATION	Gurley member	2,034.5	Mudstone	Gray	Salmon	do
		2,074	Mudstone	Dark gray	Salmon	do
	Huntsman member	2,118	Claystone	Dark gray	Salmon	do
	Cruise member	2,145	Claystone	Dark gray	Salmon and gray	do
		2,166	Mudstone	Gray—red layer	Salmon and dark red	Softer
		2,176	Mudstone	Gray	Light red and salmon	Harder
		2,193	Claystone	Gray to dark gray	Cream	Softer
		2,205	Mudstone	Light gray	Buff	do
		2,206	Mudstone	Light gray	Buff	do
		2,209	Mudstone	Light gray	Buff	Harder
		2,213	Mudstone	Gray	Buff	do
		2,214	Claystone	Gray	Buff	do
		2,220	Mudstone	Gray	Salmon	do
		2,227	Mudstone	Gray	Pink buff	do
		2,233.5	Mudstone	Gray	Buff	do
		2,247	Mudstone	Gray	Salmon and brown	do
		2,254	Mudstone	Gray	Salmon	do
KIOWA SHALE		2,308	Mudstone	Dark gray	Salmon buff	do
		2,341	Mudstone	Dark gray	Salmon	do
		2,419	Mudstone	Dark gray	Salmon	do
CHEYENNE SANDSTONE		2,425	Mudstone	Dark gray	Red	do
		2,476	Mudstone	Gray	Salmon red	do
		2,484	Claystone	Dark gray	Red	do

samples from the Cruise Sandstone member of the Omadi Formation at depths of 2,206' and 2,226 feet should be mentioned, inasmuch as siderite "pellets" are common in mudstone from the Dakota Formation at the outcrop in central Kansas (Plummer and Romary, 1942, p. 326; Swineford and Williams, 1945, p. 116).

FLUID FLOW CHARACTERISTICS OF CORE

by Floyd Preston

An analysis of routine core analysis data from the No. 1 Beaumeister well revealed a relation between porosity and permeability that is characteristic of the sands of the Dakota Group.

Experimental Procedure

Samples were taken at depths between 2,036 and 2,472 feet in all beds that contained sand. Cores ⅝ inch in diameter and 1 inch long were cut from the larger well cores with a diamond drill using water as a lubricant. The cores were oven dried at 115°C for two hours. All core samples were taken perpendicular to the axis of the well core samples.

Effective porosity of the samples was determined as the ratio of pore volume to bulk volume. Bulk volume was calculated from measurements of core length and diameter. Pore volume was taken as the volume of water necessary to saturate the core completely. Complete saturation was obtained by evacuating the air from the cores in a closed container and subsequently covering the cores with water. The volume of water saturating the cores was determined from the water density and the gain in core weight by saturation.

Permeability was determined by use of air at pressures only slightly above atmospheric pressure. No correction was made for the Klinkenberg effect. Air flow rate was measured by stopwatch and wet-test positive displacement gas meter. For the permeability tests, the cores were sealed into circular aluminum rings 1⅛ inch inside diameter by use of Cerrobend, a heavy-metal alloy melting at 170°F. This mounting permitted air to flow through the core in the direction of coring of the small samples.

Effective porosity, expressed as percent, and air permeability in millidarcys are presented in Table 9.

TABLE 9.—*Porosity and permeability data for the Dakota Group in the Guy F. Atkinson No. 1 Beaumeister well.*

