Stratigraphy of the Graneros Shale (Upper Cretaceous) in Central Kansas

By Donald E. Hattin

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DONALD E. HATTIN *Indiana University, Bloomington, Indiana*

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ABSTRACT

The Graneros Shale of central Kansas was examined at more than 60 places, fossils were collected wherever possible, and sections were measured in detail at 42 localities. Six complete sections were sampled for laboratory analysis. Thickness of the formation ranges from 23.6 feet to 40.4 feet and averages 30.5 feet for 20 sections including three that are composite. Stratigraphy of the formation and distribution of key macroinvertebrate fossils is depicted in two series of graphic columns, one of which is oriented northeast-southwest, parallel to the outcrop, and the other perpendicular to the first. Marker beds include a thick bentonite lying near the top of the formation throughout the central and northern part of the outcrop and a zone of thin beds and lenses of silty sandstone overlain by bentonite that lies near the middle of the formation in the central part of the outcrop.

The Dakota-Graneros contact generally lies at the top of an evenly bedded ferruginous sandstone unit but elsewhere is transitional through alternating beds of sandy shale, shale, and thin sandstone beds. The Graneros-Greenhorn contact lies at an abrupt change in lithology above which skeletal limestone and chalk predominate.

The Graneros consists mainly of medium dark-gray shale that contains numerous very thin layers, laminae, and lenses of very fine quartz sand or silt. Sand and silt content diminishes irregularly upward in the section. Shale in the upper part of the formation is slightly calcareous at two localities where the rock has been freshly exposed. Chief clay minerals in the shale are kaolinite, illite, and montmorillonite with relative abundance of the later generally greater in the upper part of the formation. Beds of noncalcareous quartzose sandstone containing small quantities of chert, feldspar, rock fragments, mica, glauconite, and heavy minerals characterize the lower part of the formation. These beds are supplanted in the upper part of the formation by calcareous quartzose sandstone which contains widely ranging quantities of shell debris, and skeletal limestone consisting largely of *Inoceramus* prisms and some terrigenous detritus. Coquinoidal limestone and beds containing conspicuous quantities of rounded bone and tooth pebbles are scattered through much of the formation. Layers of bentonite occur in most exposures, but only two can be traced widely with assurance.

Fossils in the Graneros are grouped into two assemblages characterizing the lower and upper parts of the formation respectively. The lower assemblage is characterized by *Callistina lamarensis* (Shumard) and consists of 15 species including 3 brachiopods, 10 pelecypods, 2 gastropods, and 1 scaphopod. Endobenthonic forms are most abundant. The upper assemblage, consisting largely of epibenthonic and nektonic forms, is characterized by *Ostrea beloiti* Logan and comprises at least 8 species, including 3 pelecypods, 2 gastropods, 2 ammonites, and 1 cirriped. The lower assemblage cannot be correlated precisely with the standard sequence of the Western Interior because distinctive species of *Inoceramus* and ammonites are lacking, but it probably represents all or part of the Zone of *Borissiakoceras compressum* or is a local biofacies of the *Plesiacanthoceras amphibolum* Zone. The upper assemblage zone embraces part or all of the *P. amphibolum* Zone and possibly a few feet of younger strata. Absence of *Plesiacanthoceras wyomingense* between Graneros strata containing *P. amphibolum* and Greenhorn strata containing molds presumed to be *Dunveganoceras pondi* supports lithologic and stratigraphic evidence for an unconformity between the two formations. The hiatus may be greater at the southern end of the outcrop where the *C. lamarensis* assemblage occupies nearly all of the formation and the *O. beloiti* assemblage is not represented in the Graneros.

Environmental conditions changed gradually through the time of Graneros deposition in consequence of eastward or northeastward marine transgression, which left the present outcrop area in a progressively farther offshore position with respect to the advancing shoreline. Widening distance to shoreline is reflected in the lesser quantities of quartz sand and silt upward in the Graneros section. Change of salinity from less than normal in the lower part of the formation to normal in the upper part is indicated by distribution of clay minerals, limestone beds, foraminifers, inarticulate brachiopods, and ammonites. Change in water depth during deposition from possibly less than 30 feet initially to a probable maximum of 100 feet ultimately was determined by study of sedimentary structures and foraminifers. Change in bottom conditions from those of rapid deposition and frequent reworking by waves and currents during deposition of the lower part of the formation to relatively slower deposition and less frequent sediment disruption during deposition of the upper part is indicated by abundance and distribution of benthonic macroinvertebrates, burrows, and thin layers, laminae, or lenses of very fine sand and silt.

Graneros sediments are polygenetic. Vertebrate and invertebrate skeletal debris is of local derivation. Montmorillonite probably came mostly from volcanos in the Nevadan orogenic belt. First-cycle detritus including angular quartz, feldspar, rock fragments, and kaolinite is believed to have come from the southern part of the Canadian Shield. Illite, chert, and rounded grains of

quartz and heavy minerals were reworked from an early Paleozoic terrain lying along the eastern edge of the Western Interior Sea. The detrital sediments were transported into central Kansas by one or several streams systems that flowed generally southwestward. The stream systems built a deltaic complex in which submarine topset beds are represented by the upper part of the Dakota and, locally, the lowest part of the Graneros. Foreset beds are best represented in the central part of the outcrop where laminated silty shale in the lower and middle parts of the formation contains conspicuous sandstone beds attributed largely to changes in river discharge, and soft-sediment flow structures which suggest greater sea-floor slope than elsewhere. Strata analogous to bottomset beds are represented by the more sparingly silty and less well laminated shale beds that lie near the top of the formation.

Graneros Shale comprises transgressive phases 2 and 3 of a seven-phase marine cyclothem beginning with the upper part of the Dakota and terminating at the top of the Codell Sandstone Member of the Carlile Shale. For an unknown time interval following deposition of phase 3, the sea floor in central Kansas was an area of non-deposition and sublevation which resulted in the stratigraphic hiatus at the Graneros-Greenhorn contact.

INTRODUCTION

Purpose and Scope of Investigation

Published work pertaining to the Graneros Shale of Kansas consists largely of generalized lithologic descriptions that are scattered through several county reports published by the State Geological Survey of Kansas. Except for studies in Russell County by Rubey and Bass (1925) little of the stratigraphic and almost nothing of the geographic distribution of the fauna has been reported in print. No prior attempt has been made to synthesize field and laboratory data gathered from exposures along the entire outcrop belt.

The present study is based on field investigations made during the summers of 1960 to 1964 and on laboratory analysis of rock samples and fossil collections assembled in the course of the fieldwork. Extensive study of Graneros exposures furnished a primary basis for detailed understanding of lateral and vertical stratigraphic relationships that are depicted graphically in Plate 1 (in pocket). Exhaustive search for macroinvertebrate fossils was made in order to establish paleontological zonation and correlation of the formation. The main objective of this study is interpretation of paleoecology and depositional environment of the Graneros in central Kansas and determination of the significance of the formation with respect to the general sedimentary history of the Western Interior Sea during Late Cretaceous time.

It is hoped that this work will furnish a framework, as well as a stimulus, for future studies, foremost among which might be geochemical studies of paleosalinity and paleotemperature of the Graneros Shale.

Previous Work

Prior to 1897 only casual reference had been made to Kansas rocks now assigned to the Graneros Shale. The earliest definitive description of the unit, then called "the Bituminous Shale Horizon," is that by Logan (1897, p. 216) in which general features such as thickness, color, and structure of the shale are recorded. Logan (1899a, p. 84) expanded this description and correlated the shale with the Graneros of Colorado. The most comprehensive previous description of the Graneros Shale in Kansas is that by Rubey and Bass (1925, p. 51-54) in Russell County. Their work emphasized lithologic and paleontologic characters of the Graneros and such additional information as its manner of exposure and distinguishing features. Other useful descriptions of the Graneros are included in reports on the geology of Ellis and Hamilton counties by Bass (1926) and Ness and Hodgeman counties by Moss (1932). The work of Plummer and Romary (1942) does not treat the formation specifically or in detail but contributes generally to knowledge of Graneros lithology, correlation, and environment of deposition in central Kansas. Among the county groundwater bulletins issued by the State Geological Survey of Kansas in recent years several include brief summaries of Graneros stratigraphy and some include measured sections of the formation. As part of a subsurface study of Mesozoic rocks in western Kansas, Merriam (1957a) published a brief description of the Graneros Shale and indicated subsurface distribution of the formation on several correlation charts. Merriam, *et al.* (1959) described the lithology and fossils of the Graneros Shale in a core from Cheyenne County. The position of the Graneros Shale in the first cycle of late Cretaceous deposition in Kansas has been discussed by Hattin (1962a, 1962b, 1964 [1966]. Previous studies of Graneros fossils are discussed under separate title elsewhere in this report.

Location and Description of Area

Geography.—In central Kansas the Graneros Shale outcrop area trends almost exactly northeastward from the southwestern terminus in Ford County to the Nebraska border in Washington County and occupies parts of thirteen intervening counties (Fig. 1). The outcrop area is approximately 210 miles long and a maximum of about 55 miles wide across Ellsworth and

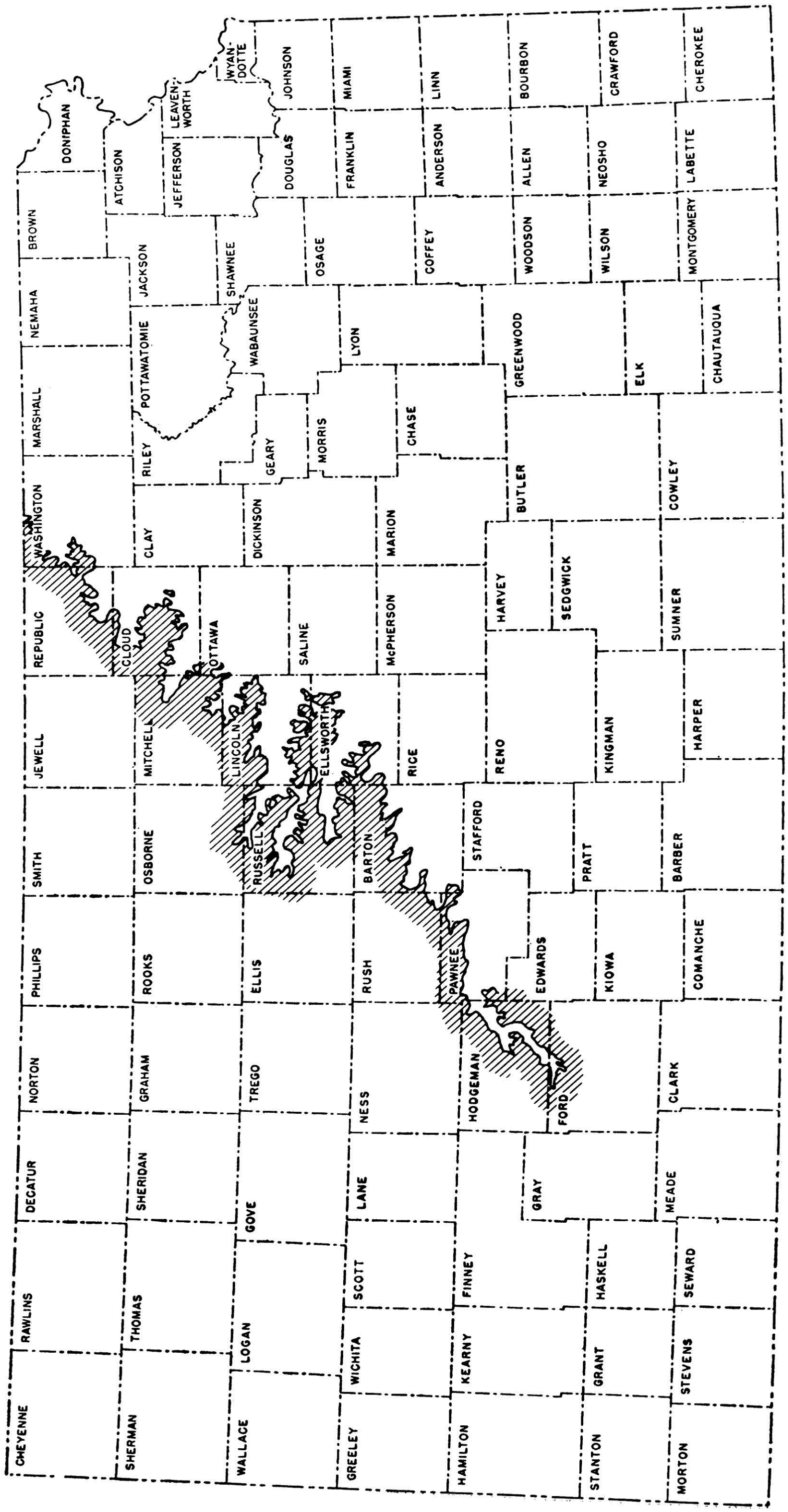

FIGURE 1.—Map showing outcrop of the Graneros Shale in central Kansas.

Russell counties, measured perpendicular to the northeast-southwest trend. Several major streams cross the outcrop, including, from south to north, the Pawnee River, Walnut Creek, the Smoky Hill River, the Saline River, the Solomon River, and the Republican River. Among the best natural Graneros exposures are those along and in tributaries to Sawlog Creek (a southern tributary to Pawnee River), Smoky Hill River (Fig. 2, *A*), and Saline River, especially in bluffs capped by Greenhorn Limestone. Exposures are poor in the northern counties owing to Pleistocene deposits and heavier vegetation and in the area between northern Barton County and central Hodgeman County owing chiefly to relatively gentle terrain.

Interstream areas in the outcrop region are mainly flat to gently rolling uplands (Fig. 2, *B*) largely underlain by Greenhorn Limestone and devoted mostly to the raising of wheat. In contrast, the Graneros outcrop generally forms a relatively steep slope (Fig. 2, *C*) in a narrow belt along valley walls (Fig. 2, *D*) and upland margins, and the land is devoted almost exclusively to pasturage. Oil is produced in eight counties along the central and southern parts of the outcrop, the most notable being Russell, Ellis, and Barton. Several bulletins of the State Geological Survey of Kansas describe ground-water conditions in the counties along the Graneros outcrop belt but the Graneros Shale is not an aquifer.

General Geology.—The Graneros Shale lies at the base of the Colorado Group, which in Kansas is subdivided as follows:

- Colorado Group
  - Niobrara Chalk
    - Smoky Hill Chalk Member
    - Fort Hays Limestone Member
  - Carlile Shale
    - Codell Sandstone Member
    - Blue Hill Shale Member
    - Fairport Chalk Member
  - Greenhorn Limestone
    - Pfeifer Shale Member
    - Jetmore Chalk Member
    - Hartland Shale Member
    - Lincoln Limestone Member
  - Graneros Shale

The Graneros of central Kansas is underlain conformably by the Dakota Formation and is overlain, with demonstrable stratigraphic hiatus, by the Greenhorn Limestone. At the southern end of the outcrop the Graneros is overlain locally by the Ogallala Formation (Pliocene) and in some measured sections along the Smoky Hill and Saline River valleys the Graneros is overlain by Pleistocene terrace alluvium. Pleistocene loess overlies the Graneros in many areas at the northern end of the outcrop.

Regional dip on top of the Dakota Formation in the Graneros outcrop belt is generally northward at approximately 6 to 7 feet per mile (Merriam, 1957b). The configuration of this surface is complicated by anticlinal and synclinal structures that lie within the outcrop belt (Merriam, 1958).

The Graneros outcrop lies mostly in the central part of the Smoky Hills section of the Dissected High Plains between hilly terrain developed on Dakota rocks to the southeast and a low, discontinuous, intricately dissected escarpment held up by Greenhorn rocks to the northwest. Topographic expression of these two features is best developed in areas of greatest relief adjacent to the major streams that cross the area. None of the major east-west highways pass close to high bluffs along the larger streams so the average traveler remains unaware of the considerable relief and extensive rock exposures in and adjacent to the Graneros outcrop. Local relief exceeds 300 feet in northeastern Russell County and much spectacular scenery is the result of stream erosion of Cretaceous strata in this and adjacent counties. Dissection of the Graneros Shale by major streams and their tributaries has produced a highly digitate outcrop, and locally extreme thinning of the outcrop in upstream areas is occasioned by low stream gradients in combination with low dip.

The width of the Graneros outcrop area is generally less than a quarter of a mile but locally exceeds one mile. Outcrop width is controlled almost entirely by topography rather than by changes in dip or stratigraphic thickness. Where local relief is high, as along the Saline River, the Smoky Hill River, and Sawlog Creek, the outcrop is commonly less than 100 feet wide. Except for a few road cuts, exposures in large interstream areas are sparse and incomplete. Few beds in the Graneros are sufficiently resistant to retard erosion but, probably because of small stratigraphic thickness, the formation generally lacks the miniature badlands that are so common in its younger analogue, the Blue Hill Shale.

Procedure

Field study of the Graneros Shale was accomplished during parts of each summer from 1960 to 1964. Exposures were located by means

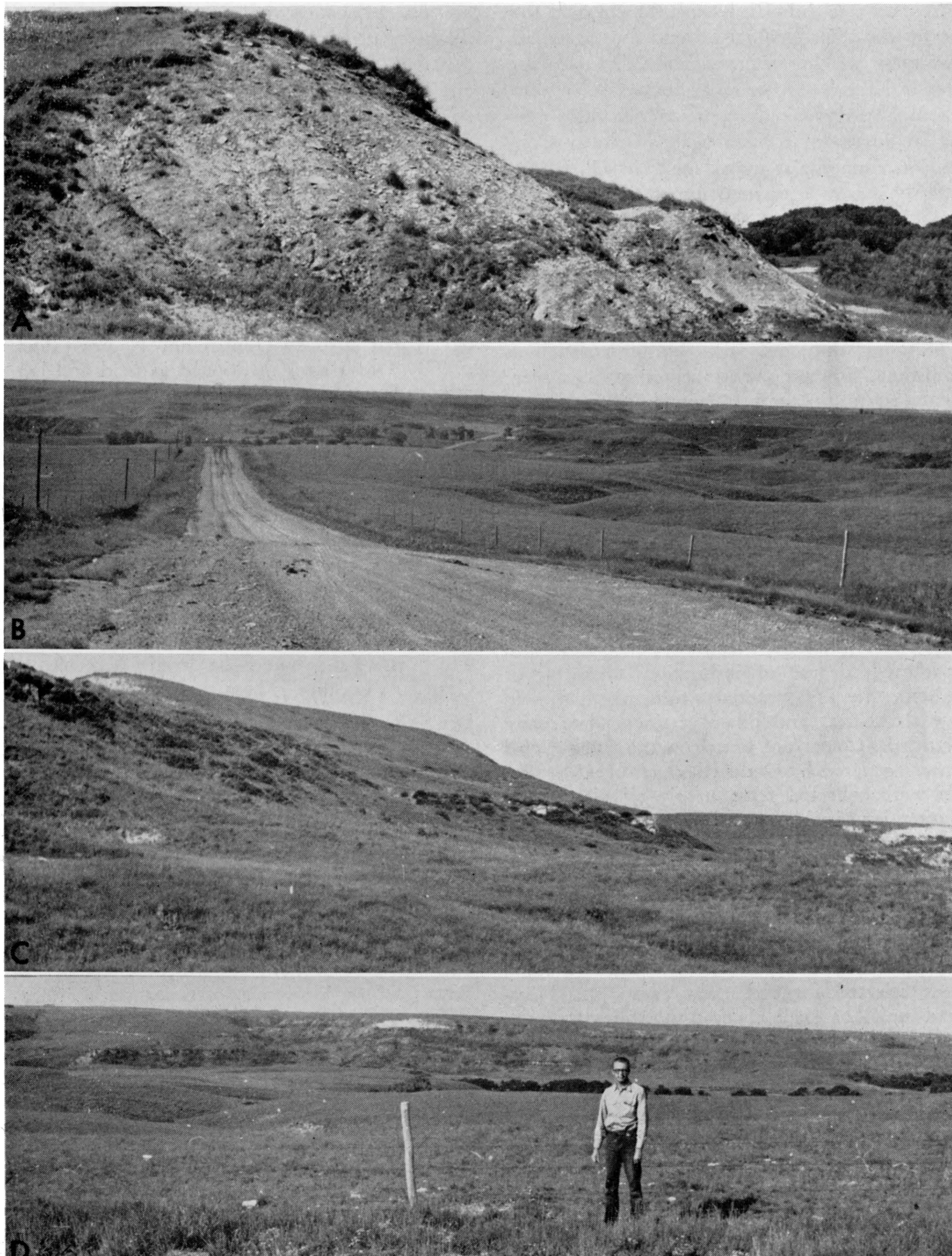

FIGURE 2.—Topographic expression of the Graneros Shale and adjacent formations. *A,* Natural exposure of Graneros Shale on south side of Smoky Hill River, sec. 26, T 15 S, R 16 W, Ellis County (Loc. 21). *B,* View from sec. 36, T 12 S, R 15 W, Russell County, looking southeast across Salt Creek valley toward upland surface developed on Greenhorn Limestone. *C,* Slope (top center) developed on Graneros Shale; Dakota Formation exposed below. View toward west in sec. 1, T 13 S, R 15 W, Russell County. *D,* Dakota, Graneros (covered), and Greenhorn in south wall of Salt Creek Valley. View toward south from sec. 36, T 12 S, R 15 W, Russell County.

of reference to published work, by personal contact with other geologists, and by systematic traversing of the outcrop area. The Geologic Map of Kansas (Moore and Landes, 1937), maps accompanying various reports of the State Geological Survey of Kansas, State Highway Commission county plat maps, maps in U. S. Geological Survey construction-materials circulars, and U. S. Geological Survey topographic maps formed the basis for planning the traverses.

Stratigraphic sections were measured with a hand level and stadia rod or a steel tape. Most measurements were made to the nearest tenth of a foot, but thin and very thin units, such as sandstone, limestone, and bentonite beds were measured to the nearest hundredth of a foot. Each measured section was subdivided into sedimentary units of uniform lithology, limited vertically by changes that are readily detected in the field. The dip and azimuth of directional sedimentary structures were made with a Brunton compass wherever possible. Exposures were ditched with a trench pick as necessary to permit the study of a continuous section of rock.

Each sedimentary unit was described separately, and lithology, thickness, color, fresh and weathered, degree of induration, character of bedding, fossils, secondary minerals, sedimentary structures, and other pertinent data were recorded. Colors are based on the Rock Color Chart prepared by Goddard, *et al.* (1948). Fossils were collected from nearly all places containing identifiable organic remains, but no attempt was made to collect all the material available at each exposure. Fragile specimens were covered with a protective coating of alvar and packaged in tissue paper to insure safe transport. Six key sections, each representing the entire or nearly entire thickness of the formation, were selected for systematic sampling. Measured units of shale, bentonite, and poorly indurated sandstone and siltstone were ditch sampled; hand samples for thin-section study were collected from lithified sandstone and limestone units. Additional hand samples were collected from other localities to insure laboratory study of each kind of rock represented in the formation. Hand specimens of sedimentary structures were collected for further study and for purposes of photography.

In the laboratory, thin sections were cut from samples of sandstone, siltstone, limestone, bone beds, and concretionary structures and point counts were made on thin sections of the more common rock varieties. Photographs were prepared from representative thin sections. Several samples of poorly indurated sandstone were disaggregated and sieved to determine grain-size distribution. Shale samples from key sections and a number of other localities were washed for study of the microfossils. Several shale samples were analyzed chemically for pyrite, gypsum, and organic-carbon content. Clay minerals and quartz content of shale samples from key sections and selected bentonite samples were determined by X-ray diffraction techniques.

The following text contains some descriptive terms that have widely divergent usages, so these terms are explained below. Bedding terminology is that cited by Dunbar and Rogers (1957, p. 97). Grain sizes mentioned in field and laboratory descriptions are based on the Wentworth scale. The term "shale" is used throughout the text for fissile, clayey sedimentary rocks. In addition, it should be noted that color codes are shown in parentheses only after names for which two colors appear in the Rock Color Chart (Goddard, *et al.*, 1948). The sample-identification code used in this report is based on alphabetic designation of age and formation, followed by locality number, followed by alphabetic unit designations lettered from the base upward. Thus KG-1-A should be read "Cretaceous, Graneros, Locality 1, basal unit."

ACKNOWLEDGMENTS

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STRATIGRAPHY

Upper Part of the Dakota Formation

Sandstone beds in the upper part of the Dakota consist mainly of light olive-gray, fine-grained silty sandstone that is composed largely of subangular to subrounded quartz grains. Some of the sandstones are argillaceous, and a few contain thin to very thin layers of silty to finely sandy shale. Nearly all of the sandstones contain carbonized plant fragments. Most of the sandstone beds are poorly cemented and friable, but where extensively weathered they are generally cemented firmly by limonite. High limonite content has colored these weathered rocks dark yellowish-orange, light-brown (5YR 5/6), other shades of brown, and several shades of red and reddish-brown. Although some of the sandstone occurs as thin or very thin beds, most of the units are medium to very thick bedded. Most units are evenly bedded, but some are irregular owing to the presence of clay-ironstone concretions. At some localities sandstone beds are gently cross laminated but ripple marks are very sparse in beds that I have examined.

Shale in the upper part of the Dakota is medium to medium dark-gray, ranges from sandy to only slightly silty, and generally contains thin lenses and laminae of silt or very fine sand. The least silty shales are indistinguishable from shale in the Graneros except for the presence of nodules or layers of clay ironstone as at Locality 3 and near the mouth of Big Creek in southwestern Russell County. Some of these shales contain large, well-formed crystals of selenite. Many shale units in the upper part of the Dakota contain an abundance of carbonaceous matter and some are lignitic.

The most common fossils in uppermost Dakota rocks are carbonized plant remains. Fish scales and bones and worm burrows and castings occur at a few localities and a single *Lingula* was observed at Locality 20. At several localities in Russell and Lincoln counties, sandstone beds lying as much as 20 feet below the top of the Dakota contain assemblages of marine invertebrates preserved as molds or limonitized shells. This fauna includes gastropods, mussels, clams, and oysters, mostly of species not found in the Graneros (Hattin, 1956, p. 87).

The Dakota-Graneros contact is transitional at many localities and differs greatly in aspect within short distances along the outcrop. The nonuniform position of the contact with respect to marker beds reflects the intertongued nature of the two units. In some exposures the uppermost part of the Dakota consists of thick-bedded, and locally clayey, sandstone and in other places consists of thin, evenly bedded layers of sandstone that lie above clayey to sandy, commonly carbonaceous, or, rarely, lignitic shale. Locally the uppermost Dakota beds consist largely of silty shale similar to that in the overlying Graneros; elsewhere the Graneros succeeds dominantly sandy beds in the upper part of the Dakota through several feet of interbedded sandstone, siltstone, and silty shale (Fig. 3, *A, B*). In general the upper part of the Dakota can be distinguished from the Graneros by the predominance of sandstone or carbonaceous shale in the former. Furthermore, where units of thick-bedded sandstone sharply underlie a typical Graneros section, as at Localities 1, 3, 10, 12, and 19, the Dakota-Graneros contact can be determined without difficulty. Where the lithology is gradational or consists of an alternating succession of sandstone and shale beds, the following criteria have been found to be useful in establishing the contact. Sandstones in the uppermost part of the Dakota contain an abundance of carbonized wood fragments and/or ferruginous matter, including clay-ironstone nodules. Molds of sideritic? spherulites are common locally in the uppermost Dakota sandstone beds. Silty shale units in this part of the section, although otherwise like shale in the Graneros, as noted above, contain layers or nodules of clay ironstone composed largely of siderite. The Dakota-Graneros contact was selected as the top of a clay-ironstone concretion zone in transitional shale sequences at Localities 7 and 37, and at the top of a thin sandstone unit containing clay-ironstone nodules or lying just above clay-ironstone-bearing shale at several localities.

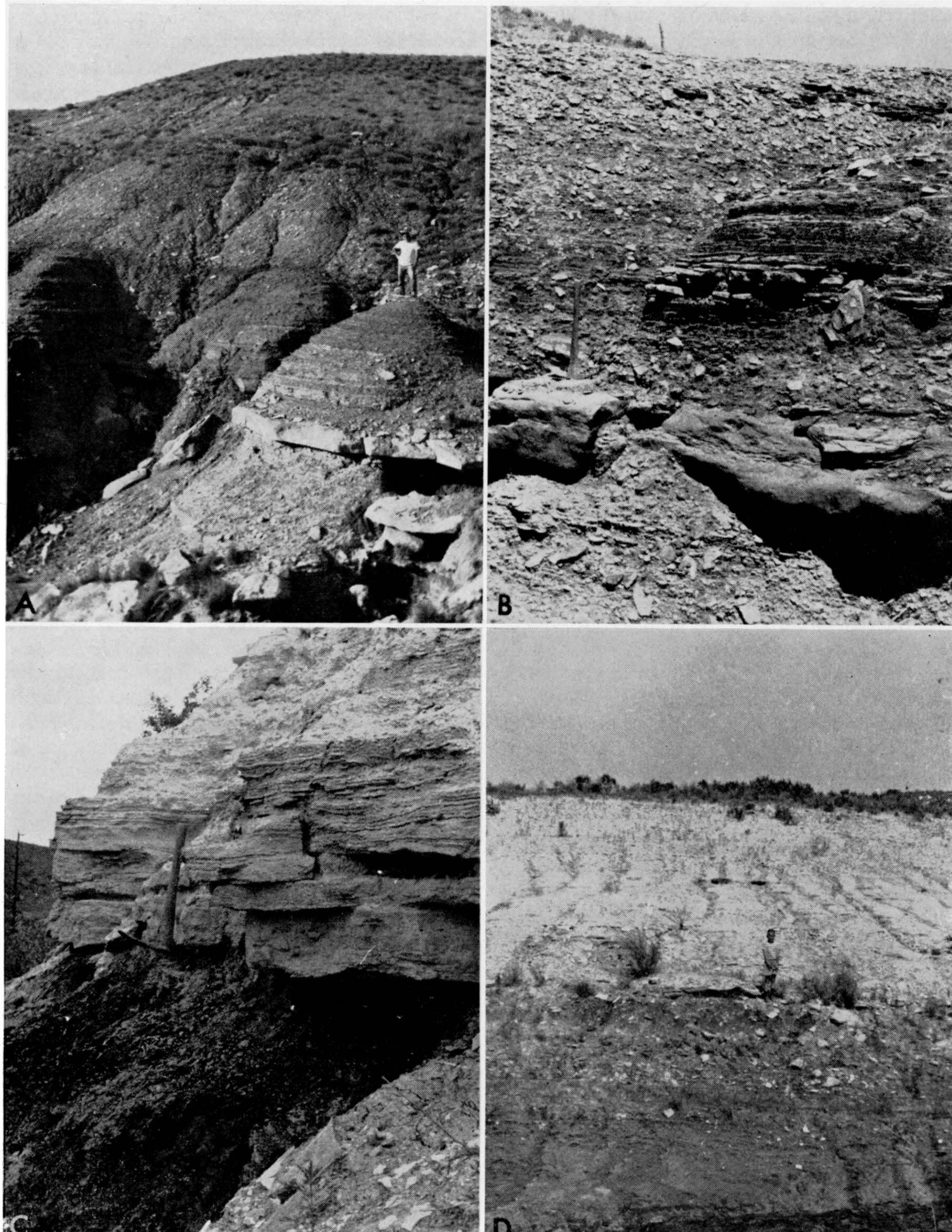


FIGURE 3.—Contacts with adjacent strata. *A*, Dakota-Graneros contact (man's feet) in sec. 24, T 22 S, R 22 W, Hodgeman County. Uppermost part of Dakota consists of interbedded sandstone and silty or sandy shale. Note color change at contact. *B*, Uppermost part of Dakota in sec. 25, T 22 S, R 22 W, Hodgeman County (Loc. 20). Note alternation of sandstone and shale beds above pick head. *C*, Graneros-Greenhorn contact (pick head) in sec. 35, T 12 S, R 14 W, Russell County (Loc. 1). Skeletal limestone at base of Greenhorn contrasts sharply with shale below. *D*, Graneros-Greenhorn contact (boy's feet) in sec. 18, T 13 S, R 12 W, Russell County. Note abrupt change of color and bed of skeletal limestone at base of Greenhorn.

The top of the Dakota is commonly marked by a highly limonitic zone according to Plummer and Romary (1942, p. 345). Such a zone marks the top of the Dakota at many exposures that I studied, especially including those at Localities 1, 2, and 20, but at many places this criterion is not applicable as, for example, at Localities 3, 13, and 19 and at several places where the two formations are gradational. The top of the Dakota is marked by a nodular bed of pyrite 0.3 to 0.4 foot thick at Locality 22.

Lower Part of the Greenhorn Limestone

Strata overlying the Graneros Shale are assigned to the Lincoln Limestone Member of the Greenhorn Limestone. At most exposures in the central Kansas outcrop the basal part of the Lincoln includes beds of hard skeletal limestone (termed *inoceramite* by Hattin, 1962) consisting chiefly of prisms broken from *Inoceramus* valves. Other common constituents are whole and fragmented shells of oysters and *Inoceramus*, sharks' teeth, coprolites, grains of quartz sand and silt, and bentonite pebbles. These limestone beds are commonly cross bedded, with as much as 14 degrees of dip locally, and have a petroliferous odor when freshly broken. Beds above the basal limestone unit include alternating layers of olive-gray to olive-black shaly chalk that weathers yellowish-brown, grayish-orange or dark yellowish-orange, and olive-gray chalky limestone that is usually weathered yellowish-gray, grayish-orange or dark yellowish-orange. The Graneros-Greenhorn contact is easily recognized in weathered exposures by marked upward change in color from gray to mostly pale shades of yellow and orange (Fig. 3, *D*).

The abruptness of contact between mostly noncalcareous shale in the upper part of the Graneros and the limestones in the overlying Lincoln Member is suggestive of a stratigraphic hiatus because the contact at most places separates rocks deposited in a low-energy environment from those of a high-energy environment of deposition (Fig. 3, *C*). At a few localities near the northern and southern ends of the outcrop skeletal limestone is lacking or inconspicuously developed at the base of the Lincoln. At Locality 38, in Washington County, a bentonite marker bed near the top of the Graneros is overlain by 4 feet of shale, the upper 1.8 feet of which is calcareous, olive-black in color, and very much like lower Greenhorn shaly rocks elsewhere. Above these rocks lie 1.8 feet of calcareous shaly beds containing a few very thin lenses of fine-grained skeletal limestone that may be equivalent to the basal Lincoln elsewhere in Kansas. The transitional character of these strata and poor development of skeletal limestone in the basal Greenhorn unit suggest that the hiatus between Graneros and Greenhorn, if indeed there is one here, is apparently of less magnitude than farther to the south. At Locality 44, Cloud County, the bentonite marker bed is overlain by 1.2 feet of calcareous shale containing a few skeletal limestone lenses. The shale is overlain by a half foot of dark yellowish-brown unfossiliferous? calcilutite that is taken as the base of the Greenhorn. The calcilutite is overlain by 5.7 feet of olive-black shaly chalk, the lower 3.0 feet of which contains numerous very thin skeletal limestone lenses with *Inoceramus pictus*, coprolites, and cirriped remains. The shaly chalk is overlain by 4.1 feet of alternating noncalcareous Graneros-like fissile shale and olive-black shaly chalk. The calcareous upper part of the Graneros, lack of a thick skeletal limestone unit in the basal part of the Lincoln, and recurrence in the lower Lincoln beds of Graneros-like shale suggests that the Graneros-Lincoln contact apparently does not represent as great a hiatus as it does farther to the south. From Locality 44 southward to Barton County, Greenhorn carbonates everywhere rest with abrupt stratigraphic contact and marked lithologic contrast upon noncalcareous or locally weakly calcareous and dominantly terrigenous rocks in the upper part of the Graneros, and lie 0.5 to 3.2 feet above the bentonite marker bed. Near the south end of the central Kansas outcrop, skeletal limestone lies at the base of the Lincoln only at Localities 20 and 39. At Localities 23, 24, and 25 a bentonite bed several inches thick lies at the base of the Greenhorn. This bentonite is not correlated with the bentonite marker bed for reasons explained below. At Locality 41 a fossiliferous sandstone bed lying 3.5 feet below the top of the Graneros can be correlated with a sandstone bed lying 16.8 feet below the top of the formation at Locality 20, just 10 miles to the north. Absence of the bentonite marker bed at the southern end of the outcrop and stratigraphic evidence of erosion of the upper part of the Graneros at Locality 41 is evidence that the hiatus at the Graneros-Greenhorn contact is of greater magnitude than it is farther north.