Sample number	Depth, feet	Effective porosity, percent	Permeability, millidarcys	Stratigraphic unit
1	2,036	6.8	432	Gurley
2	2,039½	33.8	543	Gurley
3	2,077	16.6	133	Gurley
4	2,082	25.8	1,070	Gurley
5	2,085	26.0	1,120	Gurley
6	2,088	25.7	615	Gurley
7	2,095½	20.1	86	Gurley
8	2,104	20.4	230	Gurley
9	2,106	22.1	292	Gurley
10	2,109	19.0	307	Gurley
11	2,112	24.4	1,510	Gurley
12	2,129	25.1	2,120	Huntsman
13	2,235	18.8	460	Cruise
14	2,238	4.4	31	Cruise
15	2,239	21.9	283	Cruise
16	2,243	21.6	193	Cruise
17	2,244	20.7	134	Cruise
18	2,256	22.7	186	Cruise
19	2,259	24.8	812	Cruise
20	2,263	24.7	1,750	Cruise
21	2,265	27.2	1,800	Cruise
22	2,266	27.7	1,000	Cruise
23	2,267	27.2	1,065	Cruise
24	2,268	27.6	1,330	Cruise
25	2,269	22.1	527	Cruise
26	2,270	24.4	235	Cruise
27	2,271	19.7	67.5	Cruise
28	2,273	27.1	711	Cruise
29	2,274	27.8	1,630	Cruise
30	2,275	26.5	1,280	Cruise
31	2,276	27.4	1,275	Cruise
32	2,277	26.3	747	Cruise
33	2,278	26.7	1,510	Cruise
34	2,279	27.3	2,150	Cruise
35	2,280	27.0	1,680	Cruise
36	2,281	27.7	2,170	Cruise
37	2,282	24.8	1,980	Cruise
38	2,283	26.9	1,250	Cruise
39	2,284	26.1	2,380	Cruise
40	2,285	25.1	1,720	Cruise
41	2,286	26.3	1,810	Cruise
42	2,287	25.3	1,770	Cruise
43	2,288	26.5	1,390	Cruise
44	2,289	27.2	1,560	Cruise
45	2,290	26.8	1,410	Cruise
46	2,291	26.8	1,620	Cruise
47	2,292	25.9	1,620	Cruise
48	2,293	26.7	1,750	Cruise
49	2,294	24.7	1,750	Cruise
50	2,295	26.5	1,390	Cruise
51	2,296	26.7	1,400	Cruise
52	2,297	26.8	1,680	Cruise
53	2,298	23.3	1,650	Cruise
54	2,299	28.0	1,275	Cruise

TABLE 9. (Cont.)—*Porosity and permeability data for the Dakota Group in the Guy F. Atkinson No. 1 Beaumeister well.*

Sample number	Depth, feet	Effective porosity, percent	Permeability, millidarcys	Stratigraphic unit
55	2,300	27.7	2,690	Cruise
56	2,301	27.3	2,270	Cruise
57	2,302	27.3	2,450	Cruise
58	2,303	30.0	1,550	Cruise
59	2,304	25.0	1,820	Cruise
60	2,305	21.8	1,450	Cruise
61	2,306	25.6	2,290	Cruise
62	2,421	19.7	687	Cheyenne
63	2,424	19.8	980	Cheyenne
64	2,437	24.2	308	Cheyenne
65	2,439	25.4	564	Cheyenne
66	2,440	25.1	1,580	Cheyenne
67	2,441	27.7	1,240	Cheyenne
68	2,442	25.5	750	Cheyenne
69	2,457	22.1	1,670	Cheyenne
70	2,458	21.6	301	Cheyenne
71	2,463	22.2	302	Cheyenne
72	2,464	22.2	1,270	Cheyenne
73	2,465	23.3	620	Cheyenne
74	2,466	25.4	673	Cheyenne
75	2,467	24.7	1,000	Cheyenne
76	2,468	25.1	1,270	Cheyenne
77	2,469	23.7	650	Cheyenne
78	2,470	23.7	1,030	Cheyenne
79	2,471	23.5	678	Cheyenne
80	2,472	24.0	750	Cheyenne

POROSITY—PERMEABILITY ANALYSIS

A frequent representation of a porosity—permeability correlation is that of a straight line on log-log paper (Muskat, 1949, p. 168). The equation for this line is:

$$\phi = AK^{b} \qquad (1)$$

which may also be expressed as:

$$\log \phi = \log A + b \log K \qquad (2)$$

A least squares fit to the line of equation (1) was found by use of the following substitutions:

$$\begin{aligned} \log \phi &= Y \qquad (3) \\ \log K &= X \\ \log A &= a \\ b &= b \end{aligned}$$

Use of the relation (3) with equation (2) yields:

$$Y = a + bX \qquad (4)$$

The intercept, a, and the slope, b, for the line represented by equation (4) were found from the following standard equations of least squares (Youden, 1951, p. 40-49)

$$a = \frac{\Sigma X^2 \Sigma Y - \Sigma X \Sigma XY}{n\Sigma X^2 - (\Sigma X)^2} \quad (5)$$

$$b = \frac{n\Sigma XY - \Sigma X \Sigma Y}{n(\Sigma X^2) - (\Sigma X)^2} \quad (6)$$

The term n is the number of data points (X_i, Y_i), and all summations are for n terms.

An approximate measure of the precision of the data is the standard deviation S (or alternately the variance, S^2), which is obtainable from the equation:

$$S^2 = \frac{\text{Sum of squares of deviations}}{\text{Degrees of freedom}} \quad (7)$$

$$S^2 = \frac{\Sigma Y^2 - \dfrac{(\Sigma Y)^2}{n} - \dfrac{\left[\Sigma XY - \dfrac{\Sigma X \Sigma Y}{n}\right]^2}{\left[\Sigma X^2 - \dfrac{(\Sigma X)^2}{n}\right]}}{n-2} \quad (8)$$

The measures of precision for the intercept and slope are the standard deviation of the intercept, S_a, and the standard deviation of the slope, S_b, obtainable from the following relations:

$$S_a^2 = \frac{S^2 \Sigma X^2}{n\Sigma X^2 - (\Sigma X)^2} \quad (9)$$

$$S_b^2 = \frac{S^2}{\Sigma X^2 - \dfrac{(\Sigma X)^2}{n}} \quad (10)$$

Equations 5, 6, 8, 9, and 10 were coded for a digital computer (IBM 650) using the Bell Telephone Laboratories interpretative routine.

The straight line constants of equation (4) were computed for each group of porosity—permeability data listed in Table 9. The statistical parameters S, S_a, and S_b were also determined. Computation for each group required approximately 30 seconds of machine time. Calculated results for a, b, S, S_a, and S_b are given in Table 10.

TABLE 10.—*Statistical analysis of porosity—permeability curves.*

Stratigraphic unit	Intercept, a	Slope, b	Statistical parameters S	S_a	S_b
Gurley	0.981	0.145	0.0683	0.146	0.0552
Cruise	1.145	.086	.0300	.0374	.0122
Cheyenne	1.286	.030	.0383	.115	.0399
All groups	1.111	.095	.395	.0367	.0124

The interpretation for the terms S_a and S_b are as follows: the data for porosity and permeability are regarded as a single sampling of an infinite population. If this sampling is repeated a large number of times, then approximately two thirds of the values for a, found by equation 5, will be within the limits $a \pm S_a$. The same interpretation is to be applied to S_b. The value of (a) will be within the limits $a \pm S_a$ for about 95 percent of the samples.

The curves of Figure 12 and the data of Table 10 can be used to determine the range of permeability to be expected from a sample having a given permeability. The curves also serve to illustrate the lithologic similarity of all members of the Dakota Group. The actual statistical identity of the porosity—permeability relations for all stratigraphic units could not be tested without an extensive mathematical analysis of the data.

CORE ANALYSIS DATA

Table 11 contains data made available by the Guy F. Atkinson Company. The measurements of water saturation reflect gravity drainage from the cores prior to saturation determination. Such behavior is to be expected from cores of high permeability.