The basal Lincoln beds generally contain abundant specimens of *Inoceramus pictus* Sowerby, which ranges into the overlying Hartland Shale Member of the Greenhorn, molds of a large species of *Dunveganoceras, Ostrea beloiti*

Logan, a small species of *Exogyra*, and rarely, *Exogyra columbella* Meek, and fragments of a hamitid ammonite. At Locality 41, the lower part of the Lincoln contains specimens of *Euomphaloceras alvaradoense* Stephensen and *Plesiacanthoceras wyomingense* (Reagan).

Graneros Shale

NAME AND DEFINITION

The Graneros Shale was named by Gilbert (1896, p. 564) for 200 to 210 feet of argillaceous or clayey shale lying between the top of the Dakota and the base of the overlying Greenhorn Limestone. The type locality is Graneros Creek, a southwestern tributary of Greenhorn Creek, approximately 20 miles north of Walsenburg, Colorado. According to Bass, *et al.* (1947), Gilbert included in the upper part of the Graneros some calcareous strata more appropriately assignable to the Lincoln and Hartland Members of the Greenhorn. Thus, in the Model Anticline southwest of La Junta, Colorado, the Graneros is 153 feet thick by original definition but only 105 feet thick if the upper calcareous beds are included in the Greenhorn (Bass, *et al.*, 1947). The revised, and more logical, definition was accepted by McLaughlin (1954, p. 111) for Baca County, Colorado, but not by Baldwin and Muehlberger (1959, p. 59) or Wood, *et al.* (1953) for northeastern New Mexico. The difficulty arises because the lower Greenhorn is less limy west and southwest of Kansas, and in southeastern Colorado and northeastern New Mexico it contains only a few widely separated thin limestone beds. In Kansas, the Graneros comprises mostly noncalcareous strata that lie between the Dakota Formation, below, and the limestone and impure shaly chalk of the Lincoln Limestone Member of the Greenhorn, above. Because of transitional beds between the Dakota and Graneros the contact between the two is commonly difficult to ascertain, but the well-cemented skeletal limestone that nearly everywhere marks the base of the Lincoln Member is a generally reliable guide to the top of the Graneros. My definition of the Graneros in Kansas corresponds to the usage of Bass, *et al.* (1947) and McLaughlin (1954).

Northward from Kansas, the term "Graneros" is applied generally to beds lying between the Dakota and Greenhorn formations but what has been commonly called "Dakota" in the Black Hills and Williston Basin areas is actually the top of the Lower Cretaceous Inyan Kara Group (Gries, 1954). In the Black Hills, Darton (1904, p. 391) included in the Graneros beds that are now called (ascending) Skull Creek Shale, Newcastle Sandstone, Mowry Shale, and Belle Fourche Shale. Some geologists still follow this practice. In the subsurface of eastern Wyoming, western South Dakota, and western North Dakota these formations are included in the Graneros Group by many geologists. However, Hansen (1955) abandoned the term Graneros in the North Dakota subsurface and Haun (1958, p. 86) did not see the necessity for retaining the name Graneros for these strata in the surface and subsurface areas of the southwestern Black Hills. Gries (1954, p. 447) has shown that the Newcastle Sandstone is probably a western tongue of the type Dakota; thus, the homotaxial equivalents of the Graneros in the Black Hills appear to be the Mowry and Belle Fourche shales. The former is siliceous, the latter clayey.

According to Waage (1955, p. 41) the Newcastle Sandstone is the lithologic equivalent of the upper sandstone of the South Platte Formation of the northern Colorado Front Range foothills, and the upper South Platte is the lithologic equivalent of the upper part of the Dakota in the Graneros type area. Wherever the Benton has been divided along the Front Range foothills in Colorado, the Graneros, Greenhorn, and Carlile are recognized. Thus in the area embraced by the Black Hills, the eastern South Dakota outcrop, the Kansas outcrop, the south-central Colorado outcrop, and the Front Range foothills, the Graneros might logically be defined as the body of shale that lies between the Dakota below, including major tongues thereof, and the Greenhorn above. However, the Mowry Shale, which is included in this body of shale, is lithologically unlike the Graneros of the type area and no useful purpose would be served by including the Mowry and Belle Fourche in a restricted "Graneros Group" unless it be for emphasis of homotaxial relationships. The lithologic equivalent of the Graneros in the Black Hills and surrounding areas is the Belle Fourche Shale. Considerable similarity exists between these two formations, and, if the name Graneros is to be perpetuated in the Black Hills region, it would be best used to replace the name Belle Fourche over which the former has priority.

HISTORY OF NOMENCLATURE

The earliest complete classification of Cretaceous strata in the Western Interior Region is that by Hall and Meek (1856, p. 405) who divided the Missouri River section of Nebraska into units numbered one through five from the base upward. Geographic names based on places of typical exposure were published subsequently by Meek and Hayden (1861, p. 419) in a comprehensive tabulation that included lithologic and paleontologic descriptions and thicknesses for each of the five units. The name "Fort Benton Group" was introduced for the beds of unit No. 2, now called, in ascending order, Graneros, Greenhorn, and Carlile. Later, Hayden (1876, p. 45) coined the term "Colorado Group" for No. 2 (Fort Benton), No. 3 (Niobrara), and No. 4 (Pierre) of Hall and Meek's Nebraska section. The Colorado Group was restricted by White (1878, p. 21) to units No. 2 and No. 3 and has remained thus defined to the present. The name "Benton" has fallen into general disuse in most areas where that part of the section is divided into formations. In Kansas the term "Benton Group" had formal status at least until 1920 (Moore, p. 83). The name "Benton Shale" or "Benton Formation" is used today in parts of central and north-central Colorado, southeastern Wyoming, northwestern Iowa, and southwestern Minnesota where Graneros, Greenhorn, and Carlile subdivisions are not differentiated.

In Kansas the Benton Group remained undivided until 1896 when Cragin (p. 49, 50) proposed the name "Russell Formation" for beds equivalent to the Graneros Shale, the Greenhorn Limestone, and the Fairport Member of the Carlile Shale, and the name "Victoria clays" for strata equivalent to the upper part of the Carlile. In contrast to Cragin's classification is that of Logan (1897, p. 215) who recognized in the Benton a lower limestone group and an upper shale group. Logan's lower limestone group included the Graneros and Greenhorn formations of the modern classification. Shale in the basal 20 to 40 feet of the limestone group was called "Bituminous Shale Horizon" by Logan (1897, p. 216).

The name "Graneros Shale" was proposed by Gilbert (1896, p. 564) for the lowermost of three lithologic subdivisions of the Benton Group along the Arkansas River in eastern Colorado. Logan (1899a, p. 84) recognized that the Graneros was the stratigraphic equivalent of his Bituminous shale, but the name Graneros was not used formally in Kansas until 1904 (Darton, pl. 36). Since that time the only addition to nomenclature of the Graneros in Kansas is the informal designation "bentonite marker bed" (Merriam, 1957a) for a thick bentonite that lies near the top of the formation in most of central Kansas.

DISTRIBUTION AND THICKNESS

The central Kansas outcrop of the Graneros Shale extends from Washington County in the northeast to northern Ford County in the southwest (Fig. 1). In this area the Graneros ranges in thickness from a minimum of 23.6 feet at Locality 9 to a maximum of 40.4 feet in a composite section based on exposures at Localities 32 and 40, and averages 30.5 feet for 20 measured sections including three that are composite. Additionally, a few exposures are known in Hamilton and Kearny counties, near the western border of the State, where Bass (1926, p. 36) reported a composite thickness of 61 feet. Merriam (1957a) has traced the Graneros throughout the subsurface of western Kansas and gave 100 feet as the approximate maximum thickness of the formation in Kansas. Regional distribution of the Graneros Shale and nomenclature of units into which the formation passes laterally are shown in Figure 4. Unless otherwise noted, thickness figures given in the succeeding paragraphs are for rocks that are lithologically equivalent to the Graneros, insofar as such equivalence could be determined in the cited literature.

In southeastern Colorado the Graneros thickens from 86 feet in Baca County (McLaughlin, 1954, p. 112), to 105 feet on the Model Anticline (Bass, *et al.*, 1947), to 136 feet in the Chandler Syncline (Mann, 1958, p. 158). Clair (1955, p. 34) reported 100 to 150 feet of Graneros in the subsurface of the western flank of the Denver Basin, and Scott (1963) measured 210 feet of Graneros equivalent in the Kassler quadrangle, Colorado. Thicknesses of 200 to 220 feet are cited for exposures of the Graneros throughout the Arkansas River Valley at Colorado Springs and near Walsenburg and Trinidad, Colorado, by Dane, *et al.* (1937, p. 210), but from their brief lithologic descriptions it is apparent that these figures are for the Graneros as originally defined and thus include some beds that are better referred to the Greenhorn Limestone.

The Graneros Shale crops out extensively in the northeastern part of New Mexico where exposures on the east side of the Sangre de Cristo Mountains extend as far to the south as Las Vegas. The formation thickens southwestward from 86 feet in Baca County, Colorado, to 160 feet in Colfax County, New Mexico (Griggs, 1948, p. 25), and to 215 feet in a well 3.5 miles northwest of Las Vegas, New Mexico (Griggs and Hendrickson, 1951, p. 30). Near Ocate, a few miles north of Las Vegas, Bachman (1953) measured 395 feet of Graneros Shale, but he admits the possibility of error owing to the nonuniform dip of strata. In the area west of the Sangre de Cristo Mountains, Rankin (1944) traced the Graneros Shale into the San Juan Basin and as far to the southwest as Socorro, New Mexico, at a time when the Graneros, Greenhorn, and Carlile equivalents were known only as a part of the Mancos Shale. The term Graneros is now widely used in the San Juan Basin. Beds assigned to the Graneros by Rankin (1944) range in thickness from 60 feet in the northwestern part of New Mexico to a maximum of 350 feet west of Albuquerque, but these thicknesses include some strata assignable to the Greenhorn, according to Cobban (written communication, 1964). In most of the sections measured by Rankin, a bentonite bed 0.5 to 0.6 inch thick lies approximately 1.5 feet below the top of the formation.

Northward from Kansas the Graneros is recognized throughout much of Nebraska and South Dakota, in the northwestern part of Iowa, and in western Minnesota. On the east bank of the Big Sioux River in Plymouth County, Iowa,

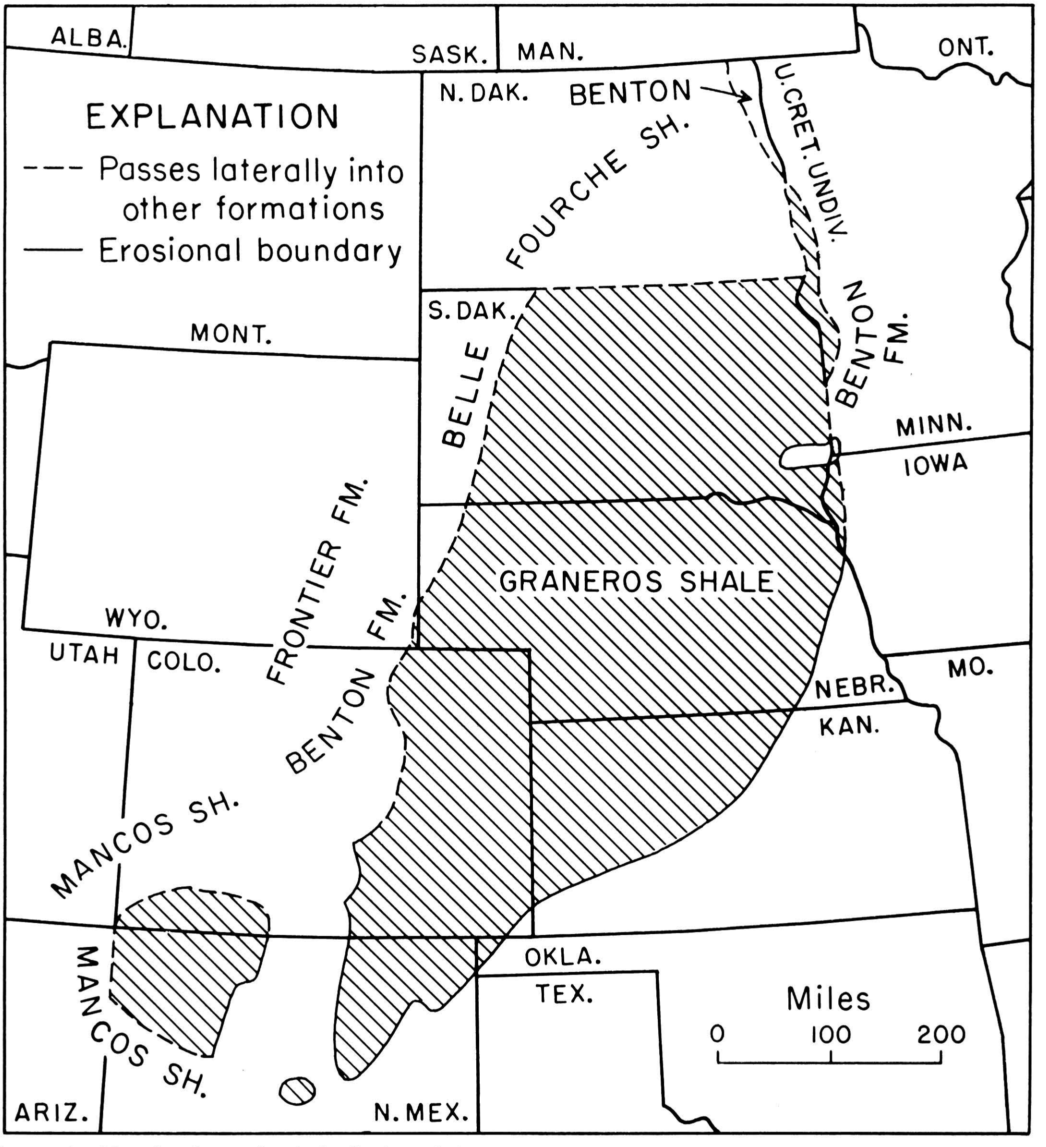


FIGURE 4.—Map showing regional distribution of the Graneros Shale and nomenclature of laterally contiguous units.

I have measured a section in which the Graneros is 34.7 feet thick. According to Condra and Reed (1959, p. 18) the Graneros is 60 to 70 feet thick in northeastern Nebraska,[1] 40 to 90 feet thick in the Republican River Valley of south-central Nebraska, and thickens to 550 to 700 feet or more in northwestern Nebraska and 900 feet in exposures around the Black Hills. In the latter two areas the thicknesses are for the combined Mowry and Belle Fourche shales but, as noted above, only the Belle Fourche is lithologically equivalent to the Graneros. In the northern part of the Julesburg Basin in Nebraska, where local facies changes complicate the stratigraphy, a shale unit that is the approximate equivalent of the Belle Fourche is about 300 feet thick as shown by McCrae (1956), and in the eastern and southeastern parts of the Powder River Basin the Belle Fourche Shale ranges in thickness from 270 to 480 feet (Haun, 1958, p. 86). At the type locality in Crook County, Wyoming, the Belle Fourche is 560 feet thick (Collier, 1923, p. 83). Fuenning (1942) noted that the Graneros Shale is missing locally over the Chadron Arch in northwestern Nebraska. Contacts picked by Fuenning apparently do not coincide with those by geologists of the State Geological Survey of Kansas because he reported 299 feet of Graneros in a well in Decatur County, Kansas, in an area where, according to Merriam (1957a, p. 13), the formation has a nearly uniform thickness of 40 feet.

In South Dakota the Graneros thickens generally from east to west. In the southeastern part of the State the formation ranges in thickness from 30 to 200 feet (Barkley, 1952, p. 13) and in the northeastern part from 200 to 300 feet (Erickson, 1954). In western South Dakota, the term "Graneros" is commonly used in the sense of Darton (1904) but, as noted above, only the Belle Fourche Shale may be regarded as the lithologic equivalent of the Graneros in Kansas. The Belle Fourche is 401 feet thick near Rapid City (Condra and Reed, 1959, p. 20), is 490 feet thick locally in the southwesternmost part of South Dakota (Baker, 1948, p. 72), and is as much as 510 feet thick in Harding County in the northwesternmost part of South Dakota (Baker, 1952, p. 18).

In North Dakota, where the term "Belle Fourche" is used for the lithologic equivalent of the Graneros of Kansas, Hansen (1955) recorded a thickness ranging from 100 feet in the eastern part of the State to 450 feet on the west side. In the Williston Basin, along the eastern edge of Montana, the Belle Fourche ranges from 80 to 370 feet in thickness (Billings Geol. Soc., 1961).

SILTY SHALE[2]

The predominant lithology of the Graneros is noncalcareous shale that ranges from very slightly silty to finely sandy. Most commonly the shale is moderately silty. In a fresh cut in the overflow spillway at Wilson Dam (Loc. 43) the upper 15.6 feet of Graneros shale are only slightly calcareous and partially preserved shell material is abundant in two shale zones. At Locality 15, in a continuously and actively eroding exposure, the upper 5.5 feet of the Graneros are also slightly calcareous. At four other localities (Loc. 1, 6, 26, 44) the upper 0.15 to 1.2 feet of shale is slightly calcareous or even somewhat chalky. Where dug from trenches fresh shale breaks into irregular and rather tough blocks that usually split easily along obscure laminae. During initial stages of weathering the shale breaks into innumerable small flakes that characterize almost every Graneros exposure. At some localities, notably 7, 17, and 18, shale in the upper part of the formation weathers into large papery sheets. The shale is soft and plastic when thoroughly wet, but it is brittle when dry. Fresh shale is most commonly of medium dark-gray color. Less than half as common are dark-gray and medium-gray colors, and only about one-fourth as common are shales of olive-gray (5Y4/1, 5Y3/1) color. At a few exposures other shades of gray, olive-gray, and black were noted. The dominant colors of partially weathered shale flakes are, in order of importance, medium light-gray, olive-gray, medium-gray, light olive-gray (5Y6/1), medium olive-gray, and medium brownish-gray. Highly weathered shale is generally pale, moderate, or dark yellowish-brown, dusky yellow, or dark yellowish-orange with none of these colors predominating. In some exposures, partially weathered shale units are mottled, owing to oxidation of organic constituents.

Most shale units in the Graneros contain numerous layers or lenses of coarse terrigenous silt or fine and very fine sand (Fig. 5, *A*, *B*). These bodies range in thickness from thin laminae to thin beds that are commonly thinly laminated. The thinnest lenses and laminae are generally the most fine-grained and serve to en-

[1] My own observations lead me to conclude that this figure is nearly double the minimum thickness in this area.

[2] The term "shale" is used throughout this report for fissile, clayey, sedimentary rocks.

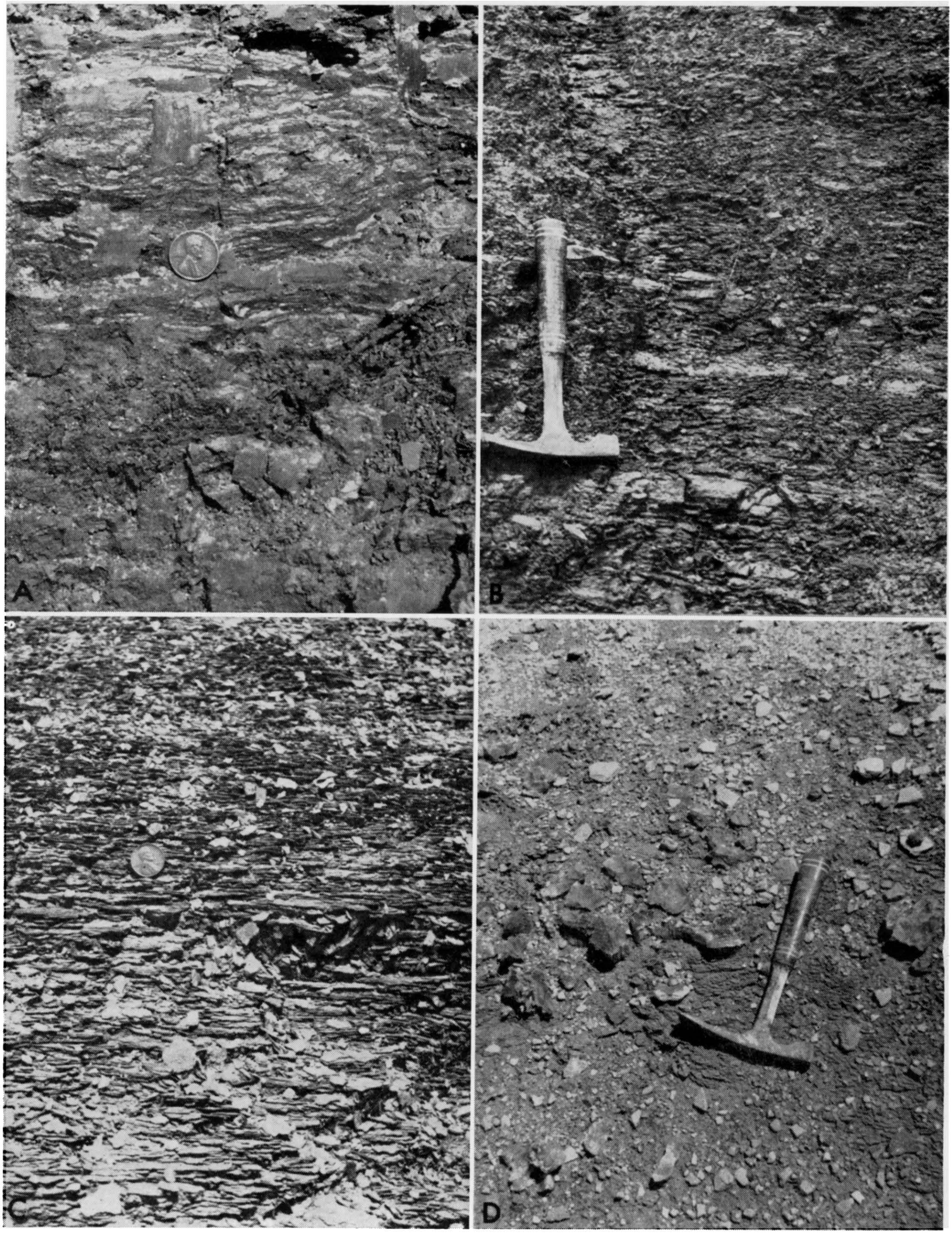


FIGURE 5.—Features of silty shale in the Graneros Shale. *A*, Silty shale containing numerous lenses and laminae of quartz silt; lower part of formation in sec. 13, T 12 S, R 15 W, Russell County (Loc. 13). *B*, Lenses of silty sandstone in silty shale in lower part of formation in sec. 29, T 15 S, R 10 W, Ellsworth County (Loc. 18). *C*, Silty shale in upper part of formation in sec. 29, T 15 S, R 10 W, Ellsworth County (Loc. 18). Note flaky weathering and lack of sandstone or siltstone beds. *D*, Large mass of selenite in lower part of formation in sec. 25, T 22 S, R 22 W, Hodgeman County (Loc. 20).

hance the fissile bedding of the shale. Although shale near the top of the Graneros is locally as sandy as shale near the base, the higher shales contain fewer laminae, lenses, and beds of fine sandstone than do those in the lower part of the section (Fig. 5, *C*).

Nearly all units of gray shale contain carbonaceous matter that ranges in size from specks less than a millimeter in width to chunks large enough to be identified as carbonized wood, the former being the most common. A majority of shale units contain gypsum either in finely granular, almost powdery form, or as isolated euhedra or platy aggregates of sparry selenite (Fig. 5, *D*). The gypsum lies along joints and bedding planes, the latter being most usual. Some euhedral crystals are several inches in length and aggregates of crystals are commonly a foot across, but small selenite crystals, a millimeter or two in length, or rosettes of small crystals, are most common. These minute crystals, where lying parallel to the bedding, also serve to enhance bedding fissility. At many exposures weathered slopes of the Graneros are aglitter with sunlight reflected from selenite crystals.

At six localities in the lower few feet of the formation, the shale contains pyrite as small oblate spheroidal nodules nowhere more than an inch in diameter or as minute crystals disseminated throughout the rock. At Locality 28 the basal shale unit is marcasitic. In the lower part of the formation and sparsely in the upper part, melanterite was detected by taste in many shale units. This mineral has probably resulted from the oxidation of marcasite or pyrite and is too fine to be detected with a lens. Seven samples of fresh shale from the lower part of the Graneros, and one sample of weakly calcareous shale from the upper part, were selected for partial chemical analysis in order to determine the relative abundance of pyrite, gypsum, and organic carbon in these rocks. The results, in percentage of the total sample, are tabulated below. The two samples poorest in organic carbon are also poorest in amount of pyrite and gypsum, suggesting a genetic relationship among these three substances. Graneros shale is usually stained along joints and bedding by a yellow-colored substance rich in iron that has been identified as jarosite by X-ray methods. Here and there this mineral also occurs in very thin layers lying parallel to general stratification. Less abundant volumetrically, but nearly as widespread, is limonite, which likewise stains both bedding and joint surfaces. These two minerals are further evidence of the iron sulfide content of the rock before oxidation.

TABLE 1.—Partial chemical analyses of shale samples from the Graneros Shale.

Locality	Unit	Pyrite*	Gypsum*	Organic carbon
KG-1†	H	0.007	0.15	0.50
KG-1	K	0.77	0.97	4.66
KG-1	L	0.82	3.54	2.22
KG-23	F	0.11	0.40	1.74
KG-23	M	0.36	1.34	1.34
KG-24	B	0.026	0.04	0.45
KG-30	F	1.72	6.01	1.22
KG-43‡	J	7.65	1.0	6.85

* Calculation based on assumption of no organic sulphur.
† Numbers are localities given in Appendix.
‡ Calcareous shale from upper part of formation.

Oblate spheroidal nodules of pure crystalline alunite lie in shale near the top of the Graneros at Locality 8 and rest just below a thick bed of bentonite that is characteristic of the upper part of the formation. The alunite is nearly white, cryptocrystalline, and brittle. Similar nodules were observed in a shale unit that lies about 15 feet below the top of the Graneros at Locality 32, and also on a weathered shale slope at the top of the section that is exposed at Locality 30.

Shale samples from four key sections were analyzed for major clay mineral constituents.[3] The results of these analyses are summarized stratigraphically in Table 2. The illite content remains nearly uniform throughout the section, including samples from the Dakota. Through the same stratigraphic interval, kaolinite decreases upward as montmorillonite increases. Despite the clayey nature of the Graneros shale, quartz is the dominant mineral in 17 of 24 units for which the clay-nonclay ratio was determined. Clay and quartz are of approximately equal abundance in two additional samples. Much of the quartz is apparently of the finer silt and perhaps even clay sizes, which cannot be differentiated in the field.

Despite a seeming paucity of fossils in the formation, more than half of all the shale units examined in detail yielded macrofossils, and in many beds fossils are abundant on some bedding planes. Except at Locality 43, where much shelly material remains, most macroinvertebrate specimens are represented by molds both in shales and in silty laminae within shale units. However, at Localities 1, 5, 8, 18, 32, 36, 43, and 46, specimens of *Ostrea* are preserved as shell material, and a single large *Inoceramus* at Locality 1 is composed of calcite. Many fossils in the upper part of the Graneros at Locality 43

[3] Some of the clay reported as montmorillonite may be thoroughly degraded three-layered clay minerals (John B. Droste, oral communication, November, 1964).

TABLE 2.—Diagrammatic tabulation of kaolinite-illite-montmorillonite (K:I:M) in shale units in four key sections, expressed as parts in ten of total clay content. (Not to scale.)

	Loc.16	K:I:M	Loc.1	K:I:M	Loc.20	K:I:M	Loc.23	K:I:M
GREENHORN FORMATION								
UPPER PART OF GRANEROS SHALE*			KG-1-T	2:2:6				
	Bentonite marker bed							
	KG-16-F	2:3:5	KG-1-P	2:4:4				
					KG-20-P	6:2:2		
LOWER PART OF GRANEROS SHALE			KG-1-N	3:2:5			KG-23-R	3:4:3
	KG-16-D	3:4:3	KG-1-M	2:4:4	KG-20-K	2:4:4	KG-23-P	3:3:4
							KG-23-O	4:3:3
			KG-1-L	2:2:6	KG-20-I	4:3:3	KG-23-N	6:3:1
							KG-23-M	4:3:3
			KG-1-J	2:4:4				
					KG-20-H	4:5:1	KG-23-K	5:3:2
							KG-23-H	4:5:1
			KG-1-I	2:2:6				
							KG-23-F	5:2:3
					KG-20-G	5:3:2		
			KG-1-H	3:4:3			KG-23-D	5:4:1
DAKOTA FORMATION	KG-16-A	5:3:2					KG-23-C	6:4:0
					KG-20-E	5:4:1		
			KG-1-C	3:3:4				
					KG-20-C	6:3:1		
			KG-1-A	6:3:1				
					KG-20-A	4:4:2		

* Upper part of Graneros not preserved in southernmost part of outcrop.

are pyritized, and gypsum-replaced oysters were observed at Localities 1, 36, and 38. Chitinous valves of inarticulate brachiopods are preserved at Localities 3, 13, and 37. Worm?trails were recorded at Locality 24 and a few silt- or very fine sand-filled burrows 1 to 3 mm in diameter are preserved in shale at Localities 6, 7, 25, 28, 32, 36, and 37. The most widely distributed fossils are fish remains, especially scales, which are the only fossils observed in some shale units.

NONCALCAREOUS SANDSTONE AND SILTSTONE

Noncalcareous sandstone consisting of quartz grains in the fine to very fine sand sizes is conspicuous in nearly all Graneros exposures and siltstone occurs in a few measured sections. In the northern part of the central Kansas outcrop such rocks occur through a widely ranging thickness in the lower part of the formation. Except for Locality 44, where sandstone is lacking, beds of noncalcareous sandstone are restricted to as little as the lower 9.0 feet of the formation at Locality 9 where the Graneros is 23.6 feet thick to as much as 25.7 feet of the formation at Locality 6 where the Graneros is 32.8 feet thick. Noncalcareous sandstone is uncommon in the higher parts of the Graneros section that contain beds of calcareous sandstone and skeletal limestone. In the southern part of the outcrop, where the upper part of the Graneros was eroded before Greenhorn deposition began, sandstone beds distributed unevenly through each of the several measured sections are characteristically noncalcareous.

Although much Graneros sand and silt occur as laminae or very thin beds and lenses scattered through shale units (Fig. 5, *A*, *B*), numerous sandstone and siltstone bodies are sufficiently distinct to be described individually. The range in thickness for such bodies is 0.05 to 8.9 feet, averaging 0.79 foot for 70 measurements. The predominating colors of fresh rock, in order of importance, are light olive-gray, 5Y6/1 being three times as common as 5Y5/2, yellowish-gray (5Y7/2), and various other shades of gray and olive-gray. Weathered rock is most commonly dark yellowish-orange, followed by yellowish-gray (5Y7/2), light brown (5YR5/6), dusky yellow, moderate yellowish-brown and several other colors of minor importance including shades of brown, red, yellow, and orange. Bedding is nearly everywhere thin to very thin, but beds of medium thickness were recorded at 4 localities, and at one place (Loc. 31) a single thick bed was measured. Thin to very thin lenses of sandstone or siltstone are present in 10 sections, nine of which contain lenses composed of a distinctive variety of very fine, silty sandstone or sandy siltstone that is described in some detail below. Laminae and thin laminae of sandstone are of minor importance. Cross lamination is common in noncalcareous sandstone; dips commonly are gentle, but locally are as great as 26 degrees (Fig. 6, *A*). Very fine silty sandstone of the kind alluded to above occurs here and there in the lower part of the Graneros from Russell County to Ford County, Kansas, and in the upper part of the formation at Locality 17. The sandstone occurs mostly as zones of lenses that project from the slope and commonly weather so as to produce platy float (Fig. 6, *B*). One zone of such lenses is widely traceable in Russell County. This variety of rock is light olive-gray (5Y6/1) to yellowish-gray (5Y8/1) and is colored yellow by jarosite. The lenses are thinly laminated to gently cross laminated and are interpreted as starved current ripples. Large numbers of long, slender worm castings about one-half millimeter in diameter are peculiar to lenses of this lithology at Localities 5, 14, and 17, and other varieties of ichnofossils are common (Fig. 7, *A-D*).

Cementation of sandstone and siltstone bodies is most commonly poor and the rock soft and friable; in a few exposures the rock can be described as noncemented. Only three-fifths as common are exposures of sandstone or siltstone that is fairly well cemented, and some of this is also friable. Well-cemented rock was observed in only one-sixth of the exposures of sandstone or siltstone beds studied. Cement, where present, is mostly limonite or jarosite, but in a few places it consists largely of sparry gypsum. Clayey matrix is the binding agent in some of the sandstone, 18 occurrences of argillaceous sandstone being recorded at 14 localities. Interbeds or laminae of shale are commonly scattered through sandstone and siltstone bodies. Despite the relative softness of noncalcareous sandstones and siltstones in a majority of exposures, most units are sufficiently resistant to erosion to form projecting ledges on weathered slopes. Primary inorganic sedimentary structures other than those mentioned above include 10 occurrences of ripple marks (three oscillation, one interference, two current, four indeterminate), eight occurrences of starved current ripples, all in very fine silty sandstone or sandy siltstone, two occurrences of groove casts, two of load casts, four of subaqueous plastic flow structure (Fig. 6, *C*), and two of indeterminate sole markings.