An analysis of the data for horizontal versus vertical permeability data revealed that, at the percent confidence limit, there is no statistical difference in permeability in the vertical and horizontal directions for short core samples. Thus, both high and low vertical permeabilities are found with equal frequency for a given horizontal permeability. The regression line, or straight line through the data of Figure 13, was found to be:

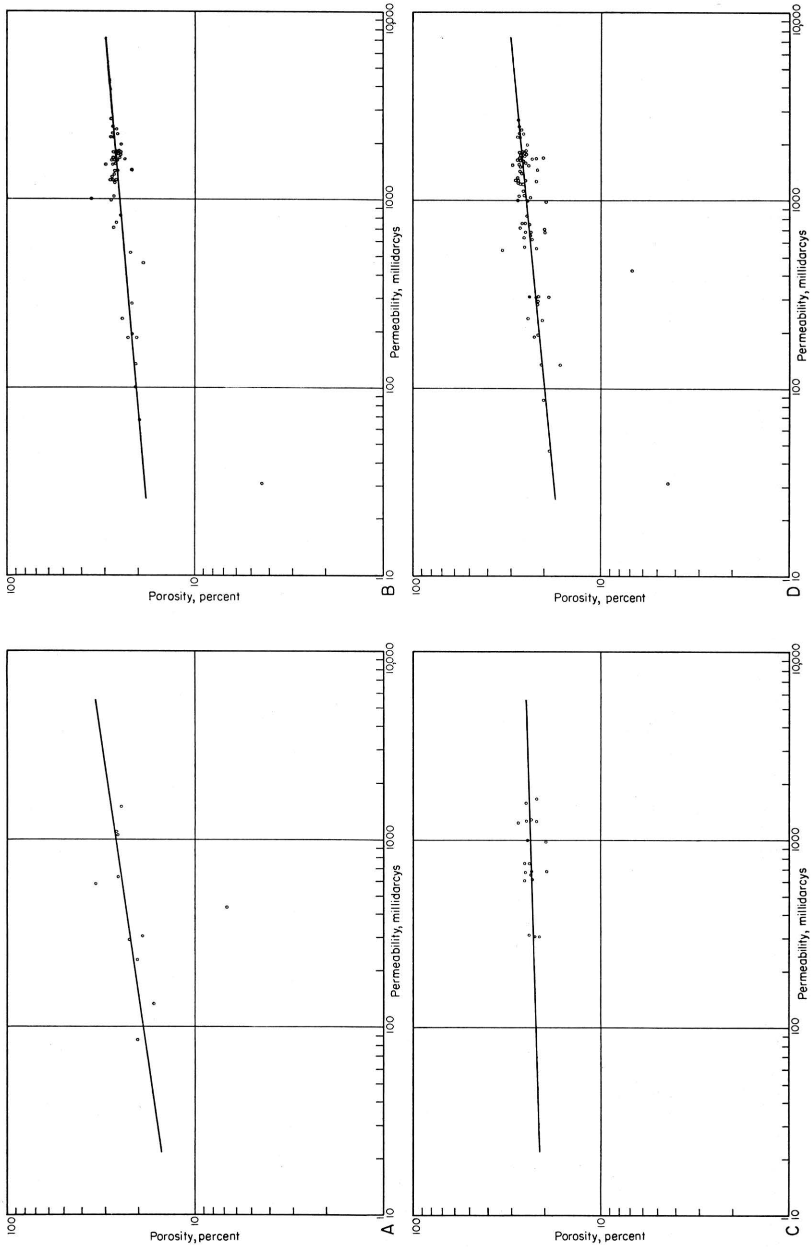

FIG. 12—Porosity—permeability relation of No. 1 Beaumeister well (A) Gurley Sandstone, (B) Cruise Sandstone, (C) Cheyenne Sandstone, and (D) Dakota Group.

$$\log K_v = a + b \log K_h$$
$$a = 0.338 \pm 0.280$$
$$b = 0.841 \pm 0.115$$

where K_v and K_h are respectively the vertical and horizontal

TABLE 11.—*Core analysis data—Guy F. Atkinson Company No. 1 Beaumeister, Cheyenne County, Kansas.*

Sample no.	Depth, feet	Vertical permeability, millidarcys	Horizontal permeability, millidarcys	Porosity, percent	Residual saturation, percent of pore space: Oil	Residual saturation, percent of pore space: Water
1	2033.9	13	111	25.0	0.0	48.0
2	2079.2	467	214	27.3	0.0	53.8
3	2080.7	377	183	28.5	0.0	63.1
4	2085.7	390	298	31.5	0.0	63.4
5	2087.5	13	54	25.7	2.3	54.1
6	2088.9	153	139	28.7	0.0	54.4
7	2090.7	5.1	148	26.4	3.0	37.1
8	2098.6	18	7.5	22.4	0.0	45.1
9	2102.6	26	7.7	21.1	3.3	45.5
10	2103.7	119	19	23.9	2.9	35.1
11	2104.6	113	211	29.5	2.4	36.3
12	2106.7	788	357	30.0	0.0	43.3
13	2112.8	140	214	30.3	0.0	35.0
14	2195.6	270	69	31.6	0.0	61.4
15	2196.5	21	222	29.3	0.0	72.0
16	2197.6	5.8	6.4	14.5	0.0	90.3
17	2198.5	362	74	30.0	0.0	65.0
18	2199.3	172	88	30.2	0.0	37.7
19	2257.5	137	560	30.2	0.0	66.9
20	2258.4	320	521	31.3	2.2	56.9
21	2259.4	234	283	30.6	2.3	50.0
22	2260.5	183	410	32.3	0.0	62.5
23	2261.7	295	377	29.5	0.0	41.7
24	2262.9	833	585	32.4	0.0	62.9
25	2263.6	893	710	33.8	0.0	57.1
26	2264.3	637	710	33.3	0.0	58.5
27	2265.7	507	666	34.3	0.0	47.2
28	2266.4	580	370	33.0	0.0	64.5
29	2269.7	48	140	31.5	0.0	65.7
30	2270.4	580	580	34.4	0.0	61.3
31	2271.3	88	140	29.5	0.0	48.5
32	2272.7	64	200	30.6	0.0	51.6
33	2273.6	630	1456	33.6	0.0	61.3
34	2274.5	157	468	34.6	0.0	65.0
35	2275.4	660	585	35.8	0.0	52.8
36	2276.6	950	914	35.3	0.0	50.1
37	2277.6	729	787	34.5	0.0	53.6
38	2278.6	414	183	32.0	0.0	58.7
39	2279.5	378	383	32.8	0.0	58.2
40	2283.6	747	570	32.8	0.0	63.4
41	2285.5	606	276	29.8	0.0	63.7
42	2288.7	1017	596	32.9	0.0	52.0
43	2290.7	660	760	33.2	0.0	58.1
44	2293.6	534	528	31.3	0.0	63.6
45	2298.5	846	787	34.5	0.0	57.7
46	2302.7	883	815	35.5	0.0	62.8
47	2304.6	998	740	35.8	0.0	57.3

permeabilities in millidarcys. The uncertainties in a and b are the standard deviations of these terms.

It is quite conceivable that a much different relation would be found if cores one to several feet in length were studied. The presence of thin shale lenses or zones of heavy cementation would effectively reduce vertical permeability but would not influence greatly the horizontal permeability.