In addition to quartz, minerals identified in the field include glauconite, limonite, jarosite, gypsum, and rare muscovite and heavy minerals. Because of its fine grain size, glauconite was identified in only seven exposures of noncalcareous sandstone or siltstone beds, but among 16 thin sections, was recorded in 10 additional places indicating much wider distribution than is apparent in the field. In nearly half of all exposures of sandstone and siltstone beds examined, the rock ranges from more or less stained by to tightly cemented by limonite. In a few exposures, such units, in addition to the silty sandstone already described, are jarosite stained, and here and there limonite and jarosite occur together. In well over half of all studied exposures these rocks are variously stained or ce-

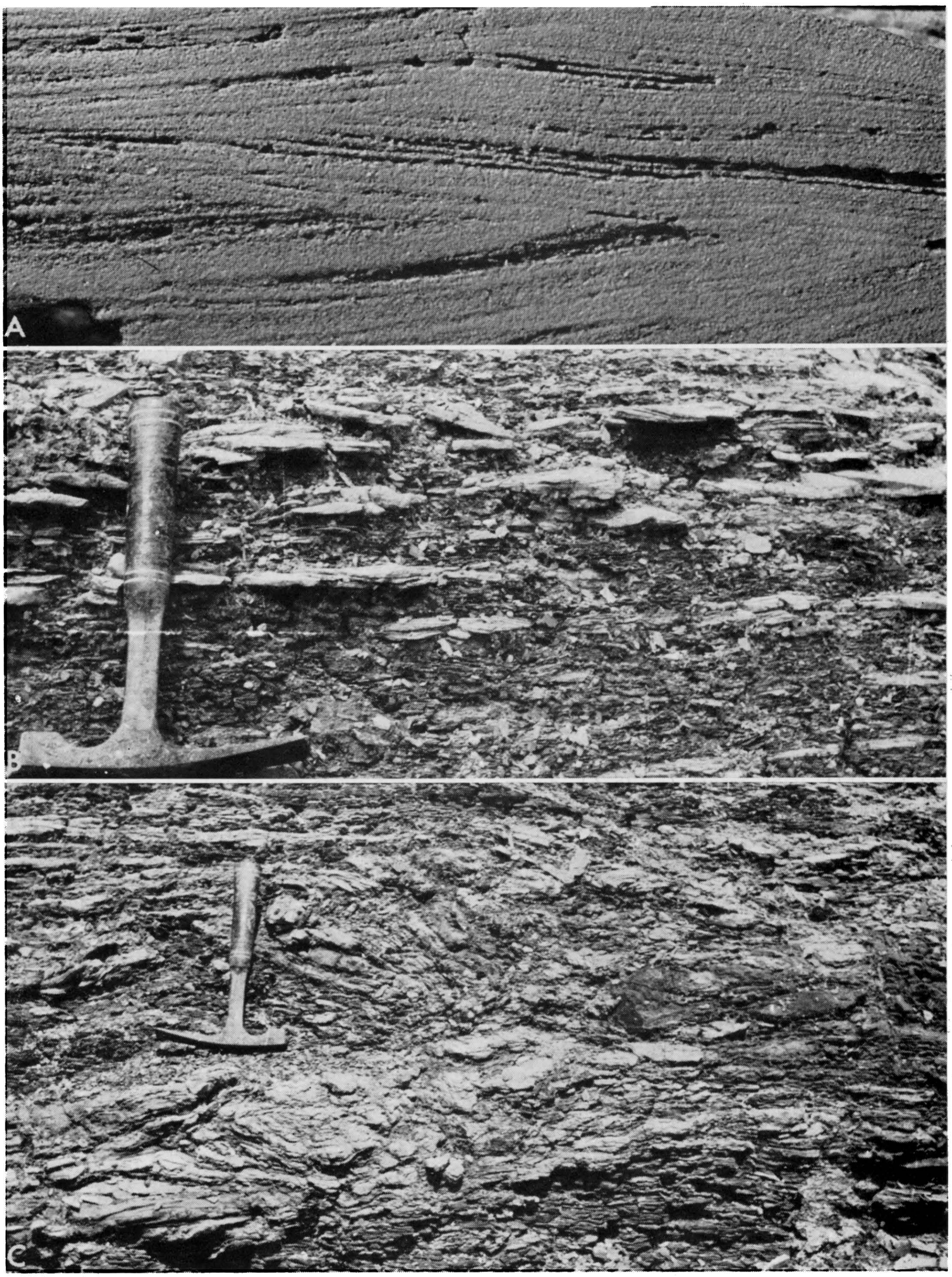


FIGURE 6.—Features of noncalcareous sandstone in the Graneros Shale. *A*, Cross laminations in sandstone from near base of formation in sec. 35, T 12 S, R 14 W, Russell County (Loc. 1), ×2. *B*, Lenses of jarositic silty sandstone near middle of Graneros in sec. 19, T 15 S, R 15 W, Russell County (Loc. 5). These are probably starved current ripples. *C*, Plastic flow structure in sandstone near middle of formation in sec. 7, T 13 S, R 14 W, Russell County (Loc. 6).

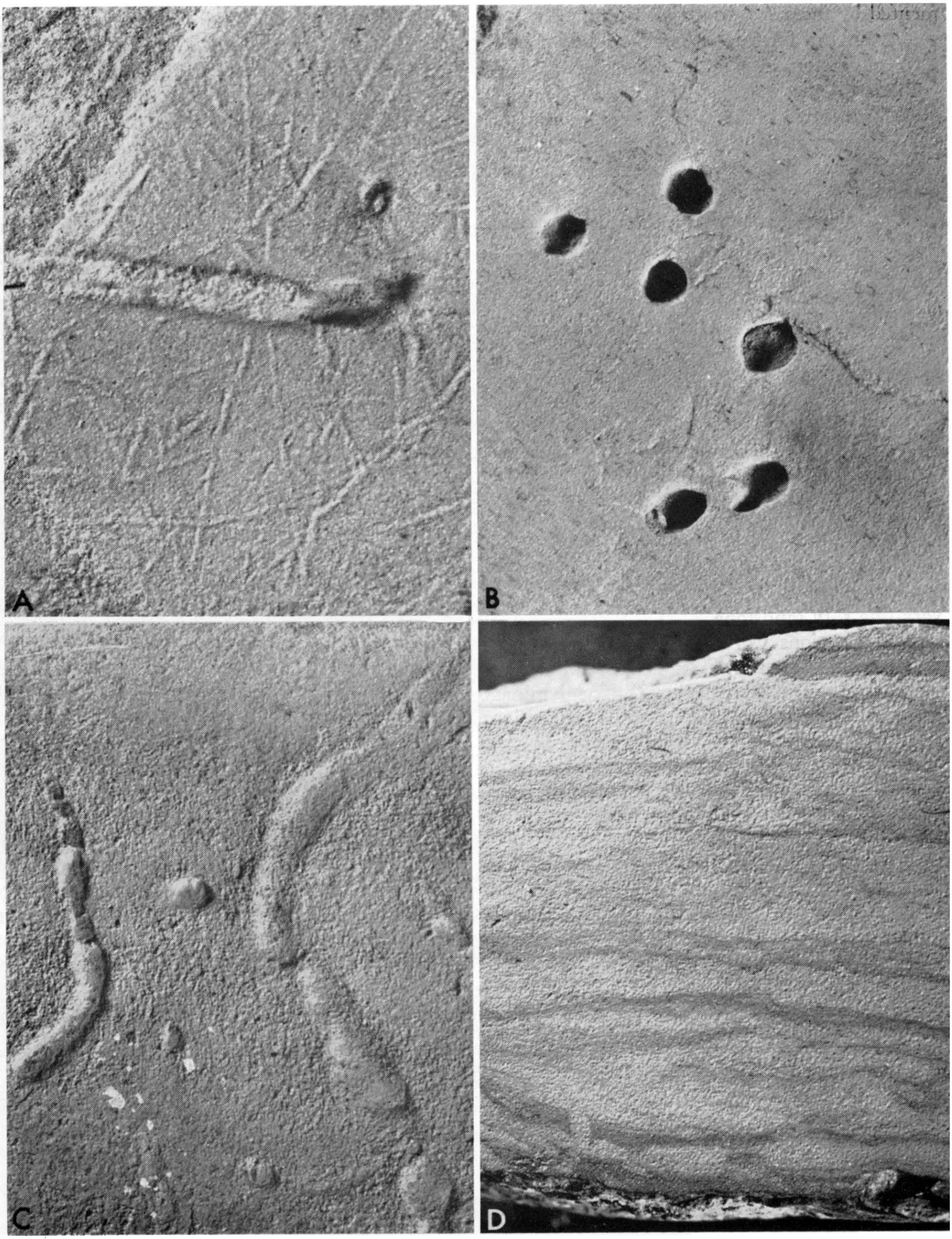


FIGURE 7.—Ichnofossils in noncalcareous sandstone of the Graneros Shale. *A*, Worm castings in jarositic silty sandstone from near middle of Graneros in sec. 19, T 15 S, R 15 W, Russell County (Loc. 5), ×2. *B*, Worm burrows (*Arenicolites*) in jarositic silty sandstone from near top of Graneros section exposed in sec. 11, T 24 S, R 23 W, Hodgeman County (Loc. 25), ×2. *C*, Worm? castings in jarositic silty sandstone near middle of Graneros in sec. 19, T 15 S, R 15 W, Russell County (Loc. 5), ×2. *D*, Endobenthonically disturbed laminae in argillaceous siltstone from lower part of Graneros in sec. 10, T 25 S, R 23 W, Ford County (Loc. 23), ×1½.

mented by these two iron compounds. Gypsum, mostly in the form of selenite crystals up to a few millimeters in length, was observed in 13 percent of the exposures of sandstone units. Very fine flakes of muscovite were observed at only two localities in the field and a concentration of heavy minerals was noted at only one locality.

Carbonaceous material in the form of minute specks requiring hand-lens identification, larger coarse sand- and granule-sized flakes of carbonized organic matter readily distinguished by the unaided eye, or small pebble-sized plant scraps and chunks of wood were recorded in nearly half of all exposures of noncalcareous sandstone.

Size analysis by sieving was accomplished for six noncalcareous sandstone and two siltstone samples, the selection of which was controlled largely by freshness of the rock and paucity of cement (Table 3). Five additional samples collected at or near the top of the Dakota were sieved for comparison. The results are given in percentages for Wentworth size classes. Except for siltstone samples, all the samples are fine to very fine silty sandstone.

Thin sections were cut from 12 samples of noncalcareous quartzose sandstone and four of sandy quartzose siltstone (Fig. 8). The dominant grain size is very fine sand in eight thin sections and fine sand in four thin sections. No observed quartz grains are larger than medium sand, and silt was sparse in only two sandstone thin sections. Coarse silt dominates the siltstone thin sections (Fig. 8, *A*), the remaining grains being mostly of very fine sand size. Grain shape in all thin sections shows a wide range from angular to rounded or well rounded, with the modal shape falling generally in the subrounded category.

Postdepositional modification of quartz grains commonly renders determination of original grain shape difficult. In most thin sections the rock is well packed; the grain arrangement and relatively large number of contacts per grain are in large measure the result of intrastratal solution. Quartz-grain margins in eight of the 12 sandstone thin sections are notched or pitted owing to the effects of solution and in all but two sandstone and siltstone thin sections, many quartz grains are tightly nestled together because of solution. In several thin sections, pyrite, limonite, or a thin film of highly birefringent material (possibly jarosite) surrounds or appears to invade quartz grains along notched or crenulated contacts that suggest replacement phenomena. Sutured quartz-grain contacts were observed in only two sandstone thin sections.

The dominant constituent in all 16 thin sections is quartz which, together with chert, makes up more than 95 percent of the land-derived detritus in the rocks. In the classification of McBride (1963, p. 667), the sandstones would be called "quartzarenites" and the siltstones, by extension of this classification, "quartzsiltites." Undulatory extinction was observed in a few grains in most of the slides and polycrystalline quartz is common in most of the thin sections. Chert was identified in about half of the slides, and sparingly in each of these. Feldspar was identified in all but one thin section and includes, in one slide or another, orthoclase, microcline, perthite, and plagioclase. Rare grains of heavy minerals, including tourmaline, zircon, and leucoxene, were identified in most slides but, except for leucoxene, each mineral is generally represented by less than a half dozen grains per slide. Muscovite and/or biotite were detected in about half of the

TABLE 3.—Sieve analyses of sandstone and siltstone samples from the Graneros Shale and the Dakota Formation. Fractions are given as percent of total.

Sample	Coarse sand 1.0-0.5mm	Medium sand 0.5-0.25mm	Fine sand 0.25-0.125mm	Very fine sand 0.125-0.062mm	Silt and clay <0.062mm
KG-1-E*	0.22	3.49	71.65	9.03	15.61
KG-1-G*	0.29	0.88	19.94	34.95	43.94
KG-1-K	–	–	0.59	48.17	51.24
KG-2-J	–	3.27	73.25	15.50	7.98
KG-2-K	–	2.69	62.57	22.79	11 95
KG-8-G	–	0.08	0.38	65.67	33.85
KG-8-I	–	0.20	2.23	22.19	75.38
KG-12-A*	0.1	0.82	31.53	36.33	21.22
KG-16-E	0.20	1.08	28.64	43.50	26.58
KG-20-B*	–	7.75	78.28	8.8	5.17
KG-20-J	0.60	0.92	25.71	37.79	34.98
KG-23-C*	–	0.92	22.39	32.00	44.69
KG-27-D	–	0.36	54.10	32.06	13.48

* Samples collected at or near the top of the Dakota Formation.

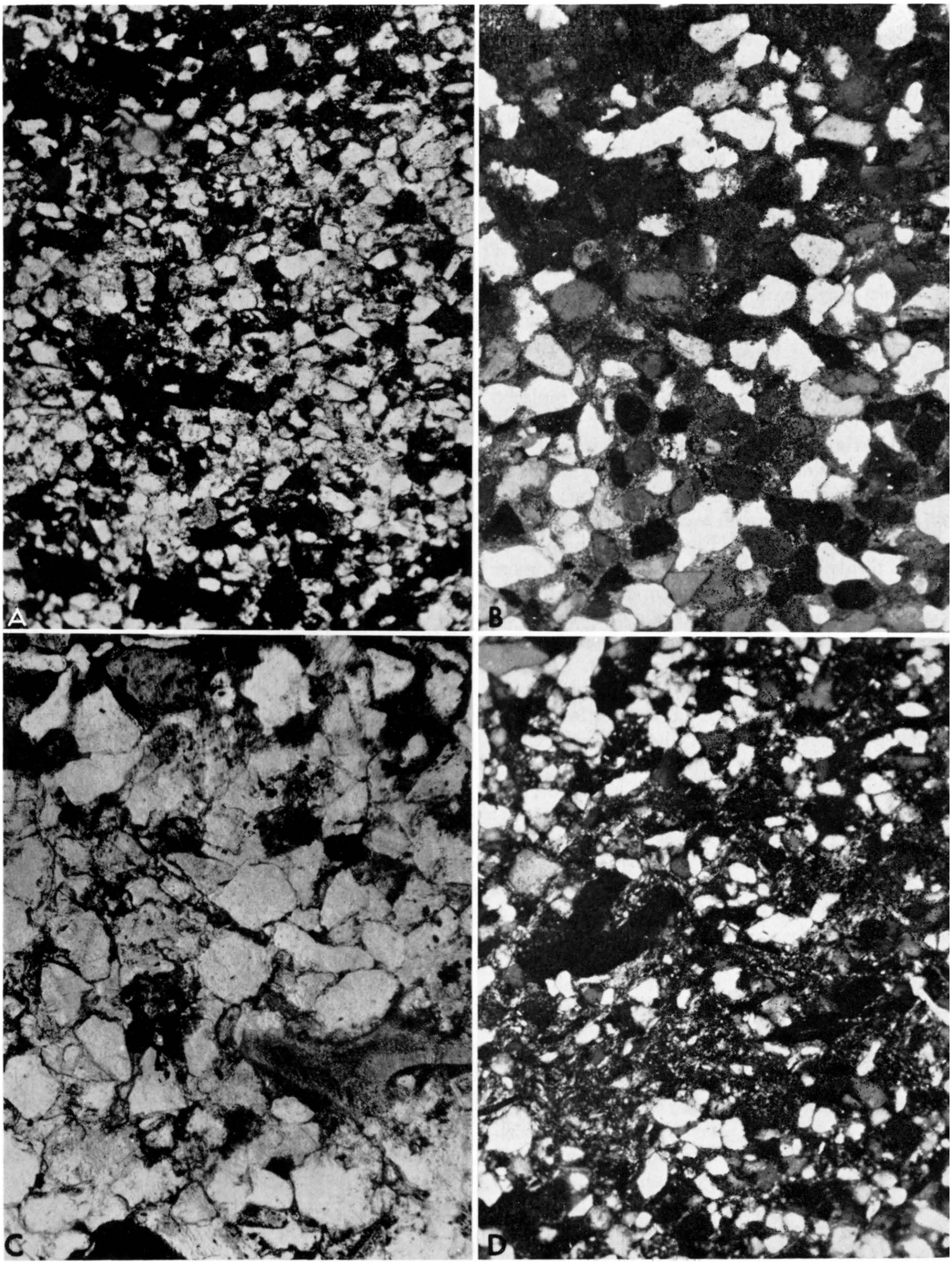


FIGURE 8.—Photomicrographs of thin sections of noncalcareous sandstone and siltstone. *A,* Siltstone from upper part of Graneros at Locality 8. Dark areas are limonite. Plane-polarized light, ×75. *B,* Jarosite-cemented silty sandstone from near middle of Graneros at Locality 5. Crossed nicols, ×75. *C,* Gypsum-cemented sandstone from lower part of Graneros at Locality 1. Note bone fragment (gray) in lower right. Plane-polarized light, ×75. *D,* Argillaceous siltstone from lower part of Graneros at Locality 23. Original clay laminae disturbed by burrowing organisms. Crossed nicols, ×75.

thin sections, but these minerals are not common constituents of the rocks. Rock fragments were identified in some sections, but are rare. Glauconite, generally as rounded to well-rounded pellets, but in some slides also as irregular (crushed?) grains, was noted in 13 of the thin sections. Few of these pellets contain evidence of shrinkage cracks. The glauconite is mostly bright green under plane-polarized light. Compatibility of grain size with that of surrounding grains and rarity of desiccation cracks suggest that this may be allocthonous glauconite. Organic grains in the thin sections are nearly all fragmentary remains of fish bones and teeth that are clear to amber colored under plane-polarized light and that are commonly filled or replaced by pyrite or its oxide, reddish-brown limonite. Bits of carbonized plant debris and, in one thin section, possible coprolites are the only other organic remains recognized in thin section.

Cement in these thin sections consists mostly of limonite or jarosite (Fig. 8, *B*), which coats grains thinly or locally fills interstices in some slides. Some of the cement identified as limonite may be limonitic clay. Sparry gypsum is a cementing agent in two thin sections from Locality 1 and one from Locality 3 (Fig. 8, *C*). Siliceous cement is scattered sparingly through one dominantly limonite-cemented thin section from Locality 20. Organically disturbed, irregular laminae of clay aid in binding siltstone in two thin sections (Fig. 8, *D*).

Point-count analyses, based on 200 points per slide, were prepared for 10 sandstone thin sections; these data are listed in Table 4.

Animal remains or traces were observed in noncalcareous sandstone and siltstone exposures at approximately three-fourths of the localities containing such rocks. These fossils, listed according to decreasing number of localities at which each was observed, include fish remains, *Callistina*, *Exogyra*, worm? castings, *Inoceramus* and *Discinisca*, vertical sand- or silt-filled burrows and *Ostrea*, *Lingula*, and *Parmicorbula?*. Except for fish remains, *Callistina* at Locality 5, *Ostrea* at Locality 18, and *Discinisca* at Localities 3 and 20, all these fossils are represented by molds. Discounting fragmentary fish remains, *Callistina*, occurring at more than half of these localities, is most abundant and characteristic of the fossils. In sandstone beds at six localities scattered across the entire outcrop, molds of this clam are so abundant as to be in contact with one another. *Exogyra* is generally sparse, but occurs with *Callistina* in eight of the nine recorded localities. More than 100 brachial valves of *Discinisca* were collected at Locality 3, but this genus is rare elsewhere. The remaining macroinvertebrate forms are uncommon and of scattered occurrence. *Lingula* was recorded only at Localities 28 (in sandstone) and 23 (in siltstone); *Ostrea* was identified in noncalcareous sandstone at Localities 18, 43, and 46, where it occurs sparsely in association with *Callistina*.

CALCAREOUS SANDSTONE[4] AND SILTSTONE

Beds of calcareous sandstone and siltstone lie in the middle part of the Graneros Shale at many localities, particularly in the Saline and Smoky Hill River areas. At Localities 7, 21, and 37, such beds occur as low in the formation as 4.7, 5.0, and 2.5 feet above the base, respectively. At Locality 9 calcareous sandstone lenses lie within the uppermost foot of the formation but at all but one other locality such rocks lie more than 5.6 feet below the top of the Graneros. The fresh rock is most commonly light olive-gray (5Y6/1) or medium-gray, less commonly medium-dark gray or darker shades of olive-gray (5Y5/1-5Y4/1). The color of partly weathered rock is light olive-gray (5Y5/2) and locally dark yellowish-orange, moderate yellowish-brown, or medium yellowish-brown. Well weathered calcareous sandstone is mostly dark yellowish-orange, much less commonly moderate yellowish-brown or light brown (5YR5/6) and locally grayish-orange or yellowish-gray. Individual measured units of calcareous sandstone and siltstone range from 0.1 (Loc. 9) to 3.1 (Loc. 7) feet in thickness, averaging 0.73 foot for 30 measurements. Such beds are relatively resistant, usually projecting prominently from weathered slopes. The rocks range from poorly to tightly cemented, depending in part upon degree of weathering and in part upon degree of original cementation, thus some are soft and friable, others hard and brittle. The latter condition is more common. Calcareous sandstone and siltstone units are mostly thin to very thin bedded but medium beds were measured at two exposures (Locs. 2 and 5). Among 30 described units, 20 are thinly laminated and 19 of these are gently cross laminated and locally cross bedded with a dip as great as 18 degrees (Fig. 9, *A*).

Ripple marks were observed in calcareous sandstone at Localities 5, 7, 21, 36, and 46 (Fig. 9, *B*). Subaqueous plastic flow structure was re-

[4] Calcareous rocks containing 50 percent or more sand-sized terrigenous detritus when deposited.

TABLE 4.—Analyses of quartzose sandstone thin sections, based on a count of 200 points.

Sample	Quartz	Polycrystalline quartz	Chert	Glauconite	Feldspar	Muscovite	Biotite	Tourmaline	Zircon	Leucoxene	Bone	Organic matter	Limonite	Cement			Other constit- uents
														Limonite	Jarosite	Gypsum	
KG-31-C	94.0	0.5	–	P	–	–	–	P	–	–	2.5	1.5	–	–	1.0	–	0.5
KG-16-E	91.5	0.5	P	P	P	P	–	P	P	1.0	P	–	0.5	0.5	6.0	–	–
KG-20-N	71.0	P	P	1.0	P	–	P	P	P	1.0	2.0	–	1.5	23.0	–	–	0.5
KG-20-N*	91.5	0.5	0.5	1.5	0.5	–	P	P	P	1.0	2.0	–	2.0	–	–	–	0.5
KG-14-B	90.0	1.0	–	P	0.5	–	–	P	P	P	2.5	1.0	0.5	4.5	–	–	–
KG-27-D	89.0	3.0	0.5	–	1.5	P	–	–	–	P	–	–	0.5	–	5.0	–	P
KG-40-M	82.5	2.0	1.5	6.5	0.5	P	P	P	–	2.0	–	–	P	–	3.5	–	1.0
KG-5-I	79.5	2.0	2.0	0.5	P	–	–	0.5	–	–	0.5	–	–	–	14.0	–	1.0
KG-1-M	79.0	1.0	0.5	4.0	P	P	P	P	P	2.5	0.5	0.5	–	1.5	4.5	1.5	4.5
KG-1-I	63.5	0.5	–	–	0.5	0.5	–	–	–	1.5	3.0	1.5	5.0†	12.0	–	12.5	1.0
KG-8-G	61.0	4.5	1.0	10.5	1.0	–	–	P	P	1.5	–	–	0.5	16.5	3.0	–	0.5
KG-8-G*	75.0	4.5	1.0	11.5	1.0	–	–	P	P	1.5	–	–	0.5	–	4.0	–	1.0

* 200 points not including limonitic cement.
† Includes 2.0% pyrite that has not been oxidized to limonite.
P=Present.

FIGURE 9.—Features of calcareous sandstone in the Graneros Shale. *A*, Cross-bedded sandstone from bed near middle of formation in sec. 19, T 15 S, R 15 W, Russell County (Loc. 5). *B*, Oscillation ripple marks from bed near middle of formation in sec. 20, T 15 S, R 15 W, Russell County (Loc. 5). *C*, Tool-mark casts on underside of sandstone slab from bed near middle of Graneros in sec. 26, T 15 S, R 16 W, Ellis County (Loc. 21). (Same unit as *A* and *B*.) Scale is one-cent coin. *D*, Worm burrows in sandstone from upper part of Graneros in sec. 20, T 15 S, R 15 W, Russell County (Loc. 5), ×1¼.

corded in two units at Locality 5 and in one unit at Locality 39, and sole marks including load casts and casts of tool marks (Fig. 9, *C*) were recorded at Localities 9, 21, 39, and 43. Other structures in these rocks include worm castings, worm burrows, arthropod trackways (Fig. 9, *D*; 10, *A*), concretions and nodules, but none of these are common except for the ichnofossils which occur in calcareous siltstone at Localities 5 and 43.

Fossils were observed in most exposures of calcareous sandstone, the most common remains being fish teeth, bones, and scales. *Ostrea*, usually preserved as original shell material, was recorded in calcareous sandstone at 13 of the 22 exposures containing this rock. Next, in order of wideness of distribution, are *Inoceramus*, as shell scraps and/or isolated prisms or prism molds, *Callistina*, and *Exogyra*. The last two, preserved as both molds and shell material, have not been observed in association with *Ostrea*. A single *Discinisca* was collected at Locality 39 from calcareous sandstone containing *Callistina* and *Exogyra*. Small fragments and specks of carbonized plant debris were noted locally in these rocks. *Arenicolites* is abundant in one bed of calcareous siltstone lying 12.9 feet above the base of the Graneros at Locality 5 (Fig. 9, *D*).

All of the calcareous sandstones were classed in the field as fine- to very fine-grained sandstone. Some beds are notably silty, a few are argillaceous, and others contain thin laminae of silty shale. Bedded calcareous siltstone occurs at Locality 5, as noted above, and lenses of calcareous siltstone lie 12.6 feet above the base of the Graneros at Locality 43. Fresh calcareous sandstone has a petroliferous odor at a few localities; weathered rock is commonly selenitic.

Ten thin sections were cut from nine representative samples classed as calcareous sandstone (Fig. 11). In all but one of these thin sections the dominant size of quartz grains is very fine; all contain some coarse silt and fine sand. Shape of quartz sand grains ranges from angular to well rounded in all thin sections, with subrounded being the most common shape. Packing ranges widely also, depending in part upon degree of intrastratal solution, which increases the number of contacts per grain. The usual number of contacts per grain in these thin sections is 1 or 2, but in a single section one can observe a range from 0 to 5 contacts per grain. Contacts of quartz against quartz are commonly embayed or nestled so as to suggest solution along mutual surfaces but no suturing is evident.

Calcareous cement ranges widely in kind from a scattering of microspar that effects only a weak cementation to sparry calcite that is optically continuous through large areas of rock and that effects a tight and thorough cementation. In sample KG-12-I, nearly one-fifth of the cement consists of coarse silt-sized dolorhombs that probably represent recrystallized sparry calcite. The latter cement nowhere shows fringing growth such as would result from the granular cementation as described by Bathhurst (1958, p. 14), but in three thin sections it is locally in optical continuity with *Inoceramus* prisms suggesting that the sparry calcite originated by rim cementation (Bathhurst, 1958, p. 21). Quartz grains in all but one thin section commonly have irregularly crenulated borders where the quartz has been replaced by calcite, which deeply invades the margins of some quartz grains.

Invertebrate remains in thin sections consist largely of isolated *Inoceramus* prisms and shell fragments. Prisms are locally optically continuous with surrounding cement, as mentioned above, and in two thin sections the edges of prisms and shell fragments are highly sutured where partly invaded by interstitial calcite. In one thin section *Inoceramus* prisms were recrystallized; in another section a few prisms were partly replaced by transverse bands of gypsum. Fish bones and scales are mostly fragmentary, of amber or yellow color under plane-polarized light, and bones are commonly replaced in part by very finely crystalline pyrite, some of which is oxidized to limonite (Fig. 11, *A*). Each of the thin sections contains glauconite, all of which is green, most of which occurs as well-rounded pellets, and some of which occurs as irregularly shaped or even angular grains. Shrinkage cracks are rare in these pellets. Some of these pellets are replaced by pyrite in sample KG-5-J. Pyrite occurs as spherical blebs in addition to modes of occurrence already described. Limonite occurs in the same modes as pyrite, originating by oxidation of the latter, and also is disseminated through cement of some thin sections as a cloudy reddish-brown stain, and fills foraminifers in two thin sections. Whitish blebs of isotropic material in seven thin sections are probably leucoxene. In two thin sections clay occurs as a rimlike coating around many quartz grains and locally has invaded quartz grains, apparently along replacement contacts. Other minerals identified in these thin sections include polycrystalline quartz, chert, plagioclase, orthoclase, microcline, tourmaline, zircon, leucoxene, muscovite, and biotite. Except for polycrystalline quartz each of these minerals is represented in the slides where

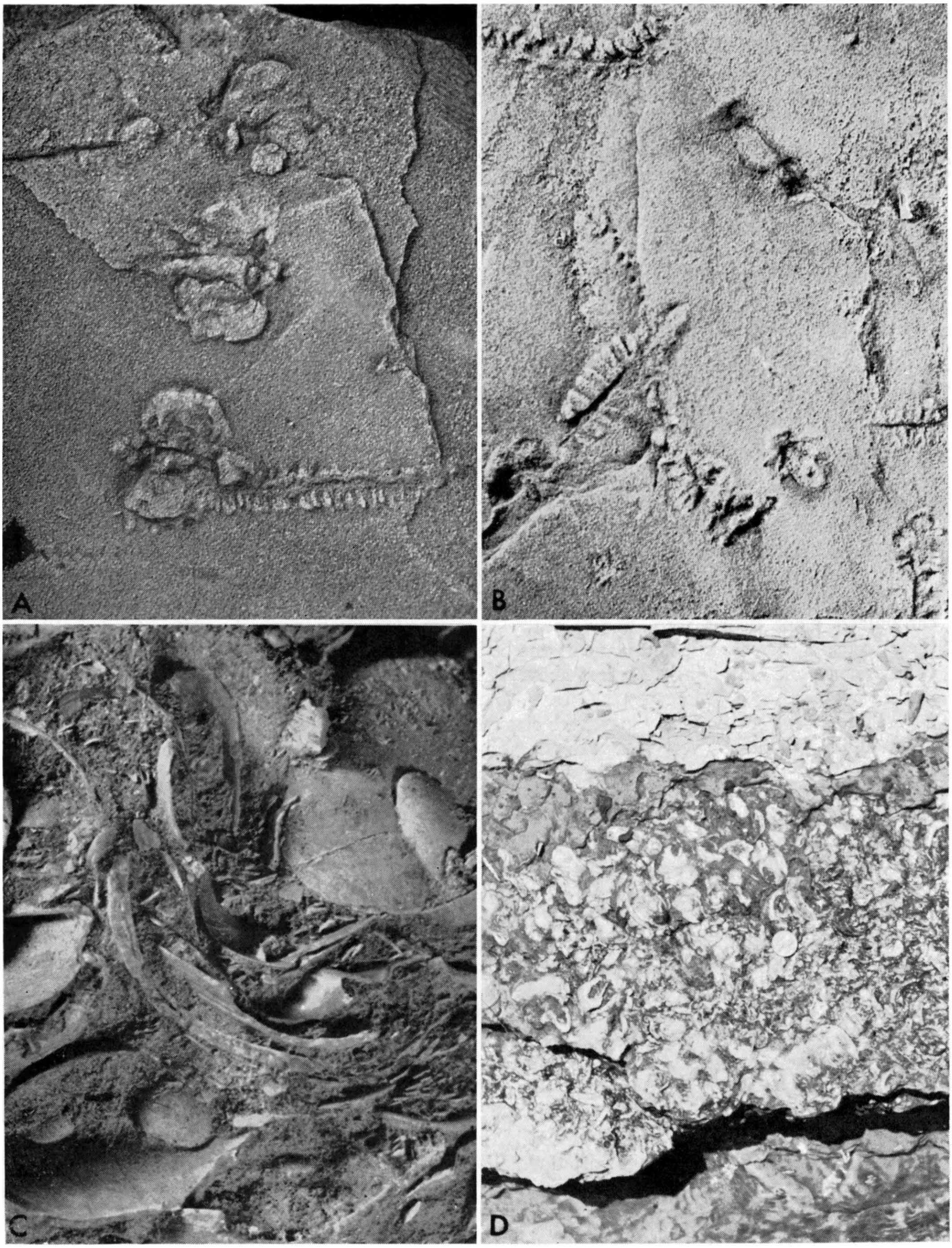


FIGURE 10.—Organic features of calcareous rocks in the Graneros Shale. *A*, Arthropod trackway (lower) and unidentified ichnofossils in calcareous silty sandstone near middle of formation in sec. 36, T 12 S, R 11 W, Russell County (Loc. 43), ×2. *B*, Arthropod trackways in skeletal limestone from upper part of Graneros in sec. 20, T 15 S, R 15 W, Russell County (Loc. 5), ×1. *C*, Coquinoidal limestone consisting largely of *Callistina*, from lower part of Graneros in sec. 20, T 15 S, R 15 W, Russell County (Loc. 5), ×2. *D*, Coquinoidal limestone, consisting largely of *Ostrea beloiti*, from upper part of Graneros Shale in sec. 4, T 12 S, R 15 W, Russell County (Loc. 15). Scale is one-cent coin.

TABLE 5.—Point-count analyses of calcareous sandstone thin sections, listed in order of decreasing percentage of quartz. Based on a count of 200 points.

Sample	Quartz	*Inoceramus* prisms	Shell fragments	Bones, scales, teeth	Glauconite	Chert*	Mica	Leucoxene	Pyrite	Limonite	Sparry calcite cement	Calcite replacing quartz	Recrystallized calcite	Other constituents
KG-31-E	86.5	—	—	—	2.5	—	—	2.0	—	—	8.0†	—	—	1.0
KG-21-J	64.0	3.0	—	0.5	2.0	0.5	0.5	1.0	1.0	0.5	21.5	5.0	—	0.5
KG-5-L-1	63.5	2.0	—	—	1.0	0.5	1.0	1.0	—	2.0	24.0	3.0	—	2.0
KG-23-L	56.0	0.5	—	1.0	6.5	1.0	—	1.5	0.5	1.0	29.5	2.0	—	0.5
KG-5-J	45.5	5.0	—	—	2.5	—	0.5	2.5	1.5	—	40.0	2.5	—	—
KG-7-O	45.5	6.0	0.5	1.5	0.5	—	—	—	—	1.5	41.0	3.5	—	—
KG-12-I‡	44.5	—	—	5.5	2.0	—	—	—	—	2.5§	34.0	1.5	9.5‖	0.5
KG-7-I	38.0	5.0	—	1.5	1.0	0.5	—	1.5	—	3.5	45.5	3.0	—	0.5
KG-17-K	28.5	19.0	1.5	1.0	1.0	—	—	3.0	0.5	3.5	35.5	5.5	0.5	0.5

* Includes polycrystalline quartz.
† Microspar.
‡ Count ignores disseminated limonite which masks identity of grains.
§ Limonite in slide may be partially concentrated in interstitial clay.
‖ Dolorhombs.

present by only 1 to 5 grains, and in no slide did I observe the entire suite.

Point-count analysis of calcareous sandstone, based on 200 points per thin section, is tabulated in Table 5. Although technically a limestone, Sample KG-17-K is considered as a calcareous sandstone on the basis of its composition before diagenesis. A marked inverse relationship exists between percentage of quartz grains and amount of cement. A rock with a few percent less quartz grains and correspondingly more *Inoceramus* prisms than KG-17-K would be classed as a skeletal limestone.

SKELETAL LIMESTONE

Limestone lenses or beds consisting largely of *Inoceramus* prisms and shell fragments, and ranging in thickness from less than 0.1 foot to 0.4 foot, are scattered sparingly through the upper 12.5 feet of the Graneros Shale. Except for Locality 31, such beds were observed only in the Smoky Hill and Saline River drainage basins of Russell, Ellsworth, and Lincoln counties. Although the limestone is composed dominantly of fine- to very fine-grained fossil fragments, most of the beds contain rudaceous organic debris including whole or fragmentary remains of *Inoceramus* and *Ostrea*. Remains of the latter are commonly concentrated at the top of the bed. Inoceramite is an informal field designation for such limestone, and the most descriptive term for such rocks is biofragmental calcarenite, but in view of current trends in carbonate rock classification, the term "skeletal limestone" (Leighton and Pendexter, 1962) is used herein. By increase in proportion of quartz relative to shell fragments and *Inoceramus* prisms, the skeletal limestone lithology is transitional with that of calcareous quartzose sandstone.