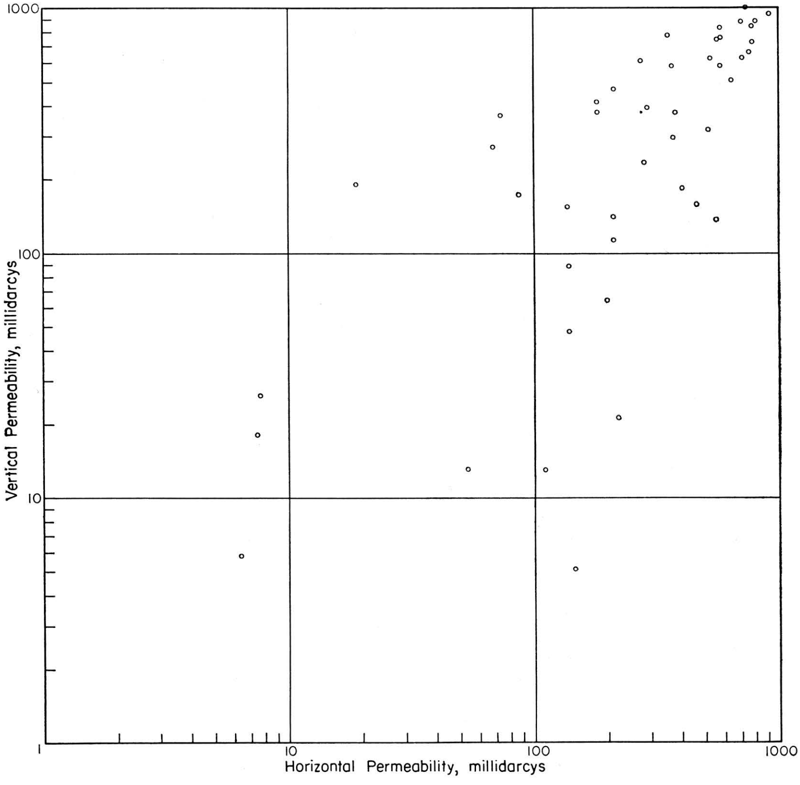

FIG. 13.—Horizontal and vertical permeability of Dakota sands from No. 1 Beaumeister well.

SUMMARY

By Daniel F. Merriam, Paul C. Franks, and Norman Plummer

This well in Cheyenne County is isolated as a result of (1) complex lithologic changes between it and the well-known outcrop area on the east in central Kansas, (2) absence of information in extreme eastern Colorado on the west, (3) poor exposures and lack of detailed studies to the south, and (4) absence of information to the north where these rocks are buried by a cover of younger deposits. Correlation of stratigraphic units with areas where information is available is difficult because of the great distances involved. Certainly much additional work on the Dakota Group, both surface and subsurface, is necessary. It is hoped that this report will serve as a reference for future studies in the area.

Thicknesses.—Thickness of the Pierre Shale is 1,120 feet in the No. 1 Beaumeister well. Regionally the formation is beveled at the top; hence thicknesses may differ radically within short distances. James D. Bishop observed a possible fault zone in the core between 1,040 and 1,060 feet, near the base of the Pierre Shale. Numerous small normal faults have been reported in northwestern Kansas, and where found in the subsurface most of these affect the upper part of the Niobrara Formation or lower part of the Pierre Shale. The Niobrara Formation is 520 feet thick. This thickness is fairly close to what would be expected (Lee and Merriam, 1954, p. 18). The Carlile Shale is 240 feet thick; average thickness in the region is about 200 feet. The Greenhorn Limestone is 85 feet thick and the Graneros Shale 59 feet. A thickness of 274 feet for the Omadi Formation conforms to the regional thickness of the formation as shown in Figure 2A. The same is true for the Kiowa Shale, which is about 111 feet thick (Fig. 2B), and the Cheyenne Sandstone, which is about 170 feet thick (Fig. 2C). Thickness of the Morrison Formation is 305 feet, which agrees with an isopachous map published by Merriam (1955).

Post-Dakota lithologic units.—The post-Dakota stratigraphic units encountered in the No. 1 Beaumeister well are lithologically similar to the same units in other parts of western Kansas. The Pierre, a dark-gray noncalcareous shale containing fragments of *Inoceramus* and other fossil shells, is easily recognized. The Niobrara Formation, which is a mottled gray calcareous shale containing numerous fragments of *Inoceramus,* may be identified with little difficulty in samples. The Fort Hays member of the Niobrara is characterized by white chalky limestone and abundant microfossils, of which *Globigerina* is most common. Many thin light-bluish-gray bentonite beds occur in the Pierre and Niobrara formations. The Carlile Shale and its three members are easily differentiated; the Codell at the top is actually more of a siltstone than a sandstone; the Blue Hill is dark gray, noncalcareous, pyritic, and fossiliferous; and the Fairport at the base is a medium-gray to dark-gray shale mottled white. At the top of the Fairport member is a thin white limestone, which is persistent over much of western Kansas. The Greenhorn Limestone is light gray and hard. The Graneros Shale is dark gray and locally contains abundant *Globigerina*. Bentonite also is prominent in the Carlile, Greenhorn, and Graneros formations, as are *Inoceramus* fragments. A 2-foot bentonite bed cored at a depth of 2,000 to 2,002 feet is thought to be the "Bentonite marker bed" that is easily traced regionally on electric logs.

Dakota lithologic units.—Rocks of the Omadi Formation bear little resemblance to the Dakota Formation, which occupies the stratigraphic interval between the Kiowa and Graneros shales at the outcrop in central Kansas. Glauconite, which is common in sandstone of the Omadi Formation, is sparse or absent in the Dakota Formation. Swineford and Williams (1945, p. 116), however, have reported a zone of calcite-cemented glauconitic sandstone about 50 feet above the base in the Dakota Formation in southwestern Russell County. Well-cemented Dakota sandstone like that described by Swineford (1947) was not observed in the core. Siderite "pellets", which are found extensively on the outcrop of the Dakota Formation, are sparse in the core of the Cruise member of the Omadi Formation.

The mudstone sequence in the Cruise member between depths of 2,190 and 2,234 feet bears some similarity to the Janssen member and to the basal part of the Terra Cotta member of the Dakota Formation. Both the mudstone sequence and the Janssen Clay member contain bedded coaly material near the top (Plummer and Romary, 1942, p. 336); both units are composed of very dark gray mudstone and siltstone near the top; clays from both units fire buff (Plummer and Romary, 1947); both units contain siderite "pellets", although the "pellets" are sparse in the Cruise and abundant in the Dakota; and the kaolinite-illite ratio in the mudstone sequence of the Cruise is somewhat greater than that in the other members of the Omadi For-
posed of very dark gray mudstone and siltstone near the top;
mation just as it is greater in the Janssen Clay. It should be noted, however, that the ratio of kaolinite to illite is much greater in the Janssen Clay member of the Dakota Formation than it is in any

part of the Omadi Formation (Plummer and others, 1954, p. 171-193).

The firing tests allowed easier differentiation of unlike clay-mineral assemblages than did either x-ray diffraction or differential thermal analysis, and accordingly allowed easier differentiation of the mudstone sequence in the Cruise, because the firing operation is much simpler and much faster.

The small number of samples of Cheyenne Sandstone examined in connection with the petrographic, x-ray, and differential thermal studies indicate that the Cheyenne Sandstone cored in the Guy F. Atkinson No. 1 Beaumeister well is similar in gross lithology (except for the clay fraction) to Cheyenne Sandstone from other parts of Kansas (Latta, 1941, p. 70; Swineford and Williams, 1945, p. 121; Nixon, Runnels, and Kulstad, 1950, p. 52). The same also is true of the Graneros and Kiowa Shales (Plummer and Romary, 1942, p. 320-347).

Pre-Dakota lithologic units.—Pre-Dakota rock units in the well are likewise similar in lithology to pre-Dakota units in other parts of western Kansas. The Morrison Formation consists principally of light-green or other pastel shades of soft sandy shale containing various amounts of limestone, sandstone, chert, and anhyrdite. Morrison rocks cored at a depth of 2,800 to 2,827 feet include part of the chert zone described by Ogden (1954) and Merriam (1955). Top of the Permian redbeds is difficult to place exactly, because the upper part of the redbeds sequence commonly is leached so that the rocks appear very light red or darker brown. Shales of these colors are easily confused with the pastel Morrison shales. The leached zone, which probably represents a weathered zone, is about 30 feet thick in the No. 1 Beaumeister well.

Stratigraphic boundaries.—Stratigraphic boundaries of the different post-Dakota and pre-Dakota formations in the No. 1 Beaumeister well are sharp. The Cheyenne-Kiowa and Kiowa-Omadi contacts also are sharp, but differentiation of the members of the Omadi Formation on lithology alone presents a more difficult problem. For example, the mudstone sequence in the Cruise Sandstone member is lithologically more easily recognizable than the Huntsman Shale member, whereas on electric logs the Huntsman is distinct in northwestern Kansas. The electrical characteristics of the Huntsman Shale seemingly are easier to recognize than the lithology of the unit. There seems to be no key or marker bed in the Omadi Formation that can be traced for long-distance correlation.