The fresh rock is mostly light olive-gray (5Y5/2) to olive-gray (5Y4/1) and weathers dark yellowish-orange, various shades of yellowish-brown, or grayish-orange. Skeletal limestone units are thin to very thin bedded; individual beds are thinly laminated and locally gently cross laminated at several localities. Such cross laminations may be related to ripple marking, but obvious ripples were noted in skeletal limestone only at Locality 32. Sole marks, including drag marks, load casts, or worm?-trail casts, were observed in skeletal limestone beds at Localities 1, 5, and 15, and arthropod tracks are common in skeletal limestone near the top of the Graneros at Locality 5 (Fig. 10, *B*). Most of the rock is well cemented where fresh and relatively resistant to erosion; beds of skeletal limestone usually project as ledges from slopes of Graneros exposures. When freshly broken, these rocks commonly emit a petroliferous color.

Inoceramus remains are ubiquitous in skeletal limestone beds, and *Ostrea* and fish remains are present in most exposures. Fish remains were observed in a majority of exposures and probably occur in all of these rocks. Rare fossils in skeletal limestone include molds of ammonites (Locs. 5 and 8), *Callistina* (Loc. 1), and a cirriped plate (Loc. 32).

A suite of eight thin sections was cut from skeletal limestone samples collected at five localities (Fig. 12). Seven of these sections were analyzed by point-counting. Point-count data are summarized in Table 6. The dominant primary constituent in each of these sections is isolated *Inoceramus* prisms which make up 35 to 50.5 percent of the thin sections studied. Scattered fragments of *Inoceramus* and *Ostrea* valves constitute from 2.5 to 19 percent of thin-sectioned rock. Maximum diameters of the *Inoceramus* prisms lie dominantly in the fine and very fine sand ranges but many are of coarse-silt size.

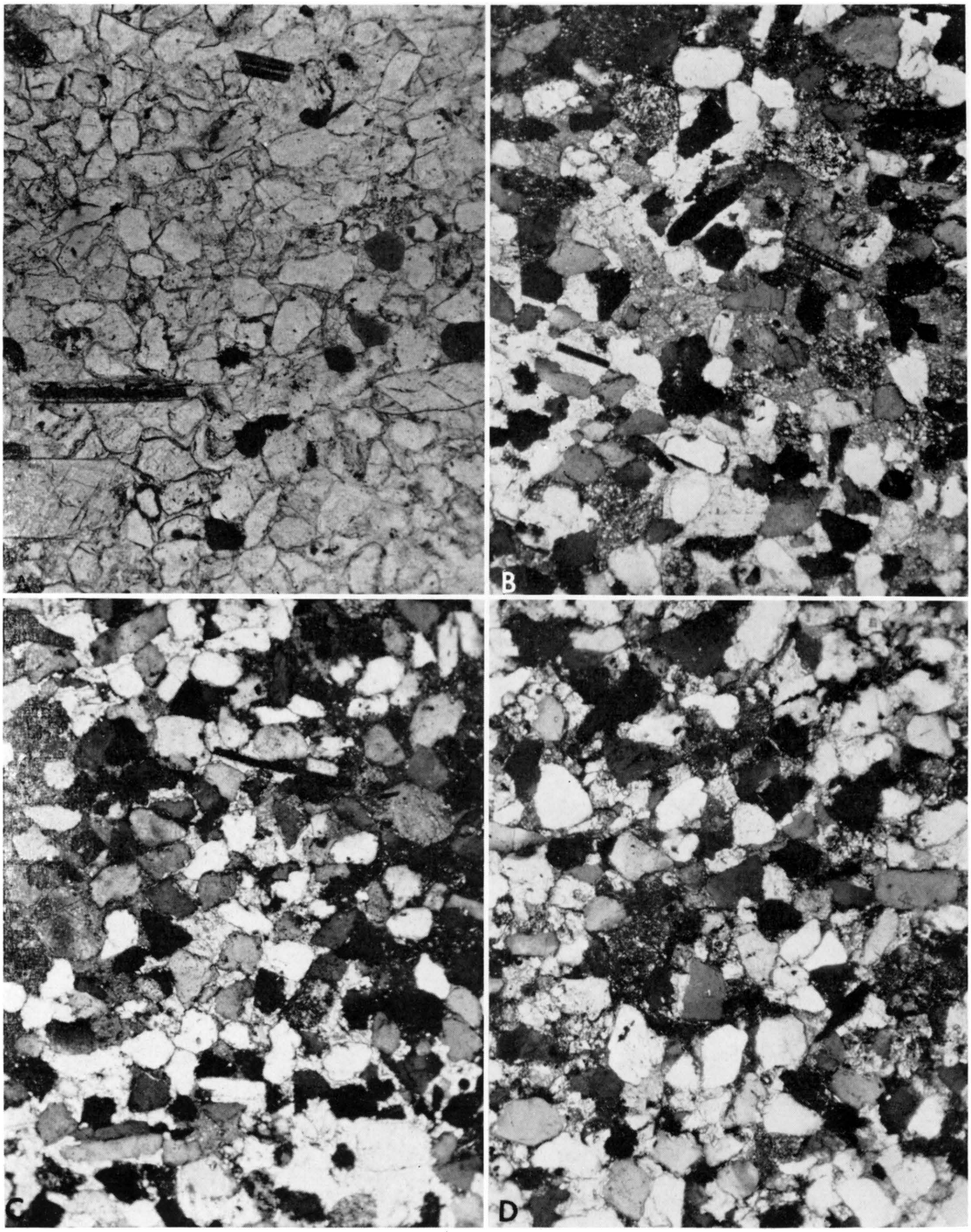


FIGURE 11.—Photomicrographs of thin sections of calcareous sandstone. *A*, Sandstone from near middle of Graneros at Locality 5 showing *Inoceramus* prisms (note grains with conspicuous cleavage in lower part of photo), fish remains (dark parallel-sided grains), and glauconite (dark rounded grains at right). Plane-polarized light, $\times 75$. *B*, Sandstone from upper part of Graneros at Locality 21 showing large areas of optically continuous calcite cement. Note replacement of quartz by calcite directly below fish fragment (black rodlike grain) in left center. Crossed nicols, $\times 75$. Sandstone from upper part of Graneros at Locality 5 showing large areas of optically continuous calcite cement. Note calcite replacement of quartz-grain borders in center of photograph. Crossed nicols, $\times 75$. *D*, Sandstone from lower part of Graneros at Locality 23. Note large glauconite grain (dark-gray) just left of center of photograph and lack of optical continuity of cement through large areas of rock. Crossed nicols, $\times 75$.

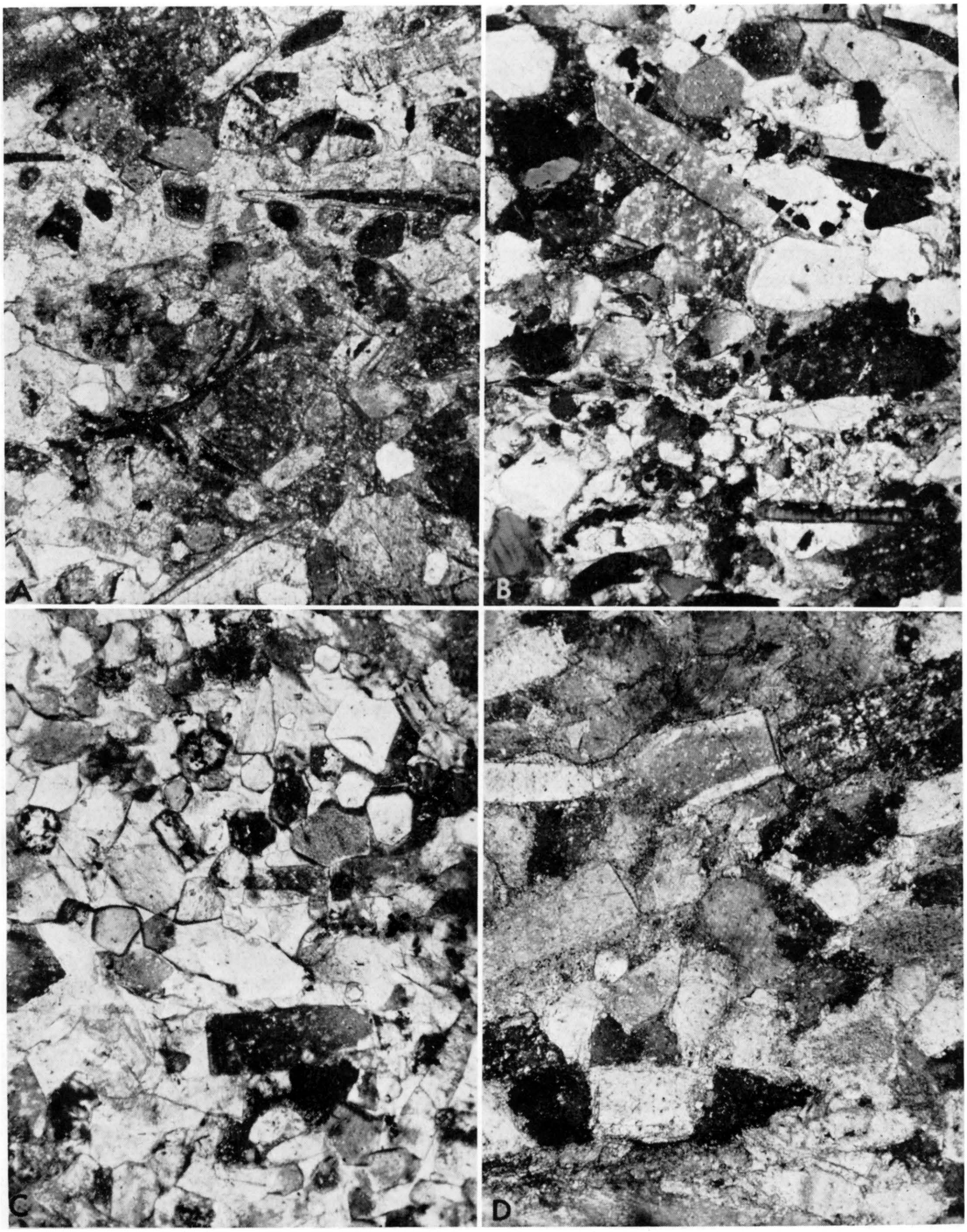


FIGURE 12.—Photomicrographs of thin sections of skeletal limestone. *A*, Limestone from upper part of Graneros at Locality 21 showing large areas of optically continuous calcite cement. Note fish remains (large elongate grains) and scattered quartz grains. Crossed nicols, ×75. *B*, Limestone from upper part of Graneros at Locality 1 showing partial replacement by pyrite of fish remains and *Inoceramus* prisms. Crossed nicols, ×75. *C*, Limestone from near top of Graneros at Locality 1 showing dominance of *Inoceramus* prisms. Plane-polarized light, ×75. *D*, Concretionary skeletal limestone from upper part of Graneros at Locality 33. Note partially recrystallized borders of *Inoceramus* prisms. Crossed nicols, ×75.

TABLE 6.—Point-count analyses of skeletal limestone thin sections, based on a count of 200 points

Unit	*Inoceramus* prisms	Shell fragments	Sparry calcite cement	Bones, teeth, scales	Quartz	Pyrite	Limonite	Glauconite	Other constit-uents
KG-1-O	43.0	9.5	34.0	2.5	8.0	—	1.0	1.5	0.5
KG-1-Q	37.0	7.0	30.0	8.0	13.0	2.5	1.5	0.5	0.5
KG-1-R	38.5	19.0	34.0	4.0	1.0	—	3.0	—	0.5
KG-1-U	45.0	15.5	35.0	1.0	1.0	—	2.5	—	—
KG-8-M	50.0	3.5	33.0	8.0	4.0	—	1.0	—	—
KG-15-A	35.0	17.0	41.0	1.0	4.5	0.5	0.5	0.5	—
KG-21-O	37.0	2.5	41.0	7.0	9.5	—	3.0	—	—

Most of the prisms are less than a millimeter in length. Fish remains, including bones, teeth, and scales, constitute from 1 to 8 percent of the thin sections examined. In all thin sections, the *Inoceramus* prisms and elongated fragments of *Inoceramus*, *Ostrea*, and fish remains are mostly arranged parallel to or at only a small angle to the bedding.

Quartz grains, which are present in all skeletal limestone thin sections are chiefly of very fine sand size but the range is from coarse silt to fine sand. These grains constitute from 1 to 13 percent of the sections studied. Quartz grains range from angular to well-rounded but most are subangular. In all of these thin sections some of the quartz grains are partially replaced peripherally by calcium carbonate. Irregular-shaped to well-rounded pellets of glauconite are present in all of the thin sections, ranging in abundance from a small fraction of 1 percent to apparently as much as 1.5 percent of the rock. A few of the pellets contain desiccation cracks, and in a sample from Locality 31, some of the grains are extensively replaced by limonite. Pyrite or limonite or both minerals are common in all of the thin sections, making up from 1 to 4 percent of the grains counted. Pyrite occurs as spheroidal blebs, as a shell-replacement mineral, or as fillings in vesicular parts of bones and teeth. Limonite occurs in the same three forms, pseudomorphous after pyrite, and is disseminated interstitially as a stain in sparry calcite cement in a few sections; locally it has replaced glauconite grains and *Inoceramus* prisms.

The cement in calcarenite thin sections is wholly of sparry calcite as crystals that are commonly in optical continuity through large areas of the rock (Fig. 12, *A*). *Inoceramus* prisms are mostly in sharp contact with the cement in all thin sections save one, in which many of the prism-cement contacts are sutured. In three thin sections a few *Inoceramus* prisms were observed to lie in optical continuity with the enclosing cement. Sparry calcite cement constitutes from 30 to 41 percent of the thin sections studied.

White spheroidal pellets, seemingly composed of phosphatic material, were observed under reflected light in each of the specimens that were sectioned. Only a dozen measurements were made, owing to paucity of such structures, but a general size range from 0.18 to 1.5 mm was determined. The pellets are concluded to be of fecal origin. Scraps of carbonized wood were observed under reflected light in four of these samples.

Graneros rocks composed mainly of skeletal debris and also containing large numbers of whole invertebrate shells or conchs are quantitatively unimportant but paleontologically of great significance. These rocks are a coquinoidal variety of skeletal limestone formed very locally under conditions of much greater energy expenditure than the more fine-grained skeletal limestones described above. In the lower part of the Graneros such rock occurs only at Locality 5, in southwestern Russell County, where abundant whole and broken shells of *Callistina* and *Exogyra* make up most of a lens that was approximately 0.4-foot thick and 6 feet wide (Fig. 10, *C*). Many of the shells are standing on edge in imbricate fashion, and some *Callistina* valves are paired. The shells are set in a calcite-cemented matrix consisting largely of prisms and small shell fragments of *Inoceramus*; the uppermost and lowermost parts of the lens consist of calcareous quartz silt, some of which exhibits cone-in-cone structure. This block of limestone has yielded specimens of nearly all the species of macroinvertebrates that occur in the lower part of the Graneros and includes some species not known elsewhere in the formation. My attempts to disaggregate pieces of this block ultrasonically and with a variety of solvents met with limited success.

Coquinoidal limestone in the upper part of the formation is exposed at Localities 32 and 33 in northwestern Ellsworth County. A less fossiliferous exposure of the same bed is at Locality 18. At Locality 32 the unit is represented by a lens 0.8-foot thick, the lower 0.6 foot of which is crowded with fossils including examples of nearly all macroinvertebrate species known to me from the upper part of the formation. Except for *Ostrea,* shell material in most of these fossils has been recrystallized and adheres to enclosing matrix rather than to the internal molds. Many fossils in this limestone were fragmented before burial, breakage being most evident among the large ammonite conchs. The fossils are enclosed in a matrix consisting largely of sparry-calcite-cemented *Inoceramus* prisms and small shell fragments. The upper 0.2 foot of this limestone lens is very fine grained and bears an outward appearance of concretionary origin but actually consists almost entirely of small *Inoceramus* prisms which are tightly packed together owing to solution transfer that has left prisms in close contact along interlocking or irregular grain borders. A thin section of similar fine-grained, concretion-like rock from the same unit at Locality 33 (Fig. 12, *D*) also consists largely of *Inoceramus* prisms with sutured grain contacts, but individual prisms have suffered less solution and retain more of the original outline than those from Locality 32. Conspicuous lenses of coquinoidal limestone are scattered through approximately 3 feet of shale at Locality 47, directly beneath the thick bentonite marker bed that lies near the top of the Graneros Shale. These lenses consist largely of *Ostrea* with some *Inoceramus* shells. A large adult specimen of *Plesiacanthoceras* was collected from one lens. Similar beds of oyster-rich coquinoidal limestone lie directly beneath the bentonite marker bed at Localities 5 and 15 (Fig. 10, *D*).

BONE BEDS

Layers of rock containing conspicuous quantities of bone pebbles are known from Graneros exposures at Localities 3 (Fig. 13, *A*), 4 (Fig. 13, *B*), 6, 18 (Fig. 13, *C*), 28 (Fig. 13, *D*), 33, 34, 39, and 43. Pebbly units near the middle of the formation at Localities 4, 18, and 34 lie in a similar stratigraphic position and may be related genetically; the same is true for the bone-bearing units at Localities 6 and 28. The bone-pebble bed at Locality 3 (Fig. 13, *A*) lies near the base of the Graneros and is the same as that at Locality 43. Except for the abundance of fragments or rounded pebbles of bones or teeth, these rocks differ widely from one another. The concentration of vertebrate remains and relatively large size of such constituents suggest similar conditions of origin, so the bone beds are discussed as a group. The bone pebbles, and clay pebbles and coprolites that are associated with them, are commonly pyritized or, by oxidation of pyrite, limonitized (Fig. 13, *A*). Bone-bed samples all contain coprolites and/or clay pebbles that are difficult to distinguish microscopically excepting those coprolites that contain bone fragments.

Thin sections of bone-bed samples are illustrated in Figure 14. Vertebrate remains commonly occur as rounded pebbles at all but Locality 28 (Fig. 13, *D*; 14, *A*) where more or less elongated fragments are the rule. The gypsum-cemented bone bed at the base of the unit KG-3-L (Fig. 14, *B*) in the lower part of the Graneros is, like most rocks in that part of the formation, noncalcareous. A similar bone bed lies near the middle of the formation at Locality 4 (Fig. 14, *C*). Other sectioned bone-bed samples, all from the upper half of the formation, are calcareous and are related mineralogically to calcareous quartzose sandstone or skeletal limestone beds depending upon relative proportions of quartz sand or shell debris, respectively. For example, the bone bed at Locality 34 grades upwards into calcareous quartzose sandstone, but the bone bed at Locality 18 contains 10 percent more shell debris than quartz sand. The bone bed at Locality 6 contains subequal amounts of quartz sand and shell debris (Fig. 14, *D*).

Cement in bone beds at Localities 3 and 4 is nearly all sparry gypsum that occurs in sharp contact with framework grains. Carbonate cement characterizes the remaining thin sections. In the latter group, sparry calcite occurs as both fine- and coarse-grained cement; in places the cement is optically continuous with *Inoceramus* prisms and is in optical continuity between several grains. In the thin section from Sample KG-28-H the cement has been largely recrystallized to dolomite. This bed also contains coarse-grained second-generation sparry calcite occurring as veins or lying adjacent to bone fragments. In Sample KG-6-P sparry gypsum surrounding many bone pebbles and coprolites? postdates the sparry calcite cement (Fig. 14, *D*). In all thin sections examined the rock is well washed and free of clay. Point counts, based on 200 points per thin section, were made on five samples of bone-bed rock (Table 7).

BENTONITE

The Graneros Shale of central Kansas contains several layers of bentonite, the thickest and most widespread of which lies between 0.5 (Loc. 12) and 3.2 feet (Loc. 18) below the Greenhorn in much of the northern and central parts of the outcrop (Fig. 15, *A*, *B*). At Locality 38 in Washington County, shale separating the bentonite

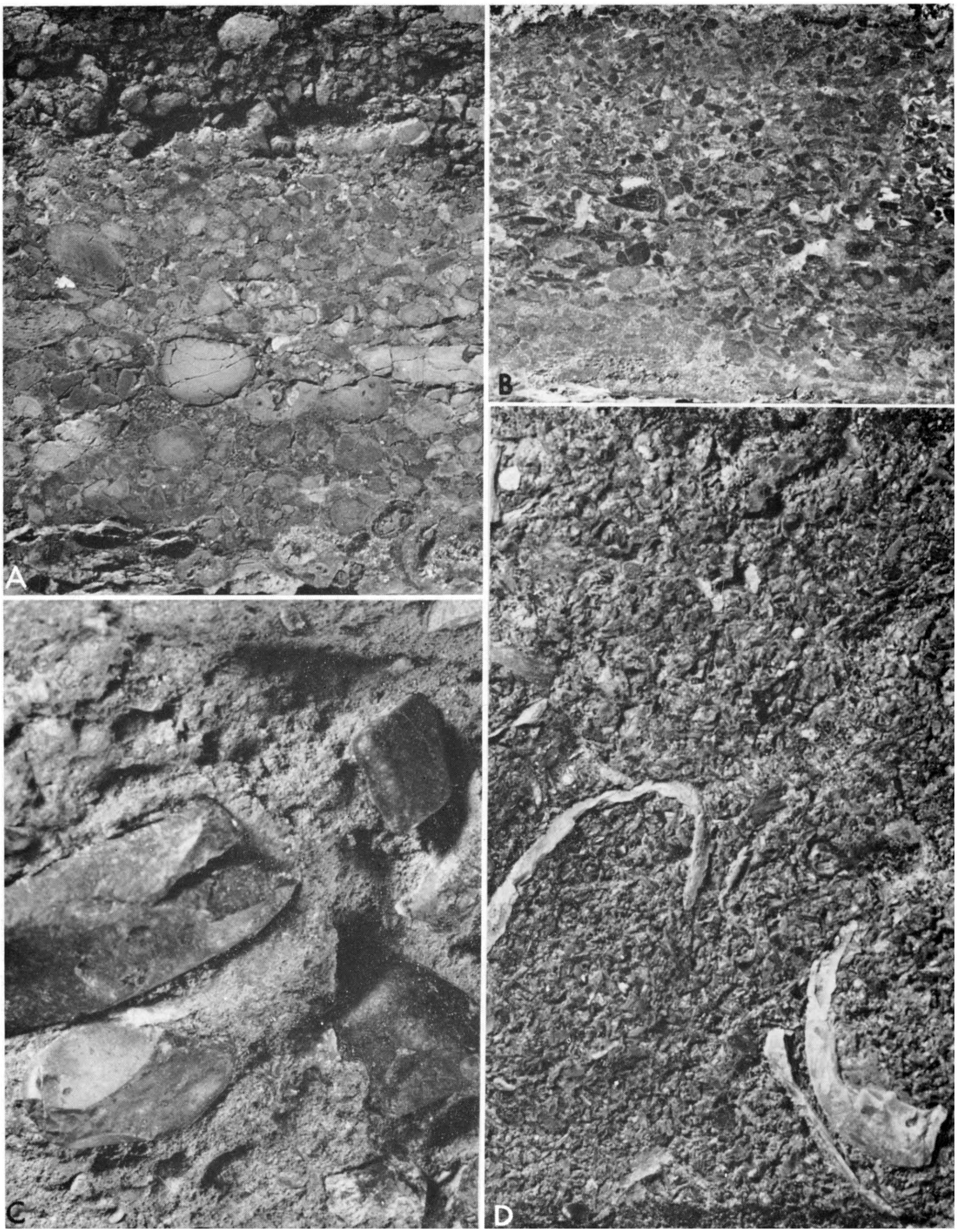


FIGURE 13.—Bone-bed samples from the Graneros Shale. *A,* Weathered gypsum-cemented bone-pebble conglomerate from near base of Graneros in sec. 3, T 13 S, R 11 W, Russell County (Loc. 3), ×2. *B,* Unweathered, gypsum-cemented bone-pebble conglomerate from bed lying near middle of Graneros in sec. 6, T 14 S, R 10 W, Ellsworth County (Loc. 4), ×2. *C,* Bone-pebble conglomerate from lens lying near middle of Graneros in sec. 29, T 15 S, R 10 W, Ellsworth County (Loc. 18), ×2. *D,* Oyster-bearing bone bed in upper part of Graneros in sec. 7, T 13 S, R 9 W, Lincoln County (Loc. 28), ×2½.

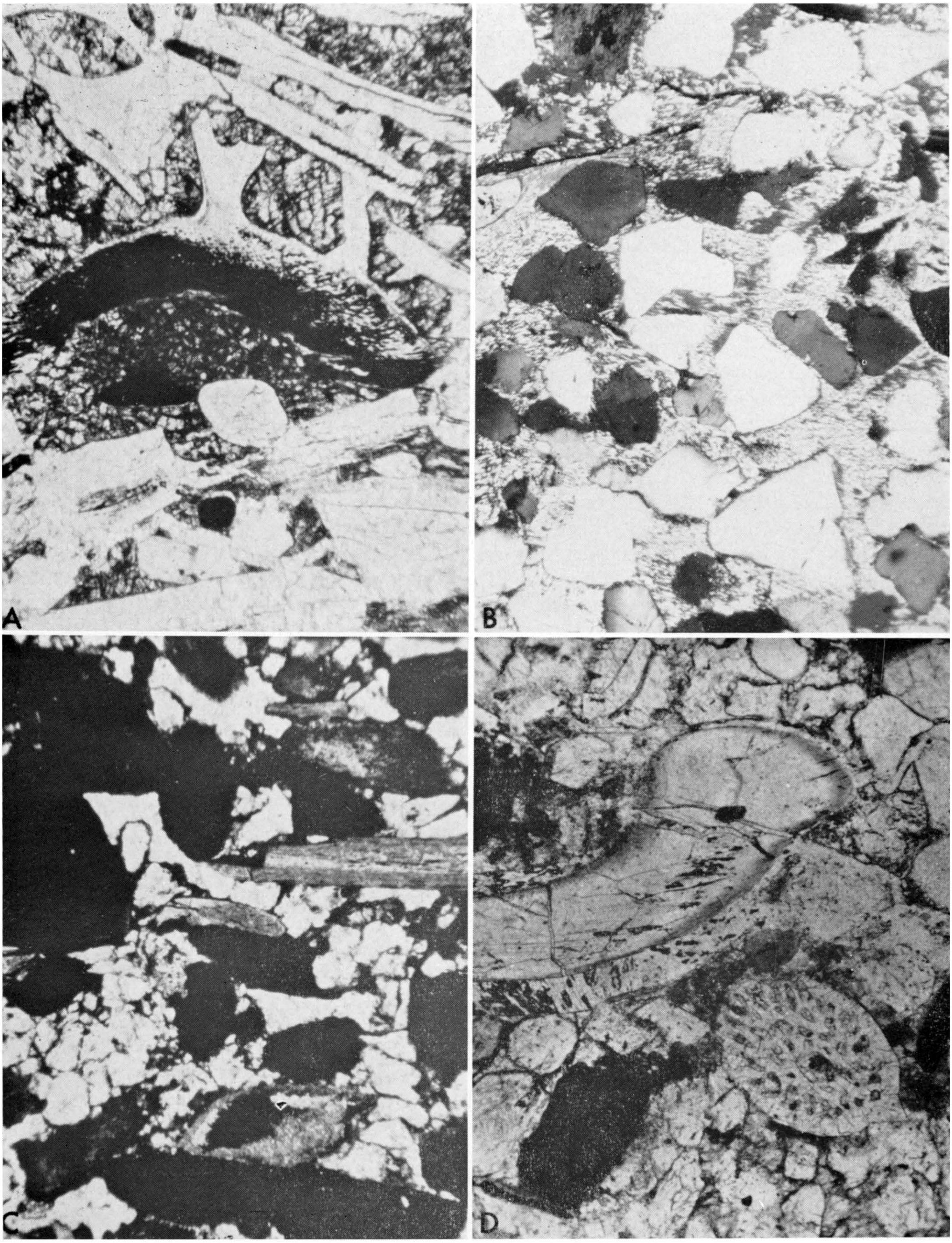


FIGURE 14.—Photomicrographs of thin sections of bone beds. *A*, Dolomite-cemented bone bed from upper part of Graneros at Locality 28. Dark areas in cement and large bone fragment (center) are limonite. Plane-polarized light, ×50. *B*, Gypsum-cemented sandstone from bone bed near base of Graneros at Locality 3. Crossed nicols, ×75. *C*, Bone bed near middle of Graneros at Locality 4 showing gypsum cement, quartz grains, rounded bone grains (black), and fish remains (tabular grains, center). Plane-polarized light, ×50. *D*, Calcite-cemented bone bed in upper part of Graneros at Locality 6 showing mixture of fish teeth, quartz grains, and *Inoceramus* prisms. Note post-calcite gypsum above and below large fish tooth at top left. Plane-polarized light, ×75.

TABLE 7.—Point-count analyses of bone-bed thin sections, based on a count of 200 points.

Unit	Bone	Bone*	Other pebbles†	Quartz	Shell debris‡	Sparry gypsum	Sparry calcite	Dolomite	Limonite cement	Pyrite§	Limonite§	Other constituents
KG-3-L	25.0	12.0	28.5	8.0	—	21.0	—	—	—	—	5.0	0.5
KG-4-I	12.5	39.5	2.0	1.0	—	35.5	1.0	—	5.5	1.5	—	1.5
KG-6-P	20.0	9.5	11.5	15.0	7.0	4.5	31.5	—	0.5	—	—	0.5
KG-18-E	17.5	1.5	1.0	14.0	24.0	3.0	29.0	—	5.0	1.5	3.0	0.5
KG-28-H	33.0	9.0	2.5	4.0	3.5	0.5	15.0	29.0	3.5	—	—	—

* Pyritized or limonitized.
† Clay pebbles and/or coprolites, many partly or wholly pyritized.
‡ Mostly *Inoceramus* prisms and fragments of *Ostrea*.
§ Not obviously replacing bones or other pebbles.

from the ill-defined base of the Greenhorn is 4.25 feet thick and is only slightly calcareous in the upper 2.5 feet. At Locality 16, a few miles to the east, beds recognizable as Greenhorn are not exposed but at least 6.0 feet of noncalcareous, Graneros-like shale lie above the bentonite bed. The thick bentonite bed, which has been called the "bentonite marker bed" by Merriam (1957a) ranges in thickness from 0.2 to 1.65 feet, averaging 0.9 foot for 25 measurements. The "fresh" rock is most commonly pale greenish-yellow, yellowish-gray (5Y8/1), or very light-gray, but exhibits a wide range of coloration from bluish-gray at one extreme to nearly white at the other. Weathering apparently has not affected the Graneros at Locality 43, as noted above, and part of the exposure at Locality 15 is essentially unweathered. The thick bentonite is light to medium bluish-gray at these localities and is likewise bluish-gray in the subsurface (Merriam, 1957a; Merriam, *et al.*, 1959) where the bed is also unweathered and lies within a calcareous shale sequence. Where long exposed to weathering, the bentonite has been stained by limonite and is usually dark yellowish-orange, but other shades of orange and some of brown have been observed locally. The bentonite is generally very slightly to slightly silty, is commonly speckled with fine flakes of biotite, and locally contains aggregates of finely crystalline pyrite or marcasite less than 1 mm in diameter. Only one fossil, an *Inoceramus* mold, was observed in the bentonite. The rock is soft and unctuous when wet, is brittle when dry, and breaks with a conchoidal fracture.

Other bentonites in the Graneros range from less than 0.01 to 0.3 foot in thickness, and individual beds show considerable range in thickness at some exposures. None of these layers can be traced with certainty for more than a few miles, probably owing to intermittent scour of the sea floor. Bentonite pinchouts were noted at a few places including Locality 4 where a bentonite near the middle of the formation is truncated by a lenticular bed of bone-pebble conglomerate. A thin bentonite layer that rests on beds or lenses of sandstone lying near the middle of the formation in the Saline and Smoky Hill river areas is a relatively widespread marker bed but its identity would be obscure were it not for association with the subjacent sand unit which was locally deformed as a result of subaqueous plastic flow. Bentonites below the thick marker bed exhibit considerable range in coloration with yellowish-gray (5Y7/2), light olive-gray (5Y6/1), and light-gray being most common, with several other shades of gray next in importance. The dominant weathering color is dark yellowish-orange owing to limonitic staining. Most of these thin bentonite beds are slightly silty, but range from non-silty to finely sandy. Finely divided biotite was observed in a few of these thin bentonite layers and the taste of melanterite was noted in some.

Several samples of bentonite were wetted and examined microscopically. All of the samples contained quartz of detrital, authigenic, or volcanic? origin but no sample contained all three. The authigenic quartz is euhedral; the volcanic? quartz is splintery. Biotite was observed in each of three samples of the bentonite marker bed thus treated, but not in any of the other microscopically studied samples. Two samples contained minute selenite crystals; such crystals are common in weathered bentonite beds. The following minerals were each observed in only one sample of bentonite examined microscopically: pyrite in crystalline aggregates less than 0.5 mm in diameter, feldspar, and glauconite. Relative proportions of major constituents in nine bentonite samples were determined by X-ray diffraction techniques. In four bentonite samples from the upper part of the formation, including two from the bentonite marker bed, the order of mineral abundance is montmorillonite (dominant), kaolinite, and quartz. In all five samples from the lower part of the formation kaolinite is the dominant mineral, montmorillonite and quartz, in either order of abundance, make up most of the remaining rock, and gypsum was

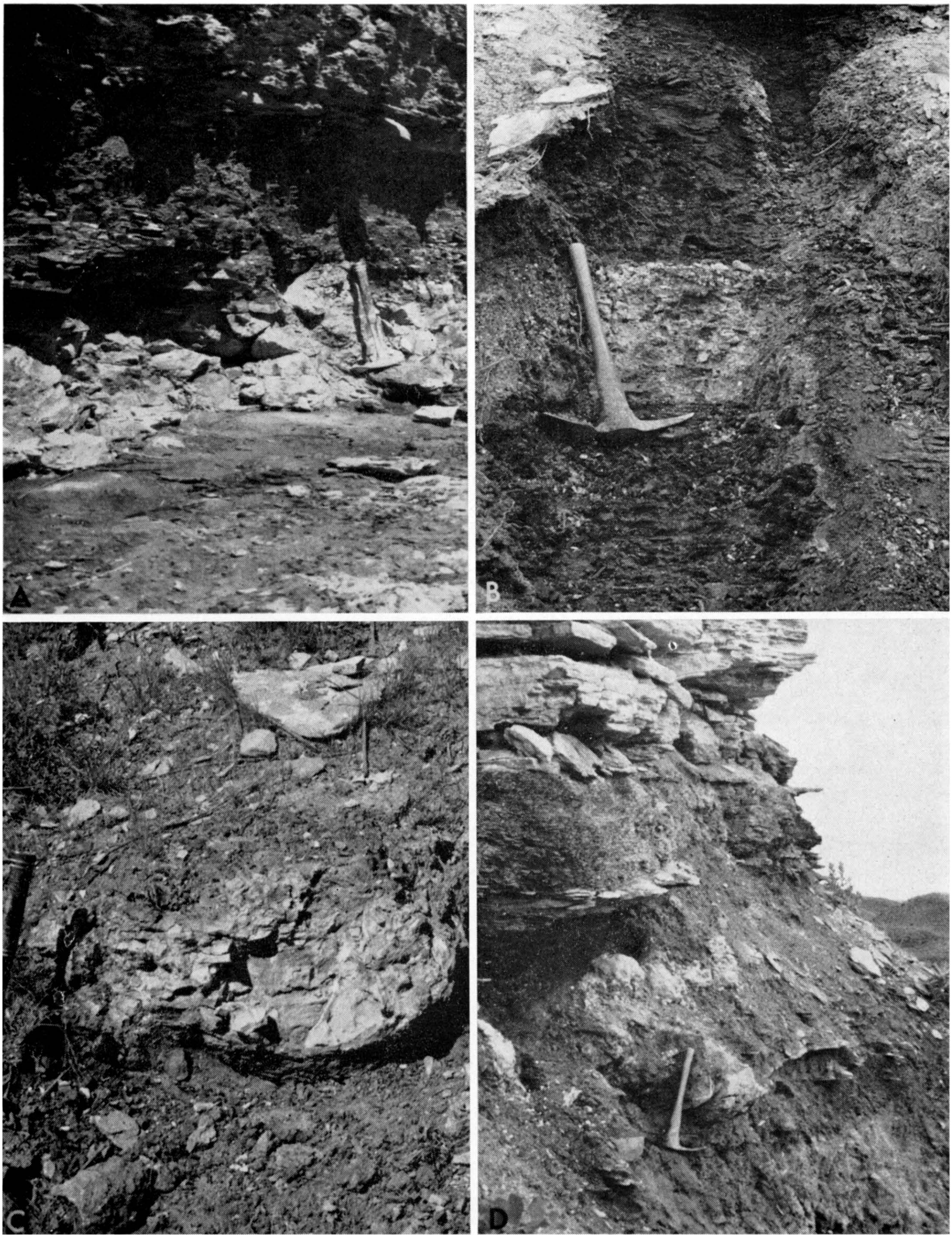


FIGURE 15.—Bentonite and concretions in upper part of the Graneros Shale. *A*, Bentonite marker bed ("X" bentonite) in sec. 4, T 12 S, R 15 W, Russell County (Loc. 15). *B*, Bentonite marker bed in sec. 35, T 12 S, R 14 W, Russell County (Loc. 1). *C*, Septarian concretion in upper part of Graneros in sec. 29, T 15 S, R 10 W, Ellsworth County (Loc. 18). *D*, Clayey carbonate concretions (above pick handle) lying along upper contact of the bentonite marker bed in sec. 36, T 14 S, R 11 W, Russell County (Loc. 34). Note sharp contact of Greenhorn Limestone (top) on Graneros Shale.

detected in two samples. The stratigraphic distribution of kaolinite-dominant versus montmorillonite-dominant bentonites apparently coincides with both paleontologic and lithologic criteria that serve to distinguish the upper and lower parts of the formation.

The bentonite marker bed that lies near the top of the Graneros in central Kansas has been traced across the subsurface of western Kansas by Merriam (1957a). This bed, known as the "X" bentonite in Colorado and southeastern Wyoming, has been traced widely in the Denver Basin by Haun (1959, pl. 1 and 2), who noted that this bentonite "can be traced with reasonable certainty to western Colorado." The bentonite is 5 to 16 inches thick in Hamilton County, Kansas, where it lies 10 feet below the top of the Graneros (Bass, 1926, p. 72). In Baca County, southeastern Colorado, the bentonite is 1 foot thick and lies 4.2 feet below the top of the Graneros (McLaughlin, 1954, p. 111). It is 8 to 10 inches thick and lies 13 feet below the top of the formation on the Model Anticline (Bass, *et al.*, 1947). Scott (1962, p. 12; 1963, p. 95) recognized this bentonite in the Littleton and Kassler quadrangles, near Denver, Colorado, but, on lithologic grounds, concluded that the Graneros-Greenhorn contact lies below the marker bed.

McCrae (1956) traced the "X" bentonite northward from the southeastern corner of Wyoming to the vicinity of Lance Creek, Wyoming, where the bed lies slightly more than 300 feet above the base of the Belle Fourche Shale. About 50 miles to the northeast of Lance Creek a major bentonite lying 325 feet above the base and approximately 15 feet below the top of the Belle Fourche, and which is seemingly correlative with the "X" bentonite, has been reported in a well a few miles southwest of Newcastle, Wyoming, by Mapel and Pillmore (1963, p. 42). They correlate this bed, which in outcrop near Newcastle is 2 feet thick and lies 350 feet above the base and 17 feet below the top of the Belle Fourche, with a northern Black Hills bentonite that has been called "bed F" by Knechtel and Patterson (1962). The latter workers note that in the area east of Alzada, Montana, the base of the Greenhorn is a thin limestone bed that was called the Orman Lake Limestone by Petsch (1949, p. 9). In its type area the Orman Lake consists of shell debris and vertebrate remains and on fresh fracture emits a petroliferous odor (Petsch, 1949, p. 10). This description fits closely that of the basal Lincoln in most areas of central Kansas. Bentonite "bed F" lies 6 feet below the Orman Lake near Belle Fourche, South Dakota, and thus lies in a position comparable to that of the bentonite marker bed of Kansas, but the base of the Greenhorn rises rather abruptly to the west of Belle Fourche, so that in parts of Crook County, Wyoming, "bed F" lies 285 feet below the base of the Greenhorn. Knechtel and Patterson (1962, p. 982) believe that "bed F" may be the same as the Soap Creek bentonite reported by them (Knechtel and Patterson, 1956, p. 18) from near the northeast flank of the Bighorn Mountains, around Hardin, Montana. *Plesiacanthoceras amphibolum* (Morrow) occurs in beds directly below the Soap Creek bentonite and *Acanthoceras?* sp. [now known as *Plesiacanthoceras wyomingense* (Reagan)] occurs in beds directly overlying the Soap Creek bentonite. The same bentonite is represented in the Frontier Formation in Johnson County, Wyoming, by 4 feet of bentonite lying between beds containing *P. amphibolum* and *Acanthoceras?* sp. (=*P. wyomingense*), respectively (Hose, 1955, p. 100). In Kansas, *P. amphibolum* occurs mostly below the bentonite marker bed, but it has been collected above the bentonite at a single exposure (Loc. 8) where specimens lie a maximum distance of 1.8 feet above the marker. Although *P. wyomingense* has not been recovered from uppermost beds of the Graneros Shale in Kansas, the species does occur in basal beds of the Greenhorn at one locality. Faunal evidence is therefore suggestive, but not conclusive, that the bentonite marker bed and the Soap Creek bentonite are correlative units.

CONCRETIONS

Concretionary rock of several kinds was observed in the Graneros Shale at a total of 17 localities in central Kansas. At Locality 7, a nodular layer of light olive-gray (5Y5/2) clay-ironstone concretions 0.25-foot thick lies 4 feet above the base of the formation. The concretions are surficially limonitized. A bed of dark yellowish-orange to moderate reddish-brown clay ironstone 0.5-foot thick lies 2.2 feet above the base of the Graneros at Locality 13. At Locality 23, a hard concretionary layer of olive-gray (5Y6/1) claystone that weathers moderate reddish-brown to dark yellowish-orange lies 0.65 foot above the base of the Graneros. At Locality 40, a 0.4-foot-thick limonitized bed of clay that lies 3.8 feet above the base of the Graneros has a concretionary appearance. The rock is light olive-gray (5Y5/2) and weathers dark yellowish-orange to very dusky red. All other concretions that I saw in the Graneros lie in the upper half of the formation, and most of these are of the calcareous septarian type.

More or less typical septaria, mostly of oblate spheroidal shape, were observed at Localities 18 (Fig. 15, *C*), 33, 43, and 47. In these concretions the matrix is dark greenish-gray, weathering at Locality 18 to moderate yellowish-brown and moderate red. The veins are grayish-yellow, grayish-brown, or pale yellowish-brown, coarsely crystalline calcite with crystal axes oriented perpendicular to vein margins and crystals tapering toward the concretion margins.

A thin section cut from a concretion lying 11.4 feet below the bentonite marker bed at Locality 43 is composed dominantly of a mosaic of microcrystalline calcite in which the grain borders are mostly indistinct. Scattered through the matrix are grains of subangular to subrounded quartz silt with calcite-replaced borders and a few calcite grains that may be *Inoceramus* prisms. Original stratification is represented by laminae of calcite-cemented quartz silt and *Inoceramus* prisms in which calcite grain borders have been made indistinct by solution transfer and in which quartz grain borders are replaced by calcite. A few grains of feldspar occur with the quartz. Concretion enlargement apparently did not disrupt the silty laminae because upper and lower surfaces of the laminae are distinct, and cross lamination is preserved in one, so concretionary expansion, if any took place, apparently was within clayey layers. The concretion is 2.6 feet in diameter, 0.7-foot thick, and lies in a unit consisting of silty shale which contains lenses of calcareous siltstone. A thin section from a similar concretion lying in an equivalent stratigraphic position at Locality 18 is also composed dominantly of a mosaic of microcrystalline calcite in which grain borders are more distinct than at Locality 43 but in which many grains are elongated and are oriented mostly at a steep angle to original stratification. Scattered streaks of dark-gray clay are oriented parallel to the original stratification. Sparse grains of subangular to subrounded quartz silt, mostly with calcite-replaced borders, are distributed irregularly through the matrix. Silt-sized grains and microcrystalline blebs of pyrite and streaks of limonite are common. A vein of mostly coarse-crystalline calcite occurs in part of the thin section. This concretion lies in a fossiliferous bed of calcareous, argillaceous, fine-grained sandstone.

A 0.48-foot-thick bed of concretionary limestone with marginal cone-in-cone structure lies 11 feet below the top of the Graneros at Locality 44. The rock is medium dark-gray, weathering dusky yellow, and is mottled in part. Thin lamination, representing original structure, is preserved in part of the bed. As seen in thin section the rock consists mostly of a mosaic of microcrystalline calcite grains through which are scattered a few grains of subrounded quartz silt, rounded glauconite, and a small number of *Inoceramus* prisms and scraps of fish bones. A vein of microcrystalline to coarsely crystalline secondary calcite cuts the thin section obliquely. Blebs of limonite or hematite are distributed irregularly through the rock. This concretionary rock apparently developed along a very thin bed or lens of quartz-bearing skeletal limestone. Marcasitized specimens of *Inoceramus* and *Borissiakoceras* were collected by W. A. Cobban in a similar kind of concretionary skeletal limestone lying beneath the bentonite marker bed at Locality 43 and marcasitized *Plesiacanthoceras* occur in much the same kind of concretionary mass lying 10.3 feet below the bentonite at Locality 18.

At Localities 8, 34 (Fig. 15, *D*), and 45, septarian concretions of hard, light-colored lithographic limestone lie in the bentonite marker bed. At Locality 34 the concretions are medium light-gray, weather dusky yellow, and contain veins of nearly white calcite, along which are vuglike openings. The concretions at Locality 8 are similar but generally more weathered with grayish-yellow to nearly white matrix and two generations of veins. Shrinkage leading to deposition of the second-generation veins caused extensive fracturing of the concretions. At both localities the concretions grade into or incorporate masses of clayey concretionary rock that has resulted from alteration of the bentonite. Fragments of *Inoceramus* and *Ostrea* were observed in these concretions at all three localities. *Ostrea* is especially abundant in some concretion fragments at Locality 8, and a single specimen each of *Plesiacanthoceras amphibolum* and *Borrisiakoceras reesidei* were collected in concretions at Locality 34. A thin section of concretionary matrix from Locality 34 is composed almost entirely of cryptocrystalline limestone and silt-sized blebs of microcrystalline pyrite. The homogeneous matrix is interrupted in a few places by areas of sparry calcite as much as 0.1 mm in maximum dimension. I believe that these concretions are fossil-centered.

At Locality 32, a 0.2-foot-thick layer of olive-gray (5Y4/1), moderate yellowish-brown-weathering, concretionary limestone that contains vertical veins of coarsely crystalline, nearly white calcite lies 13.9 feet below the top of the Graneros. As seen in thin section the rock has a mosaic texture consisting dominantly of silt- and very fine sand-sized grains of calcite with a scattering, and local concentration, along original stratification, of angular to well rounded quartz silt. The original rock was a quartz-bearing skeletal limestone cemented by sparry calcite and formed the upper part of an ammonite-rich coquinoidal limestone that has been described above. Concretionary enlargement of the original rock apparently took place mostly by calcite addition to areas of calcite cement, accompanied by solution transfer which destroyed the original outlines of many now scarcely recognizable *Inoceramus* prisms. Calcite has replaced the margins of many grains of quartz in this rock.

At Locality 42, just above the middle of the Graneros Shale, a dark reddish-brown, crumbly-weathering, calcareous, clayey septarian concretion with granular texture has formed in or on a 0.2-foot-thick bentonite bed. The concretion is 1.1 foot thick and 3.4 feet across. In thin section the rock appears as a loosely knit mosaic of calcite grains through which are scattered numerous calcitic spherulites with radial structure. Irregular bodies of clay scattered through the concretion are probably bits of bentonite that became separated by enlargement of calcite grains. Silt-sized blebs of reddish-brown limonite or hematite are distributed irregularly throughout the rock and are commonly concentrated around the margins of spherulites. Masses of clayey concretionary rock associated with the limestone septaria in the bentonite marker bed at Localities 8 and 34 are similar to rock in the concretion at Locality 42.

Septarian limonitic claystone concretions 0.1-foot thick and as much as 0.7 foot in diameter lie 12 feet below the top of the Graneros at Locality 12. Such concretions were not observed elsewhere in the formation.

FOSSILS AND CORRELATION

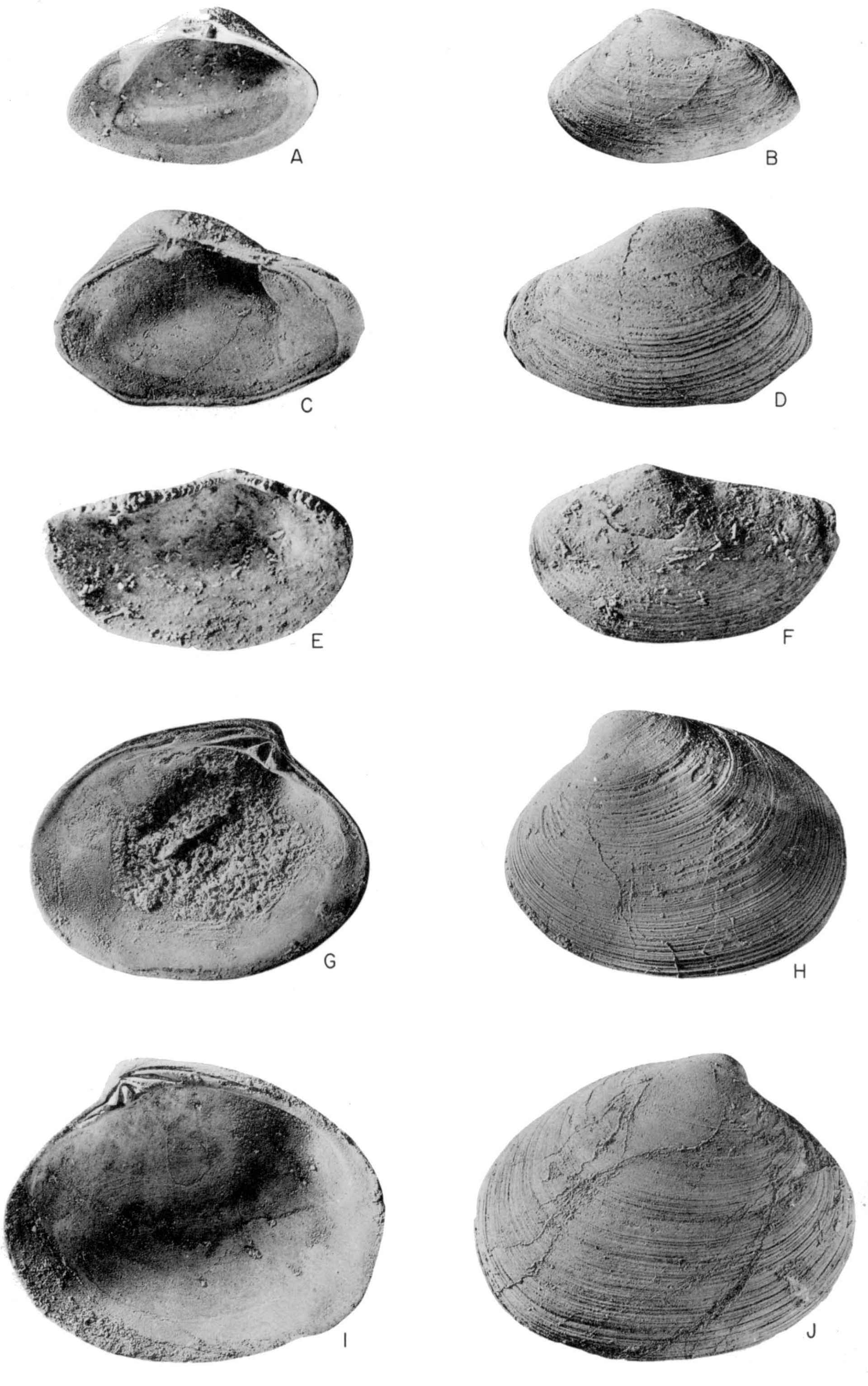
The Graneros Shale of Kansas contains a far greater diversity and number of invertebrate fossils than is evident from the literature. Rubey and Bass (1925) presented the earliest stratigraphic summary of Graneros macroinvertebrates in Kansas. They recorded approximately 10 species and noted the faunal differences between the lower and upper parts of the formation. Morrow (1934, 1935) described one foraminifer and two ammonites from the upper part of the formation. The most comprehensive work, an unpublished Ph.D. thesis by Morrow (1941), includes descriptions of 16 macroinvertebrate species and one species of foraminifer. This assemblage is considerably revised and greatly expanded herein and most of the macroinvertebrates are illustrated in Plates 2 to 5. Except for *Ostrea* in the higher parts of the formation and in a few exposures along the Smoky Hill River and Saline River valleys the macroinvertebrates are represented largely by molds, which in shale units are commonly much compressed. The more conspicuous occurrences of fossils are in sandstone, calcareous sandstone, and skeletal and coquinoidal limestone beds, but a few bedding planes in shale are literally covered with fossils at some localities, for example, 14 and 43. Distribution of fossils is erratic vertically and laterally even in adjacent localities, for example, Localities 3 and 43, which show opposite extremes in abundance of specimens in equivalent parts of the section. This erratic distribution necessitated systematic search requiring layer-by-layer splitting of shale and sandstone units, such search commonly yielding the only fossils observed at a particular locality.

Fossils from the Graneros Shale may be divided rather conveniently into two assemblages, the strata characterized by each thus constituting an assemblage zone. The dominant species of the lower assemblage zone is *Callistina lamarensis* (Shumard); the dominant species of the upper assemblage zone is *Ostrea beloiti* Logan. The two zones are herein so named, respectively. Macroinvertebrate fossils in the two zones are listed separately below. The most characteristic or abundant fossils are *preceded* by an asterisk (*). Guide fossils are indicated by a dagger (†). Forms observed at only one locality or by no more than one specimen at any locality are *followed* by an asterisk (*).

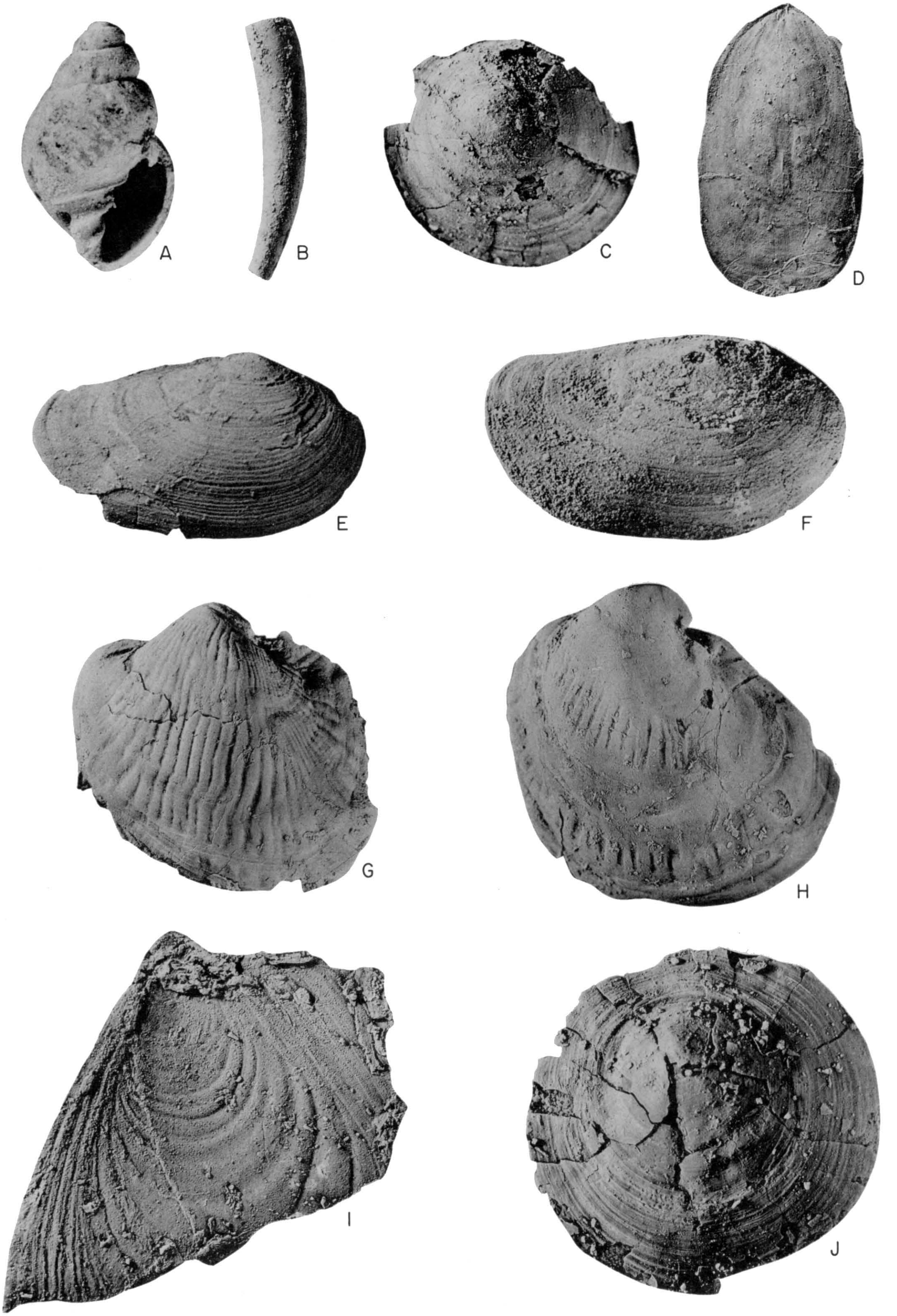
EXPLANATION OF PLATE 2

Pelecypods from the coquinoidal limestone lens in the *Callistina lamarensis* Assemblage Zone at Locality 5.

A-D. Parmicorbula? hillensis Stephenson, var., all ×3. *A,* Interior, left valve; *B,* exterior, same valve; *C,* interior, right valve; *D,* exterior, same valve.
E-F. Nuculana aff. *N. longifrons* Stephenson, ×5. *E,* Interior, left valve; *F,* exterior, same valve.
G-J. Callistina lamarensis (Shumard), all ×2. *G,* Interior, left valve; *H,* exterior, same valve, hypotype, KU12104PI; *I,* interior, right valve; *J,* exterior, same valve, hypotype, KU12104P2.



HATTIN—GRANEROS SHALE (UPPER CRETACEOUS) IN CENTRAL KANSAS



HATTIN—GRANEROS SHALE (UPPER CRETACEOUS) IN CENTRAL KANSAS

Macroinvertebrates observed in Callistina lamarensis Assemblage Zone:

Brachiopoda
- *Lingula* cf. *L. subspatulata* Hall & Meek
- *Discinisca* sp. *A*
- *Discinisca* sp. *B*

Pelecypoda
- *Anatimya* sp.*
- †**Callistina lamarensis* (Shumard)
- **Exogyra columbella* Meek
- *Inoceramus* sp.
- *Inoceramus* aff. *I. dunveganensis* McLearn
- *Nuculana* aff. *N. longifrons* Stephenson
- *Parmicorbula? hillensis* Stephenson var.
- pectenoid pelecypods, molds*
- pelecypod mold, genus *A*, unidentified*
- pelecypod mold, genus *B*, unidentified*
- *Yoldia? subacuta* Stephenson var.

Gastropoda
- *Lispodesthes* cf. *L. patula* Stephenson*
- *Ringicula* sp.*

Scaphopoda
- *Fustiaria (Laevidentalium)* sp.*

Macroinvertebrates observed in Ostrea beloiti Assemblage Zone:

Pelecypoda
- *Callistina lamarensis* (Shumard)
- **Inoceramus rutherfordi* Warren
- †**Ostrea beloiti* Logan

Gastropoda
- *Capulus* sp.
- gastropod, high spired mold, unidentified

Cephalopoda
- *Plesiacanthoceras amphibolum* (Morrow)
- *Borissiakoceras reesidei* Morrow
- belemnoid?, unidentifiable fragments*

Cirripedia
- scalpellid, capitular plates

The *Callistina lamarensis* Assemblage Zone is recognized throughout the central Kansas outcrop and is defined generally as including all Graneros strata up to the lowest occurrences of *Ostrea beloiti*. At the few localities (1, 5, 9, 18, 43, and 46) where the local ranges of *C. lamarensis* and *O. beloiti* overlap, the dominant form is taken as the zonal determinant. As thus defined, the upper assemblage zone in the area of best expression (Russell and Ellsworth counties) occupies the upper 14 to 16 feet of the formation and at Locality 18 the upper 18 feet of the formation.

The *Ostrea beloiti* Assemblage Zone is recognized in the region from Locality 16 in Washington County to Locality 31 in Barton County. North of Locality 9 the upper part of the formation is poorly fossiliferous, but normal stratigraphically, i.e., the bentonite marker bed is present as well as a foot or more of superjacent shale. The near absence of the *O. beloiti* assemblage in this area is assumed to be owing to lack of preservation. In the southern part of the central Kansas outcrop, from Locality 20 southward, the *Callistina lamarensis* assemblage occupies nearly the entire section and the *O. beloiti* assemblage is missing entirely.

General faunal zonation of the Graneros Shale and its equivalents in the Western Interior Region, as recognized by Cobban (1961, p. 740), is as follows:

Plesiacanthoceras wyomingense (Reagan)
Plesiacanthoceras amphibolum (Morrow)
Borissiakoceras compressum Cobban.

The *B. compressum* Zone of Colorado and Wyoming was not recognized in Kansas during the present study. Beds containing the *Callistina lamarensis* assemblage may be equivalent to some part or all of the *B. compressum* Zone or may be an environmentally controlled local biofacies within the *P. amphibolum* Zone. Probably for ecological reasons, ammonites are not represented in the lower part of the Graneros in Kansas. Other species from the lower part of the Graneros are too long ranging or too little known to permit precise westward correlation

EXPLANATION OF PLATE 3

Mollusks and brachiopods from the *Callistina lamarensis* Assemblage Zone.

A. *Ringicula* sp., ×7, from coquinoidal limestone lens at Locality 5.
B. *Fustiaria (Laevidentalium)* sp., ×5, from coquinoidal limestone lens at Locality 5.
C, J. *Discinisca* sp., ×5, both from shale unit lying at base of Graneros at Locality 3.
D. *Lingula* cf. *L. subspatulata* Hall & Meek, ×3, from shale unit lying at base of Graneros at Locality 13.
E. *Yoldia? subacuta* Stephenson, var., ×3, from coquinoidal limestone lens in lower part of Graneros Shale at Locality 5.
F. *Nuculana* aff. *N. longifrons* Stephenson, ×5, from coquinoidal limestone lens in lower part of Graneros at Locality 5.
G-H. *Exogyra columbella* Meek, from coquinoidal limestone lens in lower part of Graneros at Locality 5. *G,* Strongly costate left valve, ×1½, hypotype, KU12104P3; *H,* weakly costate left valve, ×2, hypotype, KU12104P4.
I. *Inoceramus* aff. *I. dunveganensis* McLearn, ×2, from shale unit lying at base of Graneros at Locality 3.

of the *C. lamarensis* Assemblage Zone at this time.

Plesiacanthoceras amphibolum and its companion, *Borissiakoceras reesidei* Morrow, are well represented, at least locally, in the *O. beloiti* Assemblage Zone of Kansas and the latter zone is equivalent to at least part of the *P. amphibolum* Zone of Colorado and Wyoming. Both of these ammonites have been collected from a concretion in the bentonite marker bed at Locality 34 but only *P. amphibolum* has been observed above the bentonite. In Kansas the Zone of *Plesiacanthoceras wyomingense* may possibly be represented, at least in part, by the uppermost 1 or 2 feet of Graneros Shale, but no identifiable ammonites are yet known from this stratigraphic interval. The Zone of *Dunveganoceras pondi* Haas succeeds the Zone of *P. wyomingense* in the Western Interior Region and lies in beds equivalent to the Lincoln Limestone Member of the Greenhorn Limestone (Cobban and Reeside, 1952a, p. 1017). In the central part of the Graneros outcrop in central Kansas, I have observed molds of a large, horned ammonite at several localities in the basal part of the Lincoln Member of the Greenhorn Limestone. This species appears to be *Dunveganoceras pondi*. Absence of the *P. wyomingense* Zone in this part of the State is taken as further evidence of an hiatus at the Graneros-Greenhorn contact.

In the southern part of the central Kansas outcrop fossils of the *C. lamarensis* Assemblage Zone are well represented at several localities, notably 20, 24, 39, and 41. At Locality 39 this species occurs within 1.8 feet of the top of the Graneros section. None of the southern exposures studied during this investigation contain elements of the *O. beloiti* assemblage, and the bentonite marker bed is not represented at any of these exposures. These facts support stratigraphic and lithologic evidence for an hiatus between Graneros and Greenhorn strata across much of central Kansas. Large numbers of *O. beloiti* at the base of the Greenhorn at Locality 39 and whole specimens and fragments of this species in the basal Lincoln beds at several localities is suggestive of reworking of the Graneros, specifically the *O. beloiti* Assemblage Zone, during a period of sublevation. Occurrence of *Plesiacanthoceras wyomingense* near the base of the Greenhorn at Locality 41 indicates that Greenhorn deposition in this area began sooner than in the central and northern areas of central Kansas.

Most common of Graneros macroinvertebrates in the lower assemblage zone is *Callistina lamarensis*, which was observed at 28 localities during the course of this study. The species has been collected near the top of the section, within 2 feet of the top at Locality 39, in the southern part of the outcrop where the upper part of the formation appears to have been removed before Greenhorn deposition began. Specimens are preserved chiefly as molds, most commonly in shale and noncalcareous sandstone units, but locally, as at Localities 1, 2, 5, 37, and 39, in calcareous sandstone. Shells are preserved only in the coquinoidal limestone lens and enclosing beds at Locality 5 and in the equivalent bed at Locality 37. Observed abundance of specimens in various depositional units ranges from as few as one specimen to specimens so numerous as to nearly cover bedding planes on which they occur. The most concentrated occurrences are in the coquinoidal limestone lens at Locality 5 and in sandstone beds cropping out along the Saline and Smoky Hill rivers in Russell County and along Sawlog Creek in Hodgeman County. This species ranges locally into the *Ostrea beloiti* Assemblage Zone, including Localities 1 and 9. *C. lamarensis* has been reported outside Kansas only in the Templeton Member of the Woodbine Formation in northeastern Texas. This species occurs also near the top of the Dakota at Locality 30 in association with several molluscan species not known from Graneros strata. Erle G. Kauffman (written communication, 1964) has discovered related forms in the middle and upper parts of the Graneros of northwestern New Mexico and southern Colorado.

Exogyra columbella was observed at 11 Graneros localities ranging geographically from Washington to Hodgeman counties. No specimens were observed higher than 14 feet above the base of the formation. The species is most common in noncalcareous sandstone. It is represented by molds at all of the localities except Localities 5, 21, and 37. At the first of these, left valves are common and well preserved in the coquinoidal limestone lens described above and a few shells were also collected from the bed containing the lens. The same bed contains well-preserved shells at Locality 37, and a sandstone bed lying in approximately the same position at Locality 21 contains a few poorly preserved shells of *E. columbella*. Specimens from Locality 8 show the wide range in surface sculpture described by Stephenson (1952 [1953], p. 77); some are almost completely costate; others are smooth except for growth rings, as in *Exogyra columbella* var. *levis* Stephenson. Because of the complete gradation from extremes of surface sculpture and because the specimens in my collection show no consistent variation in other morphologic features, I conclude that no valves from Localities 5 or 37 merit varietal assignment. No specimens were observed in the *O. beloiti* Assemblage Zone, but I have seen the species in the basal Lincoln at three localities in Kansas.

Exogyra columbella ranges geographically from northeastern Texas westward to northeastern Arizona and has been recognized as far north as central Montana. The geologic range is middle through late Cenomanian in most reported occurrences, including the upper Woodbine through basal Eagle Ford of northeastern Texas, uppermost Dakota and lower Mancos of the Four Corners Region, upper Belle Fourche Shale of the northern Black Hills, and the Mosby Sandstone Member of the Colorado Shale in central Montana. Young (1960, p. 186) notes the occurrence of *Exogyra columbella* in the Zone of *Sciponoceras gracile* (earliest Turonian) of the Mancos Shale of the Four Corners region and Stephenson (1952 [1953], p. 77) records its presence in Turonian rocks of the Western Interior without further comment. The variety *E. columbella levis* has been reported from the Woodbine of Texas and the latest Cenomanian Pouce Coupe Sandstone in the foothills of Alberta and British Columbia.

Brachiopods are not common in the Western Interior Cretaceous so the discovery of specimens at 13 exposures of the Graneros is significant. *Lingula* cf. *L. subspatulata* was collected from the Graneros and Dakota-Graneros transition beds at eight localities and is most common in the former at Locality 13. The type specimen of *L. subspatulata* is from the Pierre Shale of South Dakota. The species has been reported, sometimes questionably, from widely distributed Western Interior localities ranging from New Mexico to Minnesota and as far to the northwest as Alberta and British Columbia, as well as in New Jersey and questionably from the Nacatoch and Woodbine of Texas. The stratigraphic range suggested by these occurrences embraces most of the Late Cretaceous. Stephenson (1952 [1953], p. 54) emphasized the provisional nature of the name *L. subspatulata* as applied to poorly preserved specimens. The Graneros specimens are, for the most part, largely exfoliated or preserved as molds and for this reason I have not used the name unqualifiedly. Discinid brachiopods have been reported from only a few Upper Cretaceous localities in America, and only one discinid, from the Kiowa Shale (Merriam, *et al.*, 1959, p. 36), has been recorded previously in Kansas. In the Graneros, such brachiopods have been recorded with certainty from eight localities, and questionably from one additional locality, and these may represent two species, both of which are probably assignable to the genus *Discinisca*. Eight brachiopod occurrences are in shale, two in sandstone, two in siltstone, and one in calcareous sandstone. These brachiopods are presently of no stratigraphic value.

Evidence of *Inoceramus* was recorded in the lower assemblage zone at 16 localities. The fine-grained matrix of the coquinoidal limestone lens at Locality 5 is composed chiefly of *Inoceramus* prisms. This genus was observed in noncalcareous quartzose sandstone at six exposures, mostly as shell-fragment and prism molds, but as shell material at Localities 18 and 31. *Inoceramus* occurs most widely in shale units in which the genus is sparsely represented by molds of prisms and/or whole or fragmentary shells, nearly all of which were discovered only by extensive splitting of shale fragments. Complete or nearly complete valve molds were observed at only five localities, all in shale. These molds represent immature specimens which cannot be identified with certainty but those from the basal part of the Graneros at Locality 3 suggest affinities with either *I. dunveganensis* McLearn, a Canadian species, or, less likely, *I. eulessanus* Stephenson, a Woodbine species (Erle G. Kauffman, written communication, 1963). The former has been recorded as far north as the Arctic coastal plain of Alaska, the latter only from northeastern Texas.

Clams assigned tentatively to *Parmicorbula? hillensis* var. have been collected from the lower assemblage zone at eight or possibly nine localities as molds, mostly in shale, but as well-preserved shell material in the coquinoidal limestone lens at Locality 5. The form is common in the coquina but sparse elsewhere. This species has been reported elsewhere only from the Lewisville Member of the Woodbine Formation of northeastern Texas.

Among the remaining macroinvertebrate fossils from the *Callistina lamarensis* Assemblage Zone the scaphopod, two gastropods, *Nuculana* and *Yoldia?* were identified from shells collected in the coquinoidal limestone at Locality 5. Rare nuculanid molds were collected in shale at Localities 14, 24, and 36, and a mold of *Anatimya* was collected in shale at Locality 14. An unidentified pelecypod mold was collected at Locality 5 in the unit containing the coquinoidal limestone lens and another unidentified pelecypod mold was collected in shale at Locality 6.

Three molds of pectenoids were collected in association with *Lingula* in the basal part of the Graneros at Locality 13.

In the upper assemblage zone *Ostrea beloiti* was recorded at 27 localities extending geographically from Barton to Washington counties. The species is especially abundant in Russell, southwestern Lincoln, and northwestern Ellsworth counties where it ranges through the top 9 (Loc. 6) to 15.6 feet (Loc. 43), and at Locality 18 through the upper 21 feet of the Graneros.

Shell fragments, possibly belonging to *O. beloiti,* were observed in calcareous sandstone lying only 5 feet above the base of the Graneros at Locality 7. The species occurs in the upper part of the *Callistina lamarensis* Assemblage Zone at Localities 18, 43, and 46. The best preserved and most abundant specimens are in beds of skeletal limestone and calcareous sandstone or in coquinoidal limestone bodies. Specimens in shale are usually crushed, partially decomposed, represented only by molds, or replaced by gypsum as at Localities 1, 34, and 36, but excellent *O. beloiti,* some pyritized, are preserved in weakly calcareous shale at Locality 43. Oysters were recorded in noncalcareous sandstone at only three localities. *O. beloiti* was described originally from the Lincoln Limestone Member of the Greenhorn Limestone in Mitchell County, Kansas (Logan, 1899b, p. 214) and according to Erle G. Kauffman (written communication, 1963) ranges from the middle part of the Graneros into the Lincoln Member of the Greenhorn in Colorado. *O. beloiti* is abundant locally in the basal part of the Lincoln of Kansas, especially at Locality 39 where it forms a coquina.

During the present investigation the ammonite *Plesiacanthoceras amphibolum* (Morrow) was observed at 13 localities, mostly in Russell and Ellsworth counties and is seemingly restricted to the upper 15 feet of the Graneros Shale. At seven localities this species occurs as impressions of immature specimens in noncalcareous silty shale. Partially flattened molds of mature and immature specimens, many with shell material still preserved, are common in weakly calcareous shale at Locality 43. Well preserved internal molds were collected from calcareous concretions at four localities. At three of these, namely 18, 32, and 33, the ammonites, many of which are fragmentary, are in a concretionary coquinoidal limestone bed that lies about 14.5 feet below the top of the formation. Ammonites from the limestone at Locality 32 are abundant and the shell, exhibiting fine, closely spaced growth lines, is preserved on some specimens at Localities 32 and 33. Strong ribs are preserved in the adult stage of several specimens (Pl. 5) and the circumumbilical row of tubercles does not migrate up the flanks as in the younger *P. wyomingense* (Reagan). In my opinion, Morrow's species is transitional between *P. wyomingense* and typical *Acanthoceras.*

Elsewhere in the Western Interior Region, notably in the Powder River Basin, the upper part of the Belle Fourche Shale contains the Zone of *Plesiacanthoceras wyomingense* (Reagan) which lies between that of *P. amphibolum* and the lowermost Greenhorn ammonite zone, that of *Dunveganoceras pondi* Haas. As discussed above, the basal Greenhorn in parts of central Kansas contains large ammonite molds probably of *D. pondi,* but at these places the subjacent Zone of *P. wyomingense* is apparently not represented. This gap in the paleontological record in Kansas is represented in Wyoming and south-central Montana by the upper part of the Belle Fourche Shale and by the Zone of *P. wyomingense.* Beds in central Kansas that are at least in part chronologically equivalent to the upper part of the Belle Fourche Shale are known only from the southernmost part of the outcrop at Locality 41, where *P. wyomingense* occurs in a limestone bed lying 0.8 foot above the base of the Greenhorn. As explained above, at this locality the *Ostrea beloiti* Assemblage Zone, containing *P. amphibolum,* is absent owing to an hiatus at the Graneros-Greenhorn contact.

Published accounts of *Plesiacanthoceras amphibolum* indicate a geographic range extending east-west from central Kansas to western Colorado and W. A. Cobban (personal communication, June, 1964) reported a latitudinal range extending from the San Juan Basin to northern Montana. This species is the zonal index for the middle part of the Belle Fourche Shale and its equivalents in the Western Interior (Cobban and Reeside, 1952a, p. 1017). In Kansas the species occurs in the upper part of the Graneros Shale and in western Colorado has been collected near Delta from a horizon that lies 10 feet above the base of the Mancos Shale (Katich, 1959, p. 26). In Wyoming *P. amphibolum* has been reported from the upper part of the Frontier Formation near Kaycee and Buffalo (Cobban and Reeside, 1952b, p. 1954, 1955) and in the basal part of the Cody Shale near Greybull (Cobban and Reeside, 1952b, p. 1957). In Montana this form has been reported from the middle part of the Belle Fourche Member of the Cody Shale (Knechtel and Patterson, 1956, p. 20).

Borissiakoceras reesidei (Morrow) was described from specimens collected from a limestone concretion near the top of the Graneros Shale, probably at Locality 8. During the present study, specimens of *Borissiakoceras* were collected at 10 localities, including the presumed type locality for this species, and in all but three occurrences were associated with *Plesiacanthoceras*. Most of the specimens are flattened impressions in noncalcareous shale and because of the minute size and poor preservation, specific identification of most of these fossils is difficult. At Locality 32, a single conch of *B. reesidei* was collected in the coquinoidal limestone lens that contains *Plesiacanthoceras amphibolum*, and, in the same unit at Locality 33, part of an internal mold of *Borissiakoceras* was collected. A large, poorly preserved specimen was collected from a concretion in the bentonite marker bed at Locality 34, 2.5 feet below the top of the Graneros. Molds are common in weakly calcareous shale at Locality 43 and a well-preserved internal mold composed of calcite and marcasite was collected by W. A. Cobban in a concretionary mass of skeletal limestone lying near the top of the Graneros at the same place. Outside Kansas *B. reesidei* has been recorded in the upper part of the Graneros Shale near Pueblo, Colorado, in the basal beds of the Cody Shale near Parkman, Wyoming, and in the upper part of the Frontier Formation near Buffalo, Wyoming (Cobban, 1961, p. 750).

Specimens of *Inoceramus* were observed in the upper assemblage zone at 28 localities ranging from Washington to Barton counties. The greatest abundance of these remains is in skeletal limestone composed largely of isolated prisms and fragmentary shells and occurring as beds and concretionary masses of rock. Prisms and shell fragments, locally making up nearly 20 percent of the grains, are also common in calcareous sandstone, a class of rocks in which *Inoceramus* remains were recorded as common, though in much smaller quantity than in skeletal limestone. Shell remains occur in calcareous shale in the upper part of the Graneros at three places and are abundant at Locality 43. At 16 localities *Inoceramus* occurs in noncalcareous silty shale in which the genus is represented sparsely by prisms or by molds of prisms and/or whole or fragmentary shells which were discovered by extensive splitting of shale fragments. Shell material is preserved in noncalcareous shale in the upper assemblage zone in four localities at one of which, Locality 34, the shells are replaced by gypsum.

Identifiable specimens of *Inoceramus* were collected at Localities 15 and 43 where both shells and molds are rather poorly preserved in calcareous shale, at Localities 8 and 32 in skeletal limestone lying approximately 1 foot below the top of the Graneros, and at Localities 32 and 33 where specimens, some with shell material, are common in concretionary coquinoidal limestone that lies approximately 14.5 feet below the top of the Graneros. At the last two localities the shell is bound firmly to the rock matrix but not to the internal mold, so only fragments of the shells, usually nacreous material, can be extracted with the mold. Two specimens of *Inoceramus* were collected from the same concretionary unit at Locality 18 but these were not well preserved. W. A. Cobban discovered several well-preserved specimens in a limestone concretion at Locality 43. Dr. Erle Kauffman (written communication, 1963) examined the specimens from Localities 32 and 33 and believes that they are "definitely the same as *I. rutherfordi* Warren." Dr. Cobban (personal communication, June, 1964) confirmed this identification of *Inoceramus* specimens from the upper part of the Graneros. *I. rutherfordi* is known from the Dunvegan Formation of western Canada, and, in a zonal sequence prepared by J. A. Jeletzky (Stott, 1963, table 4), is shown as occurring in the Zone of *Plesiacanthoceras wyomingense* (Reagan) rather than that of *Plesiacanthoceras amphibolum* in which most of the Kansas specimens occur. According to Cobban (written communication, 1964), *Inoceramus rutherfordi* occurs in the zones of both *P. amphibolum* and *P. wyomingense* in the Western Interior of the United States and has a known geographic range extending from northern New Mexico to southern Montana. Early forms of *I. rutherfordi* have been collected by Dr. Kauffman (written communication, 1964) from below the Zone of *P. amphibolum* in Colorado.

Several molds assigned to the genus *Capulus* by Sohl (written communication, 1963) were extracted from the concretionary skeletal limestone bed at Localities 32 and 33. A single mold of this genus, and that of an unidentified high-spired gastropod, were collected in slightly calcareous shale at Locality 43. Hollow cylindrical objects consisting of dark-brown radially prismatic calcite were collected from the concretionary skeletal limestone at Locality 32 and are assigned provisionally to the Belemnitida.

MICROFOSSILS

Shale samples from each of the key sections, and selected samples from other localities, were washed for examination for microfossils. Foraminifers were recovered in considerable numbers from the upper part of the Dakota Formation and throughout the Graneros Shale. A suite of specimens was sent to Dr. Don L. Eicher, University of Colorado, for identification and these specimens were used as guides in making subsequent identification. The following species, listed alphabetically, are recognized in the Graneros Shale of central Kansas:

- *Ammobaculites* cf. *A. bergquisti* Cushman and Applin
- *A. impexus* Eicher
- *Ammobaculoides plummerae* Loeblich
- *Ammodiscus planus* Loeblich
- *Hedbergella amabilis* Loeblich and Tappan
- *H. brittonensis* Loeblich and Tappan
- *H. delrioensis* (Carsey)
- *H. planispira* (Tappan)
- *Heterohelix globulosa* (Ehrenberg)
- *Reophax minuta* Tappan
- *R. pepperensis* Loeblich
- *Tolypammina?* sp.
- *Trochammina* cf. *T. depressa* Lozo
- *T. rainwateri* Cushman and Applin
- *Trochamminoides apricarius* Eicher
- *Verneuilinoides perplexus* (Loeblich)

In the following discussion, notation of abundance is based on the number of specimens per sample, according to a uniform picking procedure for each sample, with rare=1 to 2, sparse =3 to 10, common=11 to 50, and abundant= 51+.

Despite the relatively small number of sections examined for microfossils, it is possible to recognize three broadly defined foraminiferal assemblage zones. The first and oldest of these zones is characterized by coiled and uniserial arenaceous species, the second zone is characterized by dominance of *Reophax minuta*, and contains species from both of the other zones, and the third zone is characterized by planktonic species. The first zone, occupying the lowest 14 to 22 feet of the formation, and corresponding approximately to the *Callistina lamarensis* Assemblage Zone, includes the following association of species:

- *Ammobaculites* cf. *A. bergquisti* (rare to abundant, mostly rare)
- *A. impexus* (rare)
- *Ammobaculoides plummerae* (rare to common, mostly rare)
- *Reophax minuta* (sparse to abundant, mostly common)
- *R. pepperensis* (rare to common, mostly rare to sparse)
- *Trochammina rainwateri* (rare to abundant, mostly sparse to common)
- *Verneuilinoides perplexus* (rare to abundant, mostly sparse to common)

The following species also occur in this zone:

- *Hedbergella brittonensis* (one sample, common)
- *H. delrioensis* (three samples, rare)
- *Heterohelix globulosa* (one sample, rare)
- *Tolypammina?* sp. (one sample, rare)
- *Trochammina* cf. *T. depressa* (one sample, rare)
- *Trochamminoides apricarius* (rare to sparse)

[In addition to the above-named species, Eicher (1965, p. 892) reported a single *Ammodiscus planus* from this Assemblage Zone at Locality 1.]

The second assemblage zone embraces strata lying between the top of the first assemblage zone and a horizon ranging from 1 to 4 feet below the top of the Graneros or, at Locality 23, extending to the top of the Graneros section. In this zone, *Reophax minuta* occurs alone or with a generally rare to sparse representation of species from both underlying and overlying foraminiferal zones. A single specimen of *Ammodiscus planus* was picked from a sample in this zone from Locality 20, and a single specimen of *Ammobaculites impexus*, probably from this zone, was recorded at Locality 1 by Eicher (1965, p. 896). At the localities studied the number of species in this assemblage zone is less than the number of species in the lowest assemblage zone.

The Graneros foraminiferal fauna of Colorado is more diverse than that of Kansas and includes most of the species I have found in Kansas. On the basis of foraminifers, Eicher (1965, p. 888) suggested that the entire Graneros section of central Kansas is equivalent to the *Trochamminoides apricarius* Zonule, which lies in the upper part of the Graneros in Colorado. Species in the Graneros of Kansas that have been recorded also in the Pepper Shale (Cenomanian) of east-central Texas (Loeblich, 1946), include: *Ammodiscus planus*, *Ammobaculoides plummerae*, *Reophax pepperensis*, and *Verneuilinoides perplexus*. The Pepper Shale is believed by Adkins and Lozo (1951, p. 113) to be the southern extension of the Lewisville Member of the northeastern Texas Woodbine Formation. From the Templeton Member of the Woodbine Formation Cushman and Applin (1947) reported the following species that occur in the Graneros of Kansas: *Ammobaculites bergquisti*, *Ammobaculoides plummerae*, and *Trochammina rainwateri*. *Reophax minuta* is a long-ranging form that has been recorded in beds as old as the Duck Creek Formation (Albian) by Tappan (1943, p. 480). *Hedbergella planispira* has been reported from beds above and below the Woodbine but not in that Formation (Loeblich and Tappan, 1961, p. 277). In Texas, *H. amabilis* and *H. brittonensis* occur in the lower part of the Eagle Ford Formation, and *H. delrioensis* in the Grayson Formation and Del Rio Clay (Loeblich and Tappan, 1961). *Heterohelix globulosa* is a long-ranging species. Additional information on distribution of Graneros foraminifers outside Kansas has been summarized by Eicher (1965).

This preliminary study of foraminifers in the Graneros of Kansas, especially the arenaceous species, tends to support the evidence of the macroinvertebrates that the Graneros Shale is correlative with the upper part of the Woodbine Formation in Texas. Precise time equivalence is difficult to establish because the Kansas micro- and macrofaunas are less diversified than those in the upper part of the Woodbine. Furthermore, much of the similarity probably reflects an ecological control because the lithologic sequence in the Woodbine and lower part of the Eagle Ford is much like that in the Dakota-Graneros-Greenhorn sequence of Kansas.

ICHNOFOSSILS

Trace fossils or *Lebensspuren* of invertebrate organisms occur in the *Callistina lamarensis* Assemblage Zone, especially near the top, at a number of localities. More or less cylindrical castings of two widely divergent sizes occur in jarosite-stained, fine-grained silty sandstone at three localities (Fig. 7, *A*). These lie parallel to the bedding surfaces, stand in relief on both upper and lower surfaces of the sandstone layers, and are probably feeding trails of some kind of worm. Solitary burrows, standing perpendicular or at a steep angle to the bedding, occur in jarosite-stained silty sandstone and sparsely in silty shale at several localities. These structures, which are filled with very fine sand or silt, are interpreted as dwelling places, also of some kind of worm. Another variety of dwelling structure consists of paired cylindrical burrows that are demonstrably U-shaped in a few examples and are assigned to the genus *Arenicolites*. The burrows, the limbs of which are each approximately 3 to 4 mm in diameter, are common in jarosite-stained silty sandstone (Fig. 7, *B*) and in a slightly older bed of calcareous siltstone at Locality 5 (Fig. 9, *D*). The ends of the burrow in some jarositic sandstone specimens open into the bottom of a cone-shaped depression. At Locality 43, calcareous silty sandstone near the top of the zone contains numerous peculiar, raised bilobate structures that are either burrows or resting marks of an unknown organism, and trackways of a small arthropod (Fig. 10, *A*). The same kind of trackway was collected from shale at Locality 14.

Trace fossils that I have observed in the *Ostrea beloiti* Assemblage Zone consist mostly of somewhat fusiform fecal castings on surfaces of calcareous sandstone and skeletal limestone beds. A skeletal limestone bed lying beneath the bentonite marker bed at Locality 5 contains arthropod trackways and resting marks (Fig. 10, *C*) and raised bilobate structures, each the same as the respective structures in calcareous silty sandstone at Locality 43.

DEPOSITIONAL ENVIRONMENT

General Statement

Determination of physical and chemical conditions in an ancient depositional environment depends not only upon stratigraphic and lithologic studies of the pertinent rock sections, but also upon ecological evidence furnished by fossils contained therein. Conversely, paleoecological interpretation of fossils demands not only a critical examination of organic remains but also detailed investigation of the enclosing strata. Despite the interrelationship between depositional environment and paleoecology, fundamental differences separate the two concepts. Therefore, in the following paragraphs I will discuss first the environmental conditions of Graneros deposition from the standpoint of stratigraphic variation of rock texture, structure, and composition. Next will follow an analysis of paleoecological implications of Graneros fossils, including further evidence bearing upon conditions in the depositional environment. Ideally, a paleoecological study should embody some combination of qualitative and quantitative techniques designed to extract a maximum of information from the incompletely preserved record of ancient biotopes. Because Graneros fossils are abundant at only a few localities and are mostly preserved as molds, paleoecological data are restricted mostly to observations pertaining to features of preservation and orientation, faunal and lithologic association, and stratigraphic distribution. Within the limits imposed by time and evolution, comparisons are drawn between some of the more common Graneros species and living representatives of the same genera or families.

Salinity

General consideration of stratigraphy and paleontology of the Dakota Formation and Graneros Shale focuses attention on two major factors bearing on salinity. The first of these is the change upward in the Dakota from plant-, fossil-, lignite-, and channel-sandstone-bearing beds to interbedded shales, carbonaceous shales, and evenly bedded sandstones, some of which contain marine fossils, and the marine character of the gradationally superjacent Graneros. The second factor is the lateral equivalence of the upper part of the Dakota in central Kansas to the lower part of the Graneros farther west. These relationships reflect an eastward transgression during which one would expect the depositional environment to change gradually from wholly nonmarine to marginal marine and ultimately to open marine conditions. The fluvial environment, represented most conspicuously by Dakota channel deposits, was one of fresh water; the marginal marine environment would have been brackish owing to discharge of streams; the open marine environment most nearly would have approached normal or nearly normal salinity as the retreating shoreline became even more remote from central Kansas and dilution by river discharge diminished.

In addition to inferences based on stratigraphy and the broad aspects of Graneros paleontology, upward change in clay-mineral content, as discussed below, suggests a gradual salinity increase during deposition of the uppermost Dakota and Graneros sediments. Trask (1937) showed the relationship between increase of salinity and increase of calcium carbonate content of marine sediments and noted (1937, p. 292) that "Sediments in areas where the salinity is less than 34 parts [per thousand] in general contain less than 5 percent of calcium carbonate. . . ." The near absence of calcareous rocks in the lower part of the Graneros and conspicuous development of such beds in the upper part of the formation, especially including skeletal limestone and calcareous shale, seemingly support other evidence for increase of salinity to normal or nearly normal as Graneros deposition proceeded. Stratigraphic distribution in uppermost Dakota and Graneros strata of certain invertebrate fossils, especially brachiopods, foraminifers, and ammonites, which are discussed in detail below, further strengthens my conclusion that salinity of the water changed gradually from brackish to normal or nearly normal during accumulation of the Graneros sediments in central Kansas.

A most fruitful area for future geochemical investigation of the Graneros Shale would be a study of trace element distribution in relation to salinity.

Turbulence and Depth of Water

A variety of stratigraphic, sedimentologic, and paleontologic evidence manifests the environmental turbulence that existed during much of the time of Graneros deposition. Shale in the lower part of the formation at many localities is streaked with irregular laminae and lenses of very fine sand and silt which impart an appearance of the kind that Häntzschel (1939, p. 202) and many other authors ascribed to rapidly changing currents and agitated waters (Fig. 5, *A, B*). The gentle cross-lamination and cleanly washed condition of many sandstone, siltstone, and skeletal limestone units that are distributed unevenly throughout the formation are ample evidence of extensive wave and current activity.

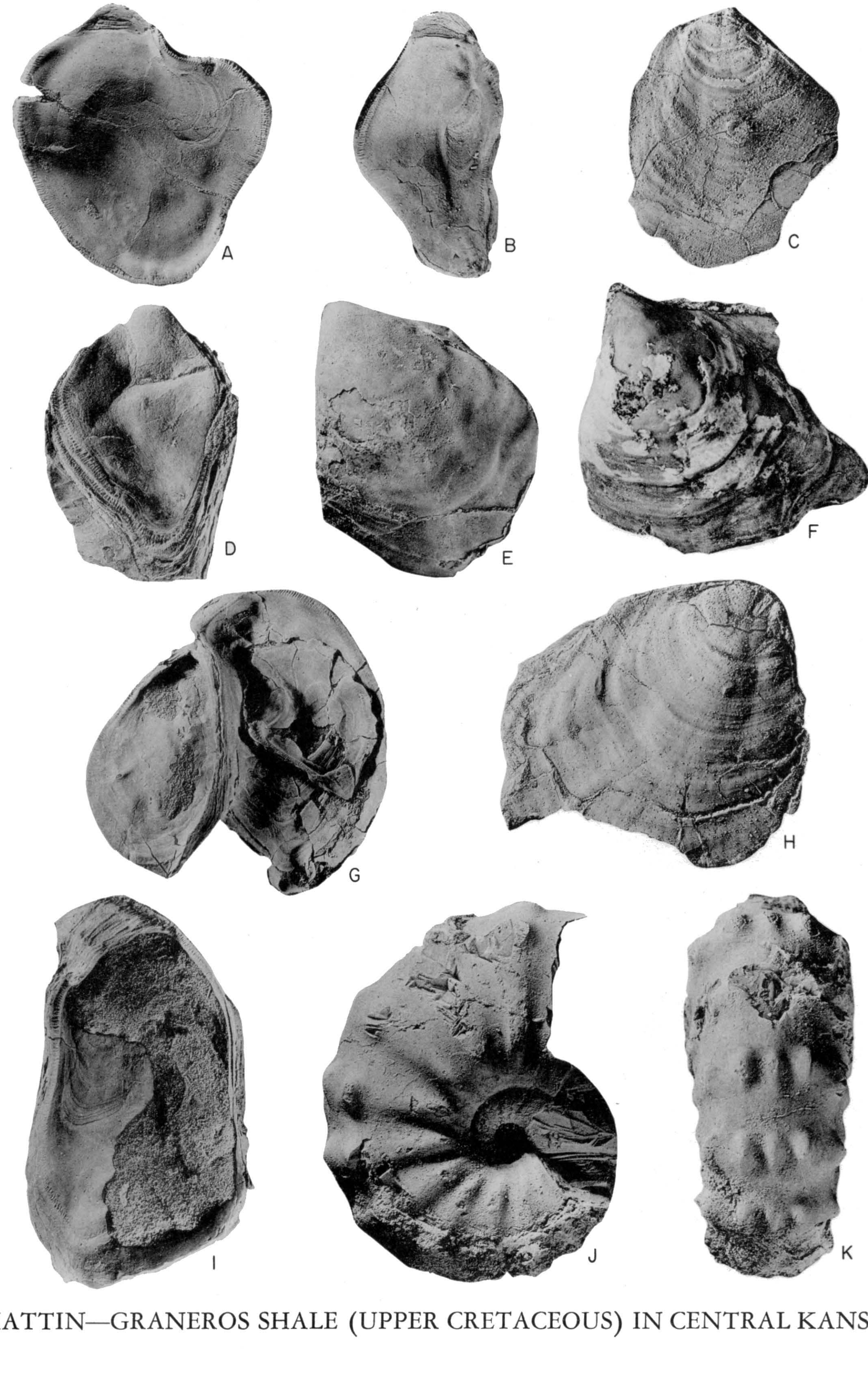
EXPLANATION OF PLATE 4

Mollusks from the *Ostrea beloiti* Assemblage Zone.

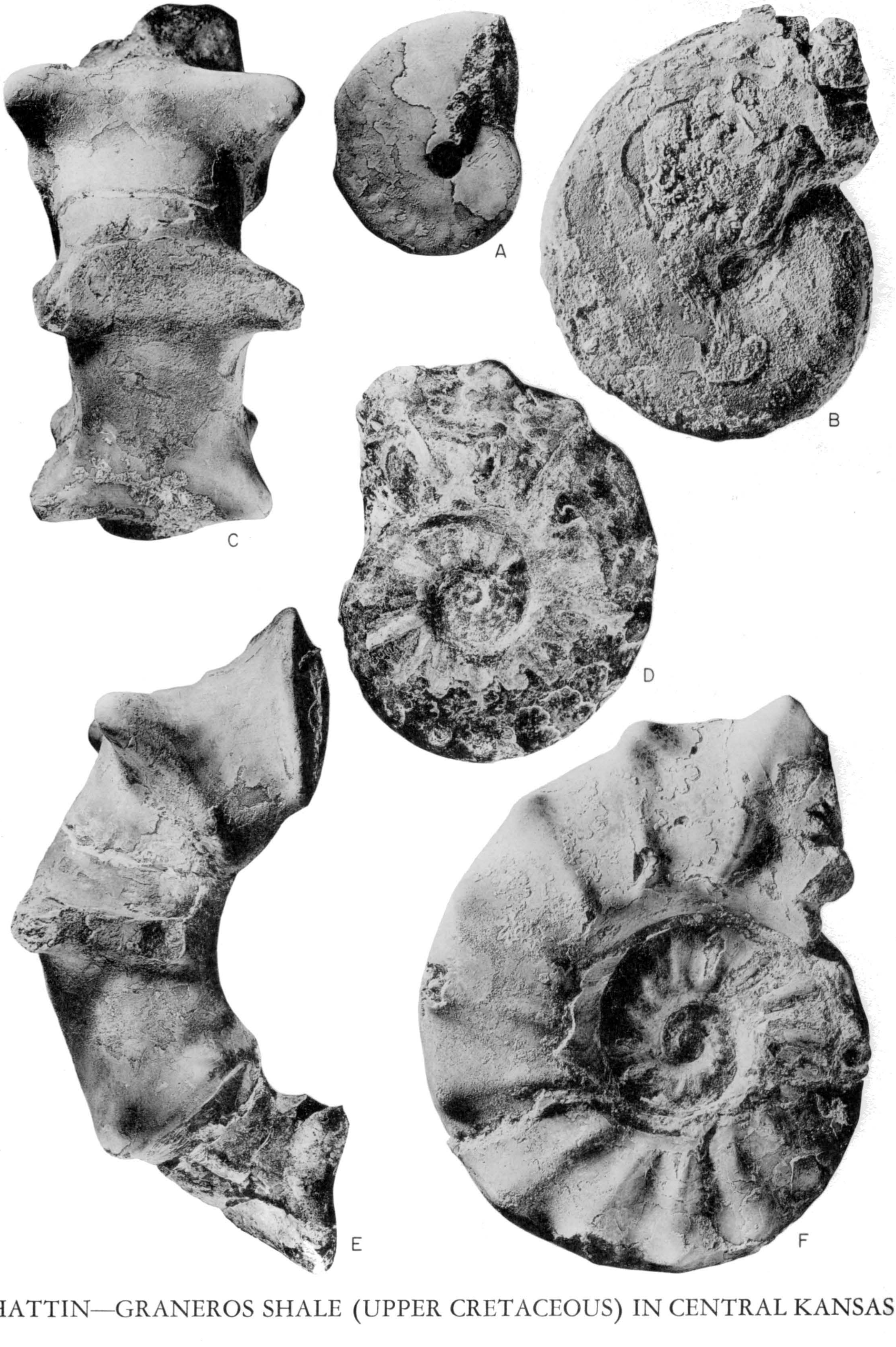
A, B, D, G, I. *Ostrea beloiti* Logan. *A, B,* Interior views, right valves, both ×1½, hypotypes, KU12104P5, KU12104P6; *D,* exterior, right valve, ×1½, hypotype, KU12104P7; *G,* Interiors of two left valves, from skeletal limestone bed in upper part of Graneros at Locality 15, ×1, hypotype, KU12105P1; *I,* interior, left valve, ×1½, hypotype KU12104P6; all from skeletal limestone beds in upper part of Graneros at Locality 5.

C, E, F, H. *Inoceramus rutherfordi* Warren, all ×2. *C, H,* Internal molds of right valves from weakly calcareous shale in upper part of Graneros at Locality 43, hypotypes, KU 12106P1, KU12106P2; *E,* internal mold, left valve, from coquinoidal limestone in upper part of Graneros at Locality 32, hypotype KU12107P1; *F,* internal mold, left valve, with bits of shell adhering, from concretionary skeletal limestone in upper part of Graneros at Locality 43, U.S. Geological Survey, Mesozoic Locality D4429.

J, K. *Plesiacanthoceras amphibolum* (Morrow), ×2, from skeletal limestone in upper part of Graneros at Locality 32, hypotype, KU12107A1. *J,* lateral view, immature specimen with recrystallized shell; *K,* ventral view, same specimen.



HATTIN—GRANEROS SHALE (UPPER CRETACEOUS) IN CENTRAL KANSAS



HATTIN—GRANEROS SHALE (UPPER CRETACEOUS) IN CENTRAL KANSAS

Many of these cross laminations are clearly related to migration of ripple structures, and perhaps all of them are. Some lenses and zones of lenses of cross-laminated sandstone lying near the middle of the formation, especially including the yellowish, silty variety of sandstone described above, are apparently starved current ripples (Fig. 6, *B*). Thin laminae and very thin lenses of cleanly washed silt or very fine sand, scattered throughout the formation, but especially abundant in the lower half of the Graneros, resulted from alternation between silty clay deposition in quiet water and gentle stirring of bottom sediments by waves and currents. Locally, at Locality 5, extensively cross-bedded sandstone with dips up to 24 degrees (Fig. 9, *A*) reflects stronger current action than do laminated and gently cross-laminated units. Throughout the lower part of the formation valves or molds of burrowing pelecypods are oriented parallel to the bedding where they were deposited following sporadic but thorough bottom-sediment reworking by currents that left no clams *in situ*. Stronger currents concentrated *Callistina lamarensis* in gently cross-laminated sand beds where most valves lie convex upward in the rock. In the *Ostrea beloiti* Assemblage Zone currents of similar strength concentrated shell debris as layers of calcareous sand composed largely of *Inoceramus* prisms, the central Kansas area of deposition by then being far from shore. Throughout the formation paired pelecypod valves are rare because of the current transport to which nearly all were subjected.

Extensive search was made for usable directional structures but unfortunately most of those found were in float. In beds likely to contain directional structures, the bedding surfaces are generally so thickly encrusted with jarosite, limonite, or gypsum that recognition of any structures present is difficult at best. A few reliable measurements, mostly from sections in the Smoky Hill River and Saline River valleys, were obtained from cross beds, tool marks, current ripples, and one ripple mark showing parting lineation. Flow direction in nearly all of these lies between N 60°W and N 60°E. Additional work is needed on this aspect of Graneros sedimentation.

Bone beds and lenses of coquinoidal limestone occurring at many places in the formation were produced by brief periods of turbulence that was greater than usual for the area. Possibly during occasional storms, sediments on the sea floor were scoured more deeply than usual, resulting in concentration, in lenses and layers, of coarse organic debris that originally was scattered widely through the sediments.

Well-preserved ripple marks are most common near the middle part of the Graneros and scarce elsewhere in the formation. Because some nearly symmetrical ripple marks in the Graneros are known from internal structure to be of current origin, the discrimination between current and oscillation types is therefore difficult in nearly symmetrical ripple marks with poorly preserved internal structures. The only clear-cut examples of oscillation ripple marks that I have found lie in a single unit near the middle of the formation at Localities 5 (Fig. 9, *B*), 7, and 32. Wave lengths of these ripples are 0.2, 0.3, and 0.3 foot, respectively. Comparison of these limited data with data published by Inman (1957) would suggest water less than 70 feet deep, but verification of this conclusion necessitates further measurements. Asymmetrical profile, or association of ripple marks with cross-laminated structure, or both, suffice to identify most of the remaining Graneros ripple marks as current-formed.

Kruit (1955, p. 97) believed that preservation of ripple marks in shallow-water marine deposits is dependent upon alternations in the supply of mud, silt, and sand. Despite apparent satisfaction of these conditions during deposition of the Graneros, I believe that the paucity of ripple marks in roughly the lowest third of the formation is primarily a consequence of nearshore, shallow-water turbulence. Above a critical current velocity current ripples are destroyed

EXPLANATION OF PLATE 5

Ammonites from the *Ostrea beloiti* Assemblage Zone.

A-B. *Borissiakoceras reesidei* Morrow. *A*, lateral view of pyritized and calcified specimen from concretionary skeletal limestone in upper part of Graneros at Locality 43, ×3, U.S. Geological Survey Mesozoic Locality D4429; *B*, lateral view of internal mold from concretion in bentonite marker bed at Locality 34, ×3, hypotype, KU12108A1.

C-F. *Plesiacanthoceras amphibolum* (Morrow) from coquinoidal limestone in upper part of Graneros at Locality 32. *C, E*, Ventral and lateral views of portion of internal mold of mature individual, ×½, hypotype, KU12107A2; *D*, lateral view of internal mold of immature specimen showing sutures and part of shell, ×1, hypotype, KU12107A3; *F*, lateral view of mature specimen showing portion of shell, ×1, hypotype KU12107A4.

(Bucher, 1919, p. 165). Above a critical orbital velocity, usually occurring in water less than 30 feet deep, wave-generated ripples are planed off (Inman, 1957, p. 31). During deposition of the lower part of the Graneros these critical velocities were frequently exceeded; indeed, the sediments were often extensively reworked, and such structures tended to be obliterated by waves and currents before burial occurred. On the other hand, paucity of ripple marks near the top of the formation indicates deeper, more quiet water conditions. In addition to lithologic evidence cited above, this conclusion is supported by distribution of epibionts in Graneros strata. More generally turbulent conditions during deposition of the lower part of the formation contributed to the scarcity of epibionts in these beds. Occurrences of large numbers of epibionts locally in the upper part of the formation indicates less frequent disruption of bottom sediments, most likely owing to greater water depth. Foraminiferal evidence for progressively increasing depth during Graneros deposition is discussed below.

Rate of Deposition

Rate of Graneros deposition cannot be determined quantitatively at this time, but several lines of evidence bear on the relative rate of accumulation of sediment in the formation. As discussed in more detail elsewhere in this report, the Graneros is believed to represent a depositional environment roughly similar to that of the pro-delta silty clay and offshore clay of the Mississippi Delta region. In that region the rate of deposition was determined by Scruton (1956, p. 45) to be most rapid near the mouths of major distributaries and to be inversely related to clay content of sediment for the first few miles off the mouths of these distributaries. By analogy the relatively pure clays in the upper part of the Graneros were deposited more slowly than the more sandy and more silty beds in the lower part of the formation. Cross-laminated sandstone units in the lower part of the Graneros, although reworked by currents before burial, were probably deposited rapidly during flood stages of the source stream(s). The relatively high quantity of carbonized plant debris in many of these sandstone units supports this interpretation. Similarly, in a report on the Rhone Delta, van Straaten (1959, p. 208) noted that during flood stage, coarse-grained sediment is carried in larger quantities and farther seaward than during low-water river stages. Decrease in abundance of coarse-grained terrigenous detritus upward in the Graneros Shale is evidence of a progressive increase in distance from shore of the sediments in the central Kansas area during accumulation of the Graneros and of an ever-decreasing rate of sedimentation.

Greater abundance of kaolinite in the uppermost part of the Dakota and lower part of the Graneros, owing to rapid flocculation in the nearer shore environment, suggests that deposition of stream-transported clay was probably faster during deposition of this part of the formation.

In the upper assemblage zone, *Ostrea beloiti* is preserved locally in clusters attached to large specimens of *Inoceramus* and one such cluster from Locality 15 involves at least two generations of *Ostrea* on a large *Inoceramus*. The time involved for growth of the *Inoceramus* and establishment of two or more generations of *O. beloiti* was apparently quite long and is further evidence that deposition of the upper part of the Graneros was relatively slow. No such occurrences of successive generations of sessile benthos were noted in the lower part of the formation, probably as the result of more rapid deposition, unstable substrate, or both.

Burrows of various sorts occur sparingly throughout the Graneros Shale and are most common in jarosite-cemented silty sandstone beds and lenses (Fig. 7, *A*, *B*, *C*) that lie in the lower two-thirds of the formation, generally in the *Callistina lamarensis* Assemblage Zone. In beds containing these structures, laminations are generally not disturbed, indicating, as suggested by Middlemiss (1962, p. 36), that accumulation and burial of the burrow-containing beds was too rapid to permit multiple penetration. Notable exceptions to the usual kind of burrowing are found in a clayey siltstone unit lying near the base of the Graneros at Locality 23, where laminae were distorted by activity of a highly mobile infauna (Fig. 7, *D*). Rarity of burrows in the upper part of the Graneros, where relatively slow deposition seems to have been the rule, and where thin cross-laminations are well preserved in skeletal limestone beds, may demonstrate paucity of a mobile infauna of worm-like creatures in this part of the formation. This view is strengthened by the fact that, unlike the lower part of the Graneros Shale, the upper assemblage zone is almost lacking in shell-bearing, burrowing macroinvertebrates.

Bottom Conditions

During Graneros deposition the sea bottom consisted chiefly of soft sediment made up mostly of clay and silt. The limited number of benthonic species in both Graneros assemblage zones may be largely attributable to the nature of this substrate. Thorson (1957, p. 466) has contrasted hard- and soft-bottom areas of the sea floor and notes lack of numerous "microlandscapes" and relatively small number of species in the latter. Such factors as lack of shelter and small quantity of fixed vegetation serve to reduce drastically the epifauna of the soft-bottom community and especially to limit the development of a sessile benthos. The development of the benthos in soft-bottom areas is particularly hampered if the sediments are unstable. The lower Breton Sound and pro-delta slope depositional environments in the east Mississippi Delta region that have been described by Parker (1956, p. 321) have a very fine silty clay to clayey silt bottom and support a limited macroinvertebrate assemblage of only 20 species. Parker believed that high turbidity and fine fluid bottom may have hindered filter feeding of some animals and hindered larval settling of others in this area. The discussion of this area by Scruton (1956, p. 38) under the heading "pro-delta silty clays" fits closely the description of at least the lower part of the Graneros Shale. Despite prevalence of a soft sea bottom throughout Graneros deposition the benthonic faunas in the lower and upper parts of the formation differ markedly and must be attributed largely to factors other than the nature of the substrate. Changes in salinity, turbulence, and rate of deposition that occurred during accumulation of Graneros sediments probably contributed to differences in the benthos.

Paleoecology

Foraminifers

The upward change in foraminiferal content from dominantly arenaceous benthonic forms in the lower part of the Graneros to almost exclusively planktonic forms in the uppermost part of the formation is an expression of the same changes of environmental conditions that are reflected in lithology and in distribution of macroinvertebrates.

The Kiowa Shale (Lower Cretaceous) of Kansas, which is lithologically similar to the Graneros, contains a foraminiferal fauna that is dominated by arenaceous forms, among which those belonging to the genera *Ammobaculites* and *Trochammina* are most abundantly represented. Loeblich and Tappan (1950, p. 3) concluded that the chief factor controlling distribution of this assemblage was salinity, with a prevalence of brackish water. In a regional study of foraminifers from the Graneros Shale, Eicher (1965, p. 888) found that arenaceous forms dominated the samples, and he concluded that the formation was deposited in waters that were generally of less than normal salinity. The occurrence of large percentages of arenaceous foraminifers in some areas of brackish water in modern seas was mentioned by Bandy and Arnal (1960, p. 1924). They note also the frequent occurrence of abundant arenaceous genera with simple interiors, including *Ammobaculites*, in shallow brackish water but point out (p. 1925) that environmental interpretation based on this criterion must be supported by other evidence. Bandy and Arnal (1960, p. 1926) suggest that absence of calcareous species in an assemblage may indicate only that these have been dissolved following deposition. That this mechanism is not responsible for absence of calcareous benthonic foraminifers in the Graneros is proved by occurrence of both calcareous planktonic and arenaceous species in some samples, even at the base of the Graneros, locally.

Muddy bottom conditions and more rapid sedimentation may have been a factor in restricting the lower Graneros benthonic microfauna to a few species of arenaceous foraminifers. However, except for *Reophax minuta*, the number of arenaceous forms decreases upward in the Graneros; yet the rocks, although indicating generally muddy bottom conditions, suggest progressively slower deposition in gradually deepening water. The decrease in arenaceous foraminifers is not compensated for by appearance of other benthonic genera; therefore, changing bottom conditions seem unlikely as a main factor controlling distribution of benthonic foraminifers in the Graneros Shale. Increasing depth, however, may have played an important ecologic role.

Stainforth (1952) related certain assemblages of large arenaceous foraminifers to environments of turbidity-controlled deposition, and Tappan (1962, p. 124, 127) has suggested such control for some of the Alaskan Cretaceous microfaunas. Although Graneros arenaceous foraminifers mostly belong to families characteristic of such turbidity-controlled environments, none are particularly large; in fact, such species as *Reophax minuta*, *R. pepperensis*, and *Verneuilinoides perplexus* are quite small. Nonetheless, the water in which much of the Graneros was deposited must have been kept quite turbid by constant discharge of fine-grained detritus from the major stream system(s) that existed to the east or northeast. Turbidity can reduce the production of food used by foraminifers, and this has the greatest effect upon calcareous species (Tappan, 1962, p. 124). This mechanism would possibly explain the lack of calcareous benthonic foraminifers in the Graneros Shale but does not account for the decrease upward in the section of arenaceous forms. Eicher (1965, p. 889) related the sporadic occurrence of calcareous benthonic forms in the Graneros of Colorado to rare occasions when salinity was high enough for a sufficiently long time, so as to permit invasion of the area by such species. For central Kansas, at least, this interpretation seems unlikely because beds in the upper part of the Graneros that contain good indicators of normal salinity, such as ammonites or predominance of species of planktonic foraminifers, are apparently devoid of calcareous benthonic species.

Planktonic foraminifers are generally regarded as indicative of open seas and normal salinity (Smith, 1955, p. 147; Tappan, 1962, p. 125; Phleger, 1964, p. 34). The scattered occurrence of planktonic foraminifers in the lower part of the Graneros and their dominance near the top is acceptable evidence of gradually increasing salinity as Graneros deposition proceeded. Smith (1955, p. 147) wrote that the absolute abundance of planktonic foraminifers is inversely related to distance from their source area and directly related to depth. If this criterion is valid generally, then Graneros sediments dominated by planktonic foraminifers were deposited farthest offshore and in the deepest water. Studies of foraminifers in the Gulf of Mexico have shown that planktonic species are essentially lacking in water less than 70 feet deep (Lowman, 1949, fig. 13), 70 to 100 feet (Bandy, 1956, p. 192), or 160 feet (Phleger, 1951, p. 67), depending upon the area investigated. If anything can be drawn from existing foraminiferal distribution in the continental shelf area nearest to Kansas, the appearance in abundance of planktonic foraminifers above the middle of the Graneros may indicate depths of 70 feet or more for that part of the formation. The benthonic macroinvertebrates that occur in the upper part of the Graneros are proof that the deepest waters were well areated, so lack of oxygen is not the reason for lack of benthonic foraminifers in this part of the section.

In conclusion, I suggest that salinity was the dominant factor controlling foraminiferal distribution in the Graneros Shale. Turbidity is the best explanation for absence of calcareous benthonic species, and increasing depth probably accounts in part for lack of arenaceous species in the uppermost part of the formation in the central and northern parts of the outcrop. Assemblages dominated by several species of arenaceous foraminifers accumulated in shallow-water, nearshore areas where seawater was diluted by discharge of nearby streams. Planktonic tests were occasionally washed by currents into these nearshore areas. As deposition proceeded, salinity increased and *Reophax minuta*, probably more nearly euryhaline than the other arenaceous species, became dominant. Toward the close of Graneros deposition in central Kansas, planktonic foraminifers became the dominant forms in an open epeiric sea in which salinity, and/or depth, was greater than could be tolerated by arenaceous species that characterized the nearer shore, shallower water sites of deposition.

BRACHIOPODS

Basal beds of the Graneros Shale contain abundant *Lingula* and abundant *Discinisca* at Localities 13 and 3, respectively. The lingulids are associated with rare pectenoid pelecypods; the discinids occur with sparse *Inoceramus* and possibly a *Lingula*. Some of the Lingulas are nearly erect in the sediment and the entire assemblage may be essentially *in situ*. Although nearly all of the *Discinisca* remains are brachial valves, these include a wide range in size, are well preserved, and thus may not have suffered extensive transport. According to Hatai (1940, p. 175), modern species of *Lingula* commonly flourish near the mouths of large rivers or in brackish-water environments. Actually, *Lingula* can tolerate a wide salinity range and is known to have lived in seawater so diluted by fresh water as to be fatal to other marine animals (Craig, 1952; Ferguson, 1963).

Occurrence of inarticulates at Localities 13 and 3, to the near exclusion of other macroinvertebrates, is taken as evidence of marine water of very low salinity. At higher levels in the Graneros Shale brachiopods occur sparsely, either alone and possibly representing similar conditions of low salinity, or with other macroinvertebrates and probably reflecting salinity increased sufficiently to support other forms of benthonic marine life. In a recent review of *Lingula* ecology, Ferguson (1963, p. 670) noted that the genus is presently restricted to tropical and subtropical waters between latitudes 30°S and 41°N and cites Hatai's personal opinion that minimum temperature requirements for *Lingula* are about the same as that for corals, namely 18°C. Hatai (1940, p. 175) reported a bathymetric range of 0 to 23 fathoms for modern

Lingula and these figures have been accepted generally by other workers. Ferguson (1963, p. 670) reasoned that since *Lingula* flourishes in the presence of a rich food supply, the genus would ". . . flourish in the tidal zone and for a short distance below low tide." The long-ranging, little-changing *Lingula*, so obviously successful in its ecologic niche, has probably experienced similar ecological controls since the early part of its history, Cretaceous time being no exception. *Lingula* was apparently not "flourishing" in areas of Graneros deposition, so one or more environmental factors may have been less than optimum. Bottom conditions were eminently satisfactory; supporting evidence for shallow depth, low salinity, and adequate food and oxygen supplies are discussed elsewhere in this report. Tentatively I have concluded that the general paucity of *Lingula* in an otherwise suitable environment is owing either to temperature below the optimum or to lack of preservation.

Concerning living species of *Disciniscа*, Muir-Wood (1928, p. 469) stated that all are shallow-water tropical marine forms that occur generally at depths ranging from 0 to 20 fathoms. She noted that large, thin-shelled, concentrically lamellar forms lacking radial sculpture, including two species that live along the east edge of the Pacific Ocean, are attached to valves of their fellows or to valves of living *Mytilus* in water of 5 to 9 fathoms. Hertlein and Grant (1944, p. 33) emended the depth range of one of these species to 0 to 9 or 10 fathoms. The Graneros discinids closely resemble these modern non-radially sculptured species and by analogy are believed to indicate water no deeper than 10 fathoms. At Localities 6 and 14 I found a total of four *Discinisca* molds that are attached to molds of clams; three are attached to *Callistina* and one to *Parmicorbula?*. Both clams were burrowers but now lie parallel to bedding, thus attachment and growth of *Discinisca* occurred after these clams had been excavated by sea-floor scour and demonstrates that sedimentation was, on rare occasions, slow enough to permit such epifaunal growth.

PELECYPODS

Paleoecological significance of *Callistina lamarensis* is difficult to interpret not only because the genus is extinct but also because the family Veneridae to which it is assigned is one of the largest and most ecologically diversified groups of living pelecypods. Modern venerids are distributed bathymetrically from the beach environment to depths of several thousand feet and around North America have been reported from Arctic to equatorial waters. Some species have great latitudinal range. Most North American venerid species prefer water of normal or of nearly normal salinity but some species are tolerant of brackish water and some live in hypersaline lagoons. Different species of the same genera show wide range in habitat. The venerids are shallow burrowers and seemingly prefer sandy rather than mud bottoms but many deeper water species have been dredged alive from mud. From the foregoing one can see the danger inherent in any direct ecological comparison of extinct and living venerid species, and the even greater hazard if the ancient species belongs to an extinct genus.

Callistina lamarensis is distributed essentially throughout the lower part of the Graneros Shale and is therefore interpreted as indigenous to the attendant depositional environment despite evidence of displacement discussed below. Except in the coquinoidal limestone lens at Locality 5, shells and molds of *Callistina* everywhere lie parallel to bedding of the enclosing shale or sandstone. Such occurrence suggests that *Callistina* lived on the surface of accumulating sediment rather than buried in the bottom mud, but knowledge that modern venerids are shallow burrowers leads me to conclude otherwise. Lenslike distribution of fine sand and silt and cross lamination of sandstone and siltstone beds in the lower part of the Graneros manifest sediment reworking by wave and current action that in turn account for the present orientation of the *C. lamarensis* valves. Depth of reworking need not have been great because this species, like certain modern venerids, may not have been completely buried while in its burrow. Even so, proposed reworking of the sea floor must have been very general, because I observed no specimens *in situ*. Transport suffered by exhumed valves varied considerably. Molds in shale and in silt lenses are complete and have sharply defined growth ridges, and articulated valves are preserved in shale at Locality 14. Molds in sandstone beds are commonly of broken valves, but many are complete and growth ridges are undamaged. The large number of *Callistina* seen in sandstone beds at a few exposures likewise accumulated as a result of bottom scour, probably during occasional periods of greater than usual current activity. Selective orientation of valves at these places is accepted as proof of current action; valve counts for five slabs are given in Table 8. *Callistina* valves in the coquinoidal limestone lens at Locality 5 range from

TABLE 8.—Valve orientation of *Callistina lamarensis*.

Sample	Valves convex upward	Valves concave upward
KG-5-F	47	0
KG-20-J	78	8
KG-28-F	70	3
KG-40-M	93	7
KG-41-C	45	5

small fragments to valves that are paired. All specimens lack signs of wear and were probably not transported far before being heaped together on the sea floor.

Although *Callistina* valves at times were scattered widely on the sea floor, none bear evidence of attachment of sessile benthonic forms such as serpulid worms, bryozoans, and cirripeds that are so abundant in some parts of the Kansas Upper Cretaceous. I found one *Exogyra* that had been attached to *Callistina* and three *Callistina* valves to which *Discinisca* was attached. I believe the paucity of epifaunal elements to have been the result of highly turbid water and generally unstable substrate which virtually prohibited development of an epifauna during deposition of beds in the *C. lamarensis* Assemblage Zone.

Callistina lamarensis furnishes no direct evidence regarding ancient salinity. The species occurs locally in uppermost Dakota strata that represent the shore zone of the Western Interior Sea and ranges locally upward into the *Ostrea beloiti* Assemblage Zone that I consider to represent water of normal or near-normal salinity. *Callistina lamarensis* is most abundant in association with strata and fossils believed to represent water of less than normal salinity and the species may have preferred this environment, but the Dakota and *O. beloiti* Zone occurrences of *C. lamarensis* suggest that this clam tolerated a wide range of salinity.

The chief occurrences of *Exogyra columbella* are in the coquinoidal limestone lens at Locality 5 and sandstone beds in which specimens have been concentrated by current action. All valves that I collected in the lens, save one pair, are disarticulated and the right valves are sparse. The turbulence that produced the shell-bearing lens caused separation of the valves and concentrated the left ones. Near the base of the formation at Locality 37, valves are also disarticulated, but right valves are common and several left valves lie with the concave side up. Apparently these specimens were moved little, if at all, from the site of growth.

Attachment scars are plainly visible on a few specimens of *Exogyra* and lie on the outer surface of the hooked beak. The angle between the plane of attachment and the plane of commissure ranges from 39 to 120? degrees in five specimens. The left valve was oriented beak downward and ventral margin uppermost. The nature of the substratum could be determined for only one specimen, the beak area of which bears the clear impression of *Callistina*. During early Graneros deposition few large objects on the sea floor, other than *Callistina*, were available to serve as a substratum for *Exogyra*. The impression of the umbonal region of one specimen on the umbonal region of another is preserved on a few left valves and was caused by crowded living conditions in the sparse habitable areas of the sea floor. At no place did I find evidence of banklike development of *Exogyra* where younger generations could have grown upon shells of the old. The footholds gained occasionally by this species were evidently ephemeral. The small size and thin shells of most Graneros specimens of *Exogyra columbella* suggest a short life span.

Like most other pelecypods in the *Callistina lamarensis* Assemblage Zone, *Exogyra columbella* has a limited stratigraphic distribution, including only the uppermost part of the Dakota Formation and lower part of the Graneros Shale. Although *E. columbella* has been collected elsewhere in rocks as young as the upper part of the Greenhorn, I have seen this form only sparingly in the Greenhorn of Kansas, and then only in skeletal limestone beds lying at or near the base of the formation. The stratigraphic distribution of this species in central Kansas may reflect an ecologic requirement of relatively high energy levels in the depositional environment. Because of the usual occurrence of *E. columbella* in sandy rocks of the Mancos Shale, Pike (1947, p. 21) believed that the species inhabited a nearshore environment and, although occupying a very limited vertical range locally, might not be a precise indicator of age. For species of *Exogyra* having a very small shell, Jourdy (1924, p. 35) postulated a precarious life in an environment characterized by shallow, turbid water and considerable current activity. The conclusions of Pike and Jourdy are entirely compatible with lithologic and stratigraphic evidence bearing on the depositional environment of Graneros beds containing *E. columbella*.

Recent North American clams of the genus *Corbula* are characteristic of the warmer waters adjacent to the Continent. *Corbula* is distributed from the littoral zone to depths of several hundred fathoms and some species, such as *Corbula swiftiana* Adams, extend through a bathymetric range of 2500 feet or more. Most records that I have examined would suggest that corbulids have a preference for a mud bottom, but the genus has been found living in silt, sand, and gravel as well. Keen (1958, p. 208) notes that corbulids are common in the intertidal zone where specimens are attached by a byssus in gravel or under rocks. The European species *Corbula gibba* Olivi burrows in muddy, gravelly sand where it lies with the posterior margin at or just below the sediment surface and is attached to a shell or stone by a single byssal thread (Yonge, 1964, p. 362). Although most American species of *Corbula* prefer water of normal salinity, some, such as the Gulf of Mexico species *Corbula contracta* Say, apparently tolerate at least moderately brackish water (Parker, 1956, p. 326), and Keen (1958, p. 208) mentions one aberrant Central American species that occupies mangrove swamps and areas near mouths of streams. Consideration of the wide variety of habitats occupied by modern species of *Corbula*, the wide bathymetric range of some species, and the wide variety of substrate or sediment types inhabited by others, renders the paleoecological interpretation of an extinct species of corbulids difficult, let alone an extinct genus of that family, which can only be compared with modern forms.

Graneros corbulids are best known and most abundant in the coquinoidal limestone lens at Locality 5 where right and left valves occur in a ratio of nearly 3 to 1 and are in an excellent state of preservation. One set of paired valves was collected from the coquinoidal limestone. Seemingly, many of these specimens, like *Callistina*, *Yoldia?*, and *Nuculana* in the same lens, probably were not transported far before burial. *Parmicorbula? hillensis* var. was observed at a few other localities in shale that I believe represents the original mud-bottom habitat preferred by the living clam. The gaping posterior end of the right valve of this species is indicative of a well-developed siphon, hence a burrowing habit, but no specimens were observed in the life position. Like the associated clams, the present orientation of *Parmicorbula?* valves is further evidence that the sea floor was reworked sufficiently often and deeply enough to displace all of these shallow-burrowing pelecypods. *Lingula*, which today is a relatively deep-burrowing form, alone among Graneros endobenthonic forms, has been discovered in a position suggesting *in situ* preservation.

Nuculanid clams in the Graneros, including the genera *Nuculana* and *Yoldia?*, are represented in Recent oceans by species of the same two genera. In North America *Yoldia* is distributed from the Arctic Ocean to the Gulf of Mexico, including waters off both the east and west coasts of the conterminal United States. According to Maury (1920, p. 8), all species of *Yoldia* in the Gulf of Mexico are deep-water forms because the genus favors cold water and is typical of the Arctic and Antarctic regions. Off the California coast *Yoldia* is typically a deep-water form, but in Atlantic waters *Yoldia* occurs in shallow water as far south as Cape Hatteras and just below the low tide mark as far south as southern New Jersey (Abbott, 1954). Some species tolerate enormous bathymetric ranges. The genus characteristically occurs in water of normal salinity but is known locally from polyhaline water as, for example, in Long Island Sound where *Yoldia limatula* lives in waters having a maximum salinity of 29.2‰ (Sanders, 1956, p. 398). *Yoldia* is a vagrant, shallow-burrowing form and prefers mud bottoms. Individuals of *Y.? subacuta* var. in the Graneros were probably not as rare as my observations would suggest. *Yoldia?* shells are preserved at only one locality; nuculanid molds from a few other localities could belong to either *Nuculana* or *Yoldia?*, but positive identification is impossible. Valves of these genera are small and could be overlooked easily despite our intensive lamina-by-lamina fossil search at many localities. The generally muddy bottom that existed during Graneros deposition is compatible with knowledge of modern *Yoldia* ecology. However, none of the Graneros nuculanid molds was oriented as in life, so these clams, like *Callistina*, apparently suffered pre-burial transport, also.

Like *Yoldia*, *Nuculana* lives today in all water bodies surrounding North America through a bathymetric range from low tide mark to the bathyal zone and prefers a mud bottom. In her book on tropical west American seashells, Keen (1958, p. 17) notes that *Nuculana* is characteristically a northern genus that prefers cold water. Nonetheless, some species have been observed in very shallow water in the tropics. Although most American species of *Nuculana* occur in offshore waters of normal salinity, some inhabit somewhat brackish water in the Gulf Coast Region (Parker, 1956, 1959, 1960).

Modern representatives of nuculanid genera found in the Graneros Shale occupy such a wide range of habitats that direct environmental comparison with the extinct species is hazardous, Nuculanid clams comprise only a small part of the *Callistina lamarensis* assemblage and for this reason are of little paleoecologic value.

The virtual restriction of *Ostrea* to the upper 10 to 15 feet of the Graneros might be taken as evidence of differential preservation because most of the calcareous beds in which oysters are abundant and well preserved lie in that portion of the section. However, noncalcareous shale units lying between calcareous beds contain identifiable *Ostrea* at several places and noncalcareous sandstone in the lower half of the formation contains *Ostrea* shells in at least one section (Loc. 18). Thus the paucity of *Ostrea* in noncalcareous sandstone and shale in the lower half of the formation is not owing to post-depositional solution but rather to some ecologic factor or factors. The stratigraphic and geographic distribution of these oysters essentially parallels that of ammonites, abundant planktonic foraminifers, and calcareous beds, all of which suggest water of normal salinity. I conclude, therefore, that the environmental factor having greatest influence in controlling distribution of *Ostrea beloiti* was salinity. This control may not have been direct, however. A fragment of an *Inoceramus* shell, or at least the impression of this genus, is discernable on the attachment surfaces of all larger specimens of lower valves of these oysters. Second-generation oysters commonly gained footholds on the valves of older specimens, but none of the oysters are attached to the shells of any other kinds of organisms. The only substrate generally suited to the development of *Ostrea* beds thus seems to have been *Inoceramus* valves. Where *Inoceramus* could not live, *Ostrea* did not become established. *Inoceramus* does occur sparingly in the lower part of the Graneros at Localities 3 and 14 but the molds observed at these localities are of a different species than that to which upper Graneros oysters were attached. *Inoceramus* fragments occur in calcareous sandstone 5 feet above the base of the Graneros at Locality 7, and shell fragments possibly belonging to *Ostrea* were also observed in this bed, but the ecologic relationship of these sparse and fragmentary remains is unknown.

In most beds where *Ostrea* is abundant, the specimens are not oriented uniformly, the attached valve commonly lying with the lower surface uppermost. At Locality 15, one cluster of oysters was in an upright position on the paired valves of a large *Inoceramus* and the assemblage may be in the position of growth; however, other oysters in the same bed are overturned. All observed *Ostrea* valves are disarticulated, but many remain unbroken. The common occurrence of these relatively well-preserved oysters in skeletal limestone, clean calcareous sandstone, and some conglomeratic beds suggests that disruption of shell beds and disarticulation of valves occurred during periods of turbulence (probably storms) when the sea floor was stirred by wave or current activity which concentrated well-washed coarser detritus and shell debris. The small size of *Ostrea* biostromes in the Graneros is apparently a consequence of sporadic turbulence. In several respects *Ostrea beloiti* is much like *O. congesta* of higher parts of the Colorado Group in Kansas, that is, in growing upon *Inoceramus*, in having a lower valve with large attachment area and nearly upright outer wall, in possessing a relatively thin shell, and in growing, where crowded, in low-lying clusters. In general form *Ostrea beloiti* is not unlike *O. equestris* Say, a modern American high-salinity oyster.

Identifiable specimens of *Inoceramus rutherfordi* associated with *Ostrea beloiti* are common at only a few localities; therefore, little can be said concerning ecology of the latter except for their possible control over distribution of *Ostrea* and, because of similar stratigraphic occurrence, the relatively high salinity that was apparently necessary for their growth. Indeed, Vokes (1948, p. 128) believed that *Inoceramus* usually inhabited water of normal salinity. The fragmentary condition of *Inoceramus* remains in most skeletal limestone beds can be attributed to shell fragility as well as to occasionally turbulent environmental conditions. Beds of skeletal limestone in which the grains consist largely of isolated prisms of *Inoceramus* attest to the delicate nature of the valves. Oyster valves are commonly whole in limestone beds where scarcely a fragment of *Inoceramus* is large enough to be detected by the naked eye.

AMMONITES

The restriction of ammonites to the upper assemblage zone of the Graneros Shale is more likely due to environmental control than to lack of preservation of such fossils in the lower part of the formation. The evidence of foraminiferal and calcareous-rock distribution, discussed above, indicates that salinity of the Western Interior Sea was increasing as Graneros deposition proceeded. The stratigraphic distribution of ammonites is similar to that of planktonic foraminifers and calcareous rocks and seems, therefore, to be also closely related to salinity. Scott (1940, p. 308) has noted the preference of modern cephalopods for water of normal salinity. Ammonites are most common in the Smoky Hill and Saline River areas of the Graneros outcrop and calcareous rocks are also most in evidence there. I observed calcareous foraminifers lower in the section here than elsewhere. Increase of salinity during the Graneros transgression may have occurred somewhat earlier here than in adjacent areas, with resulting development of more fully marine conditions as the upper part of the formation was being deposited. This conclusion excludes the Ford-Hodgeman County area where any sediments of the *Ostrea beloiti* Assemblage Zone were removed by erosion prior to inception of the Greenhorn deposition.

Cephalopod remains are common to abundant in only three of the sections I studied. At Localities 32 and 33, where specimens are in coquinoidal limestone lenses, the association of fragmentary fish remains, whole and broken oyster shells, *Inoceramus* shells and prisms, gastropods, quartz sand grains, and the broken condition of many ammonite conchs is evidence that the fossils were concentrated by storm activity when bottom sediments were deeply disturbed, fine sediments were set in suspension, and assorted coarse debris accumulated through the agency of wave or current action. Strongly sculptured conchs of *Plesiacanthoceras amphibolum* may be an adaptation to the occasionally turbulent kind of environment that produced the several shell and pebble beds that lie in the upper 15 feet of the Graneros.

The host of ammonite remains collected at Locality 43 are mostly well-preserved molds that lie parallel to the bedding at several horizons. A bedding plane on one shale block contains at least 19 specimens of *Borissiakoceras reesidei* and one of *Plesiacanthoceras amphibolum* in an area of 16 square inches. Diameter of the *B. reesidei* molds ranges from 3.8 to 19 mm. Concentration of these ammonites by gentle current action is manifest in the scattered assortment of shell fragments, fish scales, bones, and coprolites that lie on the same bedding plane in rock that otherwise consists mostly of homogeneous clayey shale.

ORIGIN OF SEDIMENTS

Inorganic Sediment

From paleontologic and stratigraphic evidence that the Western Interior Sea was transgressing in a generally eastward direction during Graneros deposition, and from consideration of general aspects of Late Cretaceous paleogeography in the Western Interior Region, the conclusion may be drawn that the source area(s) for Graneros terrigenous detritus lay somewhere to the east of the present central Kansas outcrop area. The regional cross-bedding trend in the Dakota Formation of central Kansas (Ottawa County) is generally southwestward (Franks, *et al.*, 1959, p. 237), suggesting a northeasterly source for the Graneros sediments which would have been transported by the same stream system(s) as the partially contemporaneous Dakota sediments. A similar cross-bedding trend was determined in the type Dakota area by Tester (1931, p. 280). The major source area for Dakota and Graneros sediments of Kansas would thus be the southern part of the Canadian Shield, especially the part that extends into Wisconsin, and surrounding areas of Paleozoic sedimentary rocks. An easterly source of sediment prevailed also in North Dakota where, according to Hansen (1955, p. 28), the sand or silt content of the Belle Fourche Shale (the lithologic equivalent of the Graneros) increases eastward.

Shale in the Graneros is dominated mineralogically by quartz, much of which is in the finer silt sizes. Such fine quartz detritus was probably produced partly by thorough disintegration of parent rocks in the source areas and also by size reduction of quartz particles during transportation to the sites of the late Cretaceous deposition. Kaolinite, illite, and montmorillonite are the only other major constituents of the shale, and the relative proportions of the three differ from bottom to top of the formation. Kaolinite is more abundant in the upper part of the Dakota and lower part of the Graneros and montmorillonite is more abundant toward the top of the Graneros, whereas the amount of illite remains nearly uniform throughout. If clay minerals are mainly of detrital origin, as suggested by Weaver (1958, p. 258; 1959, p. 182), their distribution in Graneros sediments requires explanation in terms of source and depositional environment as well as possible diagenesis. According to Weaver (1958, p. 259), kaolinite is most common in continental and nearshore sediments. Both kaolinite and illite flocculate and settle rapidly when introduced into seawater of even low salinity (Whitehouse, *et al.*, 1960). The general decrease in amount of kaolinite upward from the uppermost part of the Dakota Formation probably reflects gradually increasing salinity during deposition. The nearly uniform distribution of illite in the Graneros may be a result of montmorillonite diagenesis whereby some of the latter mineral was altered to illite by potassium-ion absorption. Milne and Earley

(1958, p. 331) believe that in the modern Gulf of Mexico this kind of diagenesis takes place slowly and under conditions of slow sedimentation, but Keller (1963, p. 144, 145) has presented evidence that this reaction occurs with increasing depth of burial. Study of a much larger number of samples may shed more light on this question.

Kaolinite can form by thorough leaching of parent rock, probably under humid climatic conditions. The diversity of plant remains in the famous Dakota flora, the common occurrence of carbonized plant remains in the Graneros Shale, and of calcified, carbonized, and silicified logs in the Greenhorn Limestone and Fairport Chalk Member of the Carlile Shale bespeak a humid, rather than arid, climate in the land areas adjacent to the east edge of the Western Interior Sea during Cenomanian and Turonian time. The most probable source of large quantities of koalinite would seemingly be soils in areas of Precambrian rock in the southern part of the Canadian Shield and its extension into Wisconsin. Adjacent early Paleozoic sedimentary rocks were probably not a major source of kaolinite because, as Weaver (1958, p. 259) has noted, illite is the dominant clay mineral in Paleozoic rocks; this is especially true of pre-Upper Mississippian rocks (Weaver, 1959, p. 1954). Indeed, Paleozoic rocks along the eastern border of the Western Interior Sea may have been the source for much of the illite in the Graneros Shale. Soils developed on these Paleozoic rocks may have contributed some of the kaolinite, however.

Montmorillonite concentrated in Graneros bentonite samples, and possibly some elsewhere in the formation, was derived from volcanic ash by devitrification, but much of montmorillonite in the formation may be detritus from soil. Montmorillonite flocculates and settles most rapidly in water of normal salinity (Whitehouse, *et al.*, 1960) and thus, in a transgressional sequence, detrital montmorillonite would be expected to increase in quantity upward in the section. This is the case in the uppermost Dakota-Graneros sequence and seemingly supports conclusions drawn elsewhere in this report. On the other hand, if the quantity of montmorillonite increased because of increased volcanism, we could expect progressive dilution, initially, of both kaolinite and illite upward in the Graneros. Despite such dilution, the relative quantity of illite could remain nearly uniform owing to montmorillonite diagenesis. The thickest bentonite in the Cretaceous of Kansas, the marker bed in the upper part of the Graneros, is ample testimony to the magnitude of volcanic activity during deposition of that part of the formation. Marked thickening of the presumed western equivalent of this bentonite northwestward into Wyoming and Montana indicates the general direction of the eruptive source.

In a study of late Cretaceous and Tertiary clays of the upper Mississippi Embayment, Pryor and Glass (1961, p. 48) noted the dominance of kaolinite in the fluviatile environment, dominance of montmorillonite in the outer neritic environment, and nearly equal mixtures of kaolinite, montmorillonite, and illite in the inner neritic environment. This distribution pattern is similar to that of the Graneros Shale. Pryor and Glass (1961, p. 50) reasoned that all three clay minerals were detrital and that if the montmorillonite represented ash falls, then large quantities should be found in the fluviatile sediments as well as in the marine, but altered volcanic ash is not necessarily represented by montmorillonite. Under conditions of acid leaching, volcanic ash can be altered to kaolinite (Weaver, 1963, p. 347). An X-ray study of five bentonite samples from the lower part of the Graneros Shale showed kaolinite to be the dominant clay mineral in each. However, montmorillonite is also present in these samples, so not all of the ash was altered to kaolinite. Montmorillonite in shale samples from the lower part of the Graneros could be of either detrital or volcanic origin but the local dominance of this clay mineral in the upper part of the Dakota and lower part of the Graneros, involving marginal-marine and nearshore marine environments respectively, suggests a dominantly volcanic origin. It should be noted here that bentonite beds do occur in the upper part of the Dakota Formation (see Pl. 1). It is generally agreed that the abundant montmorillonite in Upper Cretaceous rocks is of volcanic origin (Weaver, 1959, p. 168, 169).

From the mineralogical standpoint, the terrigenous sand and silt in both the calcareous and noncalcareous quartzose sandstones is remarkably mature and contains a limited group of stable heavy minerals. The mineral suite in Graneros sandstones is nearly identical with that reported by Potter and Pryor (1961) for most Paleozoic sandstones of the Eastern Interior Region with the exception of garnet which I did not detect. Earlier Paleozoic sedimentary rocks of the Eastern Interior are attributed to a Precambrian crystalline source in the Wisconsin-Michigan-Ontario area by Potter and Pryor (1961, p. 1224), who concluded that sediments from this source were recycled during each of the succeeding geologic periods with resultant supermaturity of some Paleozoic sandstones. On the basis of paleocurrent trends in the Dakota Formation mentioned above, and of the mineralogical composition of Graneros sands, the dispersal center for the latter is deemed to be generally the same as that for the earlier Paleozoic, and some of the later Paleozoic, terrigenous detritus of the Eastern Interior Region. The mixture of angular to well-rounded, but mostly subrounded, quartz grains in Graneros sandstones reflects a relatively small contribution of fresh detritus from a crystalline source and a comparatively large amount of sediment recycled from older formations that must have cropped out adjacent to the crystalline rocks. Further evidence of a primary source of sediment during Graneros deposition includes the grains of fresh, unaltered feldspar and sparse rock fragments that are scattered through the sandstone units. However, according to the conclusions drawn by Blatt and Christie (1963, p. 571), the high percentage of nonundulatory quartz grains in Graneros sandstones may indicate that the bulk of this sediment has undergone considerable recycling. Early Paleozoic rocks surrounding the southern part of the Canadian Shield would have been a convenient and likely source for chert grains that are common in the Graneros and the presence of this chert seemingly lends support to the contention that Graneros detritus is largely recycled sedimentary material. Polycrystalline quartz in the Graneros occurs as both rounded and irregular-shaped grains and thus could represent both fresh and recycled sediment, but the low polycrystalline quartz/quartz ratio is an additional index of mineralogical maturity, owing to lesser stability of the former (Blatt and Christie, 1963, p. 570) and supports the concept that Graneros sand is largely reworked detritus.

Glauconite grains in Graneros sandstone units are believed to be largely of detrital origin. The evidence for this conclusion consists of the well-rounded shape of most grains, compatibility with grain size of surrounding rock, absence of grains having the shape of skeletal cavities or the structure of cleavable minerals, and the paucity of radial cracks.

Because the grains in the Graneros sandstones are not predominantly rounded to well rounded, the rock is considered to be texturally submature.

Organic Sediment

Skeletal limestones in the Graneros Shale are interpreted as lag concentrates that were produced by current activity which, during periodic sea-floor sweeping, winnowed away finer detritus and concentrated the coarser grains, consisting mostly of shell debris, in lenses or in thin beds that are generally gently cross-laminated. At sporadic intervals storm activity stirred the sea floor more deeply than usual, resulting in concentration of coarser organic detritus including bone pebbles and invertebrate shells that are now bone beds and coquinas. The degree of rounding of the bone-pebbles suggests that such constituents were subjected to considerable abrasion, possibly along or near the ancient shoreline, before being transported to the sites of ultimate deposition.

Carbonaceous matter occurring in Graneros sediments as minute specks, larger flakes, woody chunks, and a few leaves is regarded as largely the remains of vascular plants which were swept out to sea during flood stages in the stream system(s) that bordered the Kansas portion of the Western Interior Sea.

Diagenesis

Pyrite and marcasite in clayey sediments of the Graneros Shale, occurring largely in the lower part of the formation, are probably the result of anaerobic conditions that prevailed shortly below the sediment-water interface. Here, liberation of hydrogen sulphide during decomposition of small quantities of organic matter, which was buried rapidly before thorough oxidation, reacted with dissolved iron compounds in interstitial water and caused precipitation of iron sulphide (Rankama and Sahama, 1950, p. 688). Some of the iron sulphide was concentrated (probably by aggregation of a colloidal precipitate) into blebs and nodules. Some remained scattered through the sediment in a finely divided state and is probably in part responsible for the dark color of the shale (*see* Table 1). Carbon left in the clayey sediment after decomposition of organic matter also contributes to the dark color of the shale. Upon weathering, the iron sulphide minerals, particularly marcasite, oxidize readily to iron sulphate which imparts the sharply bitter taste of melanterite to partially weathered shale at many localities, especially in the lower part of the formation. Further weathering of the iron compounds produced the limonite and jarosite that characteristically encrusts rock surfaces along joint and bedding planes throughout the Graneros and that are the cementing agents in many of the sandstone bodies. Some of the oxidized iron sulphide, while in the sulphate stage of oxidation, combined with water to produce sulphuric acid. Reaction of this acid with calcareous matter throughout the formation resulted in extensive crystallization of gypsum.

In the *Callistina lamarensis* Assemblage Zone, calcareous invertebrate fossils are preserved in only one bed and some shells have been replaced by gypsum at a few localities. Crystals and crystalline aggregates of selenite are especially abundant in the lower half of the Graneros; selenite became the cementing agent locally in sandstone and bone beds. The possibility of acid leaching causing alteration of montmorillonite to kaolinite is discussed on page 62.

In the *Ostrea beloiti* Assemblage Zone selenite is common, but usually as small crystals oriented parallel to bedding planes. In some skeletal limestone beds selenite has partially replaced sparry calcite cement and a few *Inoceramus* prisms. Oysters in shale have been replaced locally by gypsum. *Inoceramus* and ammonites in shale of the *O. beloiti* Zone are preserved mostly as molds except at Locality KG-43 where a deep excavation exposes unweathered shale in which the gypsum-producing process has not yet occurred extensively. Alunite nodules in shale at three localities were probably produced by localized reaction of sulphuric acid with clay minerals.

Sparry calcite cement, especially in quartz sandstone and skeletal limestone beds of the *Ostrea beloiti* Zone, resulted from early diagenetic crystallization of calcium carbonate from interstitial water, commonly in observable optical continuity with *Inoceramus* prisms. The calcite probably formed shortly after burial when a maximum amount of seawater could penetrate the then highly permeable sediments. That the calcite precipitation occurred under alkaline conditions is manifested by the common occurrence of quartz grains which have been partly replaced and locally deeply invaded by sparry calcite.

In a few places, alkaline conditions developed within sediments shortly after burial and created a chemical environment favoring the localized precipitation of calcite that ultimately formed the septarian concretions that lie in the upper half of the formation. Anaerobic organic decomposition results in liberation of ammonia which would create the necessary conditions for the inorganic precipitation of calcium carbonate. During enlargement of the concretions, an increasing volume of surrounding sediment was incorporated into these structures and the dark color is due to these included clayey sediments. Lithification of Graneros concretions apparently occurred during early diagenesis because fossils observed in them were not flattened by compaction, as in adjacent sediments, and enclosing shale layers bend around the concretions.

PALEOGEOGRAPHY AND GENERAL DEPOSITIONAL HISTORY

Graneros sediments were deposited near the eastern margin of the vast, shallow Western Interior Sea which occupied a differentially subsiding depression known as the Rocky Mountain trough. High lands on the west side of the trough were created during the Nevadan Orogeny and furnished much of the detritus that comprises the existing thick sections of Cretaceous rocks in the western part of the trough (Spieker, 1946; Reeside, 1957). A land area of low relief bordered on the eastern side of the trough and furnished a much smaller volume of sediment to the eastern shelf region of the sea.

Immediately prior to deposition of the Dakota Formation, the central Kansas area and much of the surrounding Great Plains and southern Rocky Mountains region was undergoing erosion (Reeside, 1957, fig. 6). Marine deposition was occurring in the northern part of the trough and in Texas. Early late Cretaceous subsidence initiated regional marine transgression across the formerly eroding region. The spreading sea ultimately inundated the entire trough in a great seaway extending, as indicated by fossils common to the two regions and to areas between, from Texas to the Arctic Region.

The earliest marine influence in central Kansas came from the south as indicated by late Cretaceous marine macroinvertebrates in the upper part of the Dakota Formation. Most of these fossils have not been reported elsewhere in the Western Interior but are known in the upper part of the Woodbine Formation of Texas (Hattin, 1965, p. 87). Indeed, the earliest Late Cretaceous marine lithologic succession in Kansas bears a close resemblance to the Woodbine—Eagle Ford beds of northeastern Texas. Mollusk-bearing ferruginous sandstone in the upper part of the Dakota of Kansas is indistinguishable from similar rock in the Lewisville Member of the Texas Woodbine. Silty shale is identical in outward appearance to that which I have seen in the Templeton Member of the Woodbine. The lower part of the Eagle Ford is calcareous, rests with sharp contact on noncalcareous beds of the Woodbine, and at many localities, like the Greenhorn, it consists at the base of skeletal limestone containing *Inoceramus* fragments and fish remains. Many fossils in the three Kansas formations are known also in the lithologic counterparts in Texas, but exact age equivalence is not implied because the faunas may be facies controlled. The late Cretaceous shoreline moved northward from Texas, and eastward from Colorado, where fossils near the top of the Dakota are of Comanchean age, and fossils collected by Erle G. Kauffman (written communication, 1964) in the lower part of the Graneros apparently represent a zone that is older than any part of the Graneros in central Kansas. Conformability of the Graneros on the Dakota in Colorado indicates inception of Graneros deposition earlier in that State than in Kansas. The shoreline lay in the central Kansas area during the time the uppermost Dakota beds were laid down in that part of the State, and the shoreline continued to migrate progressively eastward or northeastward as Graneros sediments were deposited.

The Graneros macroinvertebrate fauna is dominated by southern species, some of which have not been reported north of Kansas and among which only *Inoceramus rutherfordi*, *Exogyra columbella*, and specimens questionably identified as *I. dunveganensis* have been reported farther north than Montana. A few species of Graneros foraminifers that were first reported in Texas are also known from the Cretaceous of northern Alaska, but all of these are long-ranging forms.

The fluviatile nature of much of the Dakota Formation in Kansas is generally agreed upon (Rubey and Bass, 1925; Plummer and Romary, 1942; Franks, *et al.*, 1959). Conspicuously cross-bedded, lenticular bodies of generally ferruginous sandstone are regarded as channel deposits, thin-bedded sandstone and varicolored clays and silts are floodplain and possibly lacustrine sediments, and some of the lignites are the product of river-created paludal conditions. This nonmarine part of the Dakota locally contains a rich fossil flora. The uppermost few feet of the Dakota exhibit a wide range of variation in lithology and stratigraphy, as described above, and contain marine fossils at a number of localities. These marine beds are transitional with the nonmarine part of the Dakota both vertically and laterally. In this part of the section, stratigraphically equivalent positions are occupied at various localities within a few miles of one another by carbonaceous shale with lignite, carbonaceous sandstone and siltstone, sandstone with abundant marine invertebrate remains, sandy shale with arenaceous foraminifers, or by shale that can scarcely be distinguished from that of the Graneros. I believe that these relationships are best interpreted as the result of environmental differences on the topset plain of a major deltaic complex.

The wide distribution of channel deposits throughout the Dakota sediments in Kansas (Plummer and Romary, 1942, p. 328) can be attributed to the main channel and distributary system of the major stream(s) that deposited the formation. The complicated transition from nonmarine to marine strata near the top of the formation is the result of deposition along a coastline made irregular by seaward extension of the deltas, concomitant landward embayments of the sea between distributaries, and development of swamps and marshes virtually at sea level adjacent to the stream courses. In this sedimentary setting the Graneros-like shales near the top of the Dakota are envisioned as deposits of local coastal embayments; foraminifer-bearing carbonaceous clays in the same stratigraphic position elsewhere as deposits of coastal lagoons; lignites and underlying siltstone with upright reed molds as deposits of marshes that developed around the margins or on top of lagoonal deposits; and thick locally carbonaceous sandstone units at the top of the Dakota as deposits laid down at or just off the mouths of streams.

The inception of marine deposition in the upper part of the Dakota was brought about by continuation of subsidence that caused gradual but progressive eastward migration of the shoreline throughout the time of deposition of the Graneros in Colorado and Kansas. Graneros rocks do not exhibit complex facies relationships like those of the Dakota and represent near- and offshore marine deposition associated with the deltaic environment. The implication of a transgressional succession upward from fluviatile and marginal marine deposits in the Dakota to entirely marine conditions in the Graneros cannot be mistaken; however, the sections that I have examined lack unequivocal evidence of beach deposits. Such beach sediments as may have developed wherever waves attacked the deltaic shoreline were apparently reworked during the transgression and may now be represented by the more or less evenly bedded sandstone that lies at the top of the Dakota in most places and that locally contains invertebrate fossils and/or fragments of carbonized wood.

Although there is an obvious danger in making a direct comparison between the preserved record of an ancient delta and sediments of a modern one, qualitative similarities are manifest between marine sediments of the Dakota—Graneros stratigraphic sequence and the seaward sequence of Mississippi Delta sediments as described by Scruton (1956, 1960). Deltaic frontal deposits of the Cretaceous submarine-topset plain are represented by bodies of very fine-grained sandstone and by sand and silt layers and lenses, which were concentrated by wave and current reworking, and that are interlaminated with silty shale. Beds of this kind, occurring especially in the uppermost part of the Dakota and locally in the lowest part of the Graneros, are characterized by paucity of fossils and abundance of carbonaceous matter. Beds analogous to Mississippi pro-delta silty clays or foreset beds are represented in the Graneros by silty shale in the lower and middle parts of the formation. Lenses and laminae of sand and very fine silt show an irregular but progressive decrease upward in this part of the formation. Beds in the Graneros analogous to Mississippi Delta offshore clays or bottomset beds lie near the top of the formation where laminae and lenses of silt are sparse and very fine calcareous sand is locally concentrated in thin beds of skeletal limestone. Laminations are very rare in offshore clays in the Mississippi Delta at depths of 120 feet or more, apparently because waves capable of performing the necessary winnowing did not reach these depths (Scruton, 1955, p. 39). In the Western Interior Sea, waves the size of those on an exposed continental shelf probably could not form, but the presence of silt laminae and lenses near the top of the Graneros, even though sparse, would seemingly indicate depths of water considerably less than 120 feet as a maximum in which Graneros deposition took place.

The seaward changes in character of deltaic sediments are not peculiar to the Mississippi Delta. For example, in the pro-delta slope of the Rhone Delta van Straaten (1959) found a seaward gradation from more sandy and silty deposits near distributary mouths to purer clays in the distal reaches of deltaic deposition. He likewise observed a seaward decrease in degree of sediment lamination. Similar observations have been recorded recently for the Niger Delta by Allen (1964).

According to Shepard (1956, 1960) woody material is common in all Mississippi Delta sediments but is decreasingly abundant in a seaward direction. In the Graneros Shale, carbonaceous matter is progressively less abundant upward in the section, but is more abundant and of larger particle size in some sandstone beds than in the surrounding shale. As I have stated above, this is because the sandstone beds reflect, at least in part, temporary increases in river discharge.

Sandstone beds are most prominent in the Saline and Smoky Hill River valley areas, and denote nearness to the ancient river mouth(s). Subaqueous plastic flow structures were observed only in sandstone beds lying near the middle of the Graneros in this same area, attesting to slightly greater seaward inclination of the sea bottom at that time, perhaps on a deltaic foreset slope. Some of the most spectacularly cross-bedded channel sandstone bodies in the Dakota lie near the top of that Formation in the Saline River area. These sandstones were interpreted as deposits of a major channel in Russell County by Rubey and Bass (1925, p. 61). The available evidence indicates that a major center of deltaic sedimentation existed in this area during a part of late Cenomanian time.

In the Dakota—Graneros strata the preserved sedimentary sequence is the reverse of that accumulating in the modern Mississippi Delta because the latter is a prograding deposit and the Dakota—Graneros complex accumulated during marine advance. As noted by Scruton (1960, p. 82) the constructional and destructional phases of development in rapidly built deltas are clearly differentiated, but this is not true in slowly built deltas. Except for possible beach destruction, the uppermost Dakota—Graneros sequence is well preserved, owing perhaps to a rate of subsidence sufficient to prevent extensive reworking of the entire complex during transgression rather than to slow deposition.

Migration of the late Comanchean—early Gulfian shoreline in the Great Plains states was not in a continuously eastward direction. The "D" and "J" sandstones of the subsurface in western Kansas and adjacent states to the west and northwest are tongues of the Dakota Formation and reflect westwardly prograding phases of deltaic deposition each of which was followed by renewed eastward transgression (for discussion see Haun, 1963).

Deposition of Graneros sediments occurred during the transgressive half of a clearly defined cycle of marine sedimentation that culminated with deposition of the Greenhorn Limestone and has been named the Greenhorn cyclothem (Hattin, 1962b, p. 124). The cyclothem is asymmetrical stratigraphically but nearly symmetrical lithologically and comprises seven phases including: (1) ferruginous marine sandstone and silty, carbonaceous, or sandy shale in the upper part of the Dakota Formation; (2) silty or sandy shale and thin sandstone beds of the lower part of the Graneros Shale; (3) silty shale with calcareous sandstone, skeletal limestone, and local septarian concretions of the upper part of the Graneros; (4) shaly chalk and chalky limestone of the Greenhorn and the Fairport Chalk Member of the Carlile Shale; (5) silty concretionary shale comprising most of the Blue Hill Shale Member of the Carlile; (6) silty or sandy, locally concretionary, shale of the upper part of the Blue Hill; and (7) siltstone, sandstone, and silty or sandy shale of the Codell Sandstone Member of the Carlile. Details of the cyclothem are discussed more fully elsewhere (Hattin, 1964 [1966]).

CONCLUSIONS

1. The Graneros Shale of central Kansas is a distinctive, mappable lithostratigraphic unit that is transitional vertically and laterally with the underlying Dakota Formation and which underlies, along a sharp contact, the Greenhorn Limestone.

2. Graneros rocks are chiefly of polygenetic terrigenous origin and were derived from source areas lying to the east or northeast of the present outcrop. Kaolinite, angular quartz, and rock fragments are believed to be first-cycle sediments and probably came from the southern part of the Canadian Shield. Illite, chert, rounded quartz and heavy minerals, and possibly much of the glauconite were reworked from a Paleozoic sedimentary terrain. Montmorillonite was derived largely from a volcanic source lying beyond the western edge of the Western Interior Sea. Shell and bone debris in limestone and bone beds is of local origin.

3. The bentonite marker bed is the same as the "X" bentonite of Colorado and Wyoming and possibly also the Soap Creek bentonite of Montana. Northwestward thickening of the bentonite suggests an eruptive source in the Nevadan orogenic belt, probably in Idaho.

4. Marine macroinvertebrate fossils in the Graneros of central Kansas are more numerous and widely distributed than heretofore supposed. These fossils comprise two assemblages, the strata characterized by each constituting an assemblage zone. The lower assemblage zone is characterized by *Callistina lamarensis*, the upper by *Ostrea beloiti*.

5. Faunal evidence substantiates temporal correlation of the Graneros of Kansas with part of the Graneros of the southern Rockies, part of the Mancos Shale of Utah and New Mexico, part of the Belle Fourche Shale of Wyoming and Montana, part of the Dunvegan Formation of Alberta, and with some part of the Lewisville and Templeton members of the Woodbine Formation in Texas. The *Callistina lamarensis* Assemblage Zone lacks index species of *Inoceramus* or ammonites presumably because of adverse environmental conditions. It cannot, therefore, be correlated precisely with the standard zonal sequence elsewhere in the Western Interior. This Zone may be equivalent to part or all of the *Borissiakoceras compressum* Zone, or may be merely a part of the *Plesiacanthoceras amphibolum* Zone, but for paleoecologic reasons, lacks species indicative of that zone. Strata containing the *Ostrea beloiti* assemblage embrace part or all of the Zone of *P. amphibolum* plus a few feet of younger strata.

6. Absence of *Plesiacanthoceras wyomingense* in the upper part of the Graneros in the central part of the Graneros outcrop supports lithostratigraphic evidence for an unconformity at the Graneros—Greenhorn contact. The same unconformity is recognized in the southern part of the outcrop belt, the *C. lamarensis* assemblage occupies all of the Graneros, and the *Ostrea beloiti* assemblage is not represented in the formation. Although *P. wyomingense* occurs near the base of the Greenhorn at one locality in the latter area the Graneros—Greenhorn contact there apparently represents a larger hiatus than it does farther to the north in Kansas.

7. Stratigraphic, lithologic and faunal evidence indicates that deposition of the Graneros began in shallow, turbid, nearshore marine water of less than normal salinity. Later deposition occurred in progressively deeper, less turbid, offshore water of normal salinity. As a consequence of unstable bottom conditions during deposition, most benthonic macroinvertebrates in the *C. lamarensis* assemblage were endobenthonic forms whereas those in the *O. beloiti* assemblage were epifaunal and nektonic forms. Increasing salinity during deposition is indicated by the combined evidence of distribution of kaolinite, inarticulate brachiopods, limestone beds, foraminifers, and ammonites. Sedimentary structures and planktonic foraminifers suggest that water depth probably ranged from less than 30 feet during deposition of the lower part of the formation, to perhaps 70 feet for the middle part, with a maximum not exceeding 100 feet for the upper part of the formation. Coquinoidal limestone and bone beds are a consequence of storms which stirred bottom sediments to greater depths than usual and concentrated coarse organic debris while finer material was carried temporarily in suspension.

8. Deposition of Graneros sediments in central Kansas was influenced largely by discharge

of a major stream system or systems which created a deltaic complex along the eastern margin of the Western Interior Sea. Nonmarine channel, floodplain, and swamp deposits in the Dakota formed on the surface of the delta. Overlying or laterally gradational marine sandstone and silty, carbonaceous, or sandy shale in the uppermost few feet of the formation are interpreted as deposits of a deltaic submarine topset plain, and sedimentation in local coastal embayments is represented by silty shale like that of the Graneros. Silty shale and thin sandstone beds in the lower part of the Graneros accumulated in a relatively nearshore environment and may be largely the deposits of a deltaic foreset slope, especially in areas where plastic flow structures indicate a submarine slope that was greater than that for adjacent beds. The purer, less silty shale beds near the top of the Graneros were deposited farthest from shore and are interpreted as bottomset beds of the deltaic complex.

9. The Graneros Shale represents part of the transgressive hemicycle of the Greenhorn cyclothem which was laid down during the first late Cretaceous cycle of marine deposition in Kansas. The cyclothem is asymmetrical stratigraphically and nearly symmetrical lithologically and comprises seven phases. Maximum transgression, and greatest distance from the eastern shoreline, is represented by the Greenhorn Limestone (phase 4); the Graneros Shale constitutes phases 2 and 3.

10. In central Kansas erosion of the Graneros Shale occurred before the inception of deposition of the Greenhorn Limestone. Evidence for subaerial erosion is lacking; accordingly, I believe that removal of parts of the Graneros resulted from the process known as sublevation. Because basal Greenhorn strata contain less terrigenous detritus than adjacent parts of the Graneros, sublevation apparently did not result from regressional phenomena. I conclude, therefore, that positive crustal movement in the central Kansas region was the primary factor responsible for the hiatus at the Graneros—Greenhorn contact.

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APPENDIX

Descriptions of Key Sections

Explanation.—In the following descriptions, fossil abundance, where recorded, is given in accordance with the following notations: (r) rare, 1-2 specimens; (s) sparse, 2-10 specimens; (c) common, 11-50 specimens; (a) abundant, 51+ specimens. Macrofossil abundance is based on a bed-by-bed examination of each measured unit in a trench dug down to fresh rock. Foraminiferal abundance is based on the number of specimens on a population slide for each unit. Color chart codes are given for those color names that appear in two places on the Rock-Color Chart (Goddard, *et al.*, 1948) except for those rocks intermediate in color between the two.

KEY SECTION 1.

Road cut on east side of U.S. Highway 281, just north of Saline River, Russell County, Kansas.

Locality 1. NW sec. 35, T 12 S, R 14 W.

GREENHORN LIMESTONE

Lincoln Limestone Member

Unit	Thickness, feet
22. Limestone, skeletal, light olive-gray, weathers grayish-orange to dark yellowish-orange, thin- to medium-bedded, in part cross-laminated, composed chiefly of *Inoceramus* prisms with shell fragments and some quartz sand; basal 0.5 foot is conglomerate of bentonite pebbles, coprolites, fish remains, shell fragments; rocks have petroliferous odor when fresh. *Fossils: Inoceramus pictus*, fish remains.	1.8
Measured thickness of Greenhorn Limestone.	1.8
Rests with sharp contact on:	

GRANEROS SHALE

Unit	Thickness, feet
21. Shale, calcareous, and limestone, skeletal; shale medium-gray, weathers moderate yellowish-brown, laminated, chalky; limestone pale yellowish-brown, weathers dark yellowish-orange, very thin lenticular beds with local load casts, fine to very fine-grained, composed chiefly of *Inoceramus* prisms. *Fossils: Ostrea* sp. (s), *Inoceramus* sp. (c), fish bones, *Hedbergella planispira* (r), *H. amabilis* (r).	0.5
20. Shale, dark-gray, weathering dark yellowish-brown, blocky to fissile, weathering flaky, very slightly to slightly silty, limonite staining common on joints and bedding planes; finely granular gypsum common on bedding planes. *Fossils: Inoceramus* sp. (prisms), unidentified foraminifers (r).	2.2
19. Bentonite, grayish-yellow (5Y8/4) to pale greenish-yellow (10YR8/2), weathers dark yellowish-orange, very slightly silty.	0.8
18. Shale, dark-gray, weathers medium brownish-gray, poorly laminated, blocky to fissile, weathers flaky, very slightly silty throughout, laminae and lenses of very fine sand or coarse silt scattered throughout, limonite and jarosite staining on joints and bedding planes, abundant minute selenite crystals; lenses of quartz sandstone, calcareous, sparsely glauconitic, fine to very fine-grained, thinly laminated to cross-laminated, with petroliferous odor, lie near and at top of unit; 0.2-foot-thick lenses of limestone, skeletal, fine-grained, composed chiefly of *Inoceramus* prisms with some quartz sand lie 2.6 feet above base. *Fossils:* in shale, *Ostrea* sp. (r), *Inoceramus* sp. (r), fish scales, *Reophax minuta* (c); in limestone, *Ostrea beloiti* (a), *Inoceramus* sp. (s), *Callistina lamarensis* (float) (s).	4.3
17. Limestone, skeletal, weathers moderate yellowish-brown, thin-bedded, laminated and gently cross-laminated, composed chiefly of *Inoceramus* prisms, quartz sandy, sparsely glauconitic, well-cemented and resistant at top, lower part argillaceous and with fewer prisms, unit ferruginous and gypsiferous throughout. *Fossils: Inoceramus* sp. (prisms), *Ostrea beloiti* (c), fish vertebra.	0.5
16. Shale, dark-gray, dries medium-gray, weathers flaky, slightly silty throughout, evenly laminated to thinly laminated appearance imparted by very thin laminae of silt, flecked locally with abundant carbonaceous matter, stained by limonite and jarosite on joints and bedding planes, very weak melanterite taste, planar masses of minute selenite crystals locally; lenses of limestone, skeletal, 1.3 feet above base, well-cemented, resistant, fine-grained, composed chiefly of *Inoceramus* prisms and quartz grains with fish and oyster remains common, locally thinly cross-laminated. *Fossils:* in shale, *Ostrea*-covered *Inoceramus* 1.0 foot below top, gypsum-replaced *Ostrea beloiti* (c) near base, *Reophax minuta* (c); in limestone, *Ostrea beloiti* (a), *Inoceramus* sp. (prisms), fish remains.	2.6
15. Limestone, skeletal, olive-gray (5Y4/1), weathers moderate yellowish-brown, thin-bedded to thinly laminated, locally cross-laminated, well-cemented, resistant, chiefly composed of *Inoceramus* prisms and fine to very fine quartz sand, moderately glauconitic, carbonized plant fragments and selenite crystals common locally, some drag mark casts. *Fossils: Inoceramus* (prisms), *Ostrea* sp. (r), *Callistina lamarensis* (c), fish remains.	0.4
14. Shale, dark olive-gray grading upward to dark-gray, fissile, weathers flaky, slightly silty to finely sandy throughout, with common thin laminae and lenses of silt or very fine sand, jarosite stains common on joints and bedding planes, very strong melanterite taste, limonite staining common in middle part, minute selenite crystals scattered throughout; sandstone, fine-grained, friable, mostly nonresistant, in thin to very thin layers, lying near middle of unit; very thin layers of bentonite at base and 1.7 feet above base are yellowish-gray (5Y7/2). *Fossils:* fish scales, grass microfossils.	3.8
13. Shale and sandstone; shale, dark-gray, soft	

Unit	Thickness, feet
and plastic when wet, fissile, weathers flaky, slightly sandy throughout with thin laminae and lenses of quartz sand common locally, specks of carbonaceous matter common, jarosite stains on joints and bedding planes, very strong melanterite taste, minute selenite crystals abundant throughout; sandstone, composed chiefly of fine to very fine quartz grains, some beds contorted owing to subaqueous plastic flowage, where well-cemented and resistant, rock is light olive-gray weathering yellowish-gray (5Y7/2), thinly laminated and gently cross-laminated, and locally limonite-stained; where poorly cemented, sandstone is grayish-orange. *Fossils:* fish scales, grass microfossils.	1.9
12. Shale, dark-gray, soft and plastic when wet, fissile, weathers flaky, slightly sandy throughout with thin laminae and lenses of fine quartz sand common locally, small specks of carbonaceous matter common throughout, jarosite stains on joints and bedding planes, strong melanterite taste. *Fossils:* fish scales, *Reophax minuta* (s), grass microfossils.	2.6
11. Siltstone, yellowish-gray (5Y7/2) weathers light olive-gray, thinly laminated and locally cross-laminated, composed chiefly of quartz with sparse glauconite, unit interlaminated with dark gray shale. *Fossils:* fish scales.	0.3
10. Shale, medium dark-gray, weathers dark brownish-gray, soft and plastic when wet, slightly silty to finely sandy with many thin laminae and lenses of carbonaceous quartz silt or very fine sand, specks of carbonaceous matter common, jarosite and some limonite stains on joints and planes, strong melanterite taste, minute selenite crystals abundant throughout; sandstone, composed chiefly of fine quartz grains, in layers 0.2 and 0.4 foot thick and lying 0.9 and 1.8 feet above base, respectively, upper sandstone gently to steeply cross-laminated; bentonite, white, 0.01-foot thick, lies 2.5 feet above base.	4.5
9. Sandstone and shale; sandstone weathered dark yellowish-orange, thin to very thin-bedded, possibly ripple marked on upper surface, moderately well-cemented and resistant, composed chiefly of medium- to very fine-grained quartz, silty, highly limonitic, abundant small selenite crystals; shale, forms middle part of unit, medium dark-gray, finely sandy, fissile, sparsely flecked with carbonaceous matter, jarosite- and limonite-stained, filled with minute selenite crystals. *Fossils:* in shale, fish scale, *Ammobaculites* cf. *A. bergquisti* (a), *Trochammina rainwateri* (c), *T.* cf. *T. depressa* (r).	1.2
8. Shale, light brownish-gray at base grading upward to dark-gray, weathers medium brownish-gray, soft and plastic when wet, slightly sandy at base, very thin lenses of fine quartz sand common throughout, slightly to very silty in middle and upper parts, lower and middle parts blocky, evenly laminated, upper part poorly laminated, flakes of carbonaceous matter scattered throughout, pyrite nodules common in middle and upper parts, jarosite and limonite stains on joints and bedding planes, selenite crystals common in lower half. *Fossils: Trochammina rainwateri* (s), *Ammobaculoides plummerae* (r), *Verneuilinoides perplexus* (s), *Reophax pepperensis* (r).	4.8
Total thickness of Graneros Shale.	30.4
Rests conformably on:	

DAKOTA FORMATION

Unit	Thickness, feet
7. Sandstone, pale yellowish-brown (10YR6/2), poorly consolidated, friable, composed chiefly of fine and very fine quartz grains, argillaceous with sandy clay streaks, flakes of carbonaceous matter disseminated throughout, jarosite stains characteristic, limonite and small selenite crystals common.	0.5
6. Sandstone, weathered dark yellowish-orange to dark reddish-brown, thick-bedded, well-cemented, resistant, composed chiefly of medium to fine quartz grains, carbonaceous matter common, ferruginous cement contains molds of siderite? spherulites, unit highly weathered with rough upper surface, many ferruginous concretionary structures.	2.3
5. Sandstone, light olive-gray (5Y5/2), weathers dark yellowish-orange, poorly cemented, friable, nonbedded, composed chiefly of fine quartz grains with small amounts of clay matrix, abundant carbonized plant remains, minute selenite crystals common locally, sandy shale at base.	1.3
4. Clay-ironstone, concretionary, light olive-gray (5Y6/1), weathers moderate-brown to light-brown (5YR5/6), concretions closely spaced in matrix of quartz sand.	0.4
3. Shale, medium gray to medium dark-gray, plastic when wet, fissile when dry, sandy at base and top, very thin lenses of fine quartz sand scattered throughout, jarosite-stained on joints and bedding planes, large selenite crystals at top, clay-ironstone concretions near middle have limonite "shell." *Fossils: Trochammina rainwateri* (c), *?Ammobaculoides plummerae* (c), *Verneuilinoides perplexus* (r).	2.2
2. Sandstone and sandy shale, sandstone light olive-gray (5Y5/2), moderately well consolidated, composed chiefly of fine quartz grains, argillaceous, carbonaceous, ferruginous, locally selenitic, as nodular beds surrounded by shale; shale, medium dark-gray, quartz sandy, alternating with layers of sandstone, light olive-gray (5Y5/2), poorly consolidated, argillaceous, fine-grained.	1.4
1. Shale, medium gray to medium dark-gray, plastic when wet, fissile, quartz sandy at base, more sandy at top, alternating with thin layers of fine quartz sand in upper 0.25 foot, jarosite stains on joints and bedding planes, minute selenite crystals along joints. *Fossils:* fish scale, *Trocham-*	

Unit		Thickness, feet
	mina rainwateri (a), *Verneuilinoides perplexus* (r), *Reophax minuta* (r).	1.5
	Measured thickness of Dakota Formation.	9.6
	Total thickness of measured section.	41.8

KEY SECTION 2.

Graded bank and ditch on west side of north-south county road approximately 3 miles south of Wilson, Kansas.

Locality 8. E NW sec. 6, T 15 S, R 10 W.

GREENHORN LIMESTONE

Unit		Thickness, feet
17.	Limestone, skeletal, light olive-gray (5Y5/2), weathers dark yellowish-orange, tightly cemented, resistant, composed chiefly of *Inoceramus* prisms, petroliferous odor when fresh. *Fossils: Inoceramus* prisms.	0.15
16.	Bentonite, light olive-gray (5Y6/1) to very light-gray, weathers dark yellowish-orange, sparse biotite.	0.3
15.	Limestone, skeletal, mostly weathered dark yellowish-orange, thin- to very thin-bedded, composed chiefly of *Inoceramus* prisms and fine to very fine quartz sand, petroliferous odor when fresh; bentonite, 0.08-foot thick, nearly white, biotite-bearing, lies 0.1 to 0.2 foot above base. *Fossils: Inoceramus* sp., fish remains, coprolites.	1.1
	Measured thickness of Greenhorn Limestone.	1.6
	Rests with sharp contact on:	

GRANEROS SHALE

Unit		Thickness, feet
14.	Shale, similar to 12. *Fossils:* fish remains, *Inoceramus* sp. (prisms), *Hedbergella brittonensis* (s), *H. amabilis* (r), *H. delrioensis* (r), *H. planispira* (s).	1.1
13.	Limestone, skeletal, light olive-gray (5Y7/2), weathers dark yellowish-orange, very thin-bedded, thinly laminated and partly cross-laminated, well-cemented, resistant, composed chiefly of *Inoceramus* prisms, very finely quartz sandy, has petroliferous odor when fresh. *Fossils: Ostrea beloiti* (c), *Inoceramus rutherfordi* (c), fish remains.	0.3
12.	Shale, all partly weathered light olive-gray to dark yellowish-orange, soft and plastic when wet, irregularly fissile, silty throughout, streaked with silt or very fine quartz sand that is light olive-gray (5Y6/1), sparsely specked with carbonaceous matter. *Fossils: Inoceramus* sp. (c), *Ostrea* sp. (s), fish remains, *Hedbergella brittonensis* (