Only two recognizable breaks occur in the stratigraphic section in the No. 1 Beaumeister well that suggest interruption in sedimentation followed by weathering and perhaps erosion. One of these breaks is that at the top of the Permian redbeds, where the upper part of the sequence seemingly has been leached as in a weathered zone. The other interruption occurs at the top of the Cheyenne Sandstone, where seemingly the formation of montmorillonite-like clay at the expense of illite suggests erosion and weathering prior to deposition of the Kiowa Shale. An interruption in sedimentation is indicated at the Omadi-Graneros contact; lithology changes from predominantly sandstone (Omadi Formation) to mainly shale (Graneros Shale); clay-mineral composition of interbedded shales in the Omadi Formation is different from clay-mineral composition of the Graneros Shale.

Paleontology.—It is unfortunate that none of the fossils found in the Dakota core are diagnostic, index forms. Because the organisms range through the Cretaceous, and even farther than that, they offer no information useful for placement of the Comanchean-Gulfian boundary, which falls somewhere between the Kiowa and Graneros Shales.

Environment of deposition.—Seemingly a larger proportion of the Dakota Group is marine in northwestern Kansas than on the outcrop farther east and south. The Graneros and Kiowa Shales are marine in the subsurface as on the outcrop. The Graneros Shale in the No. 1 Beaumeister contains not only invertebrate fossils (foraminifers, pelecypods, and cephalopods) but an abundance of fish teeth and scales. Spores also are present, but they probably were transported to the sea from relatively nearby land areas. The Kiowa Shale contains fish scales, in addition to brachiopods, pelecypods, and foraminifers.

In south-central Kansas the Cheyenne Sandstone, judged to be of nonmarine origin deposited on or near the strand line of a northward-advancing sea, contains abundant fossil land plants (Latta, 1946, p. 238, 241). In the No. 1 Beaumeister well the present of *Valvulineria,* pelecypods, illite, and glauconite would seem to indicate that in northwestern Kansas at least part of this formation is marine.

No fossils were found in either the Gurley or Huntsman members of the Omadi Formation. Pelecypods, brachiopods, and fish teeth and scales indicate that the Cruise member was deposited at least in part under marine conditions. Illitic clay is generally believed to be formed (or preserved) under marine conditions; hence its relative abundance in the Omadi Formation seemingly would indicate that at least some of these beds are marine. Glauconite, found in the sandstones, is thought to be formed under marine conditions. Spores in the Cruise member probably were transported from adjacent land areas. Although fossil assemblages, abundance of illite, and presence of glauconite and collophane indicate that most beds of the Omadi Formation in the No. 1 Beaumeister well were deposited mainly in marine and perhaps brackish-water environments, it also is possible that some of the rocks may have been deposited under nonmarine conditions. In contrast, the outcropping Dakota rocks are judged to be nonmarine on the basis of the clay mineralogy and the absence of marine fossils (Plummer and Romary, 1947).

Economic possibilities.—A study of the No. 1 Beaumeister well has revealed that Cretaceous rocks in this area are chiefly marine. For the most part the Omadi Formation is a good reservoir rock, as indicated by the extremely high porosity and permeability encountered by the No. 1 Beaumeister well. Although core analyses indicate much water in the Omadi Formation in the well, some oil was noted. The Graneros Shale, as well as the shale in the Omadi itself, affords good cover rock. Structural and stratigraphic conditions seemingly are favorable for the accumulation of oil. Although the Omadi beds occupy a geological setting similar to that of beds that produce commercial quantites of petroleum farther west in Colorado, nevertheless this similarity provides no assurance that commercial quantites of petroleum are present in the Cretaceous rocks of Kansas.

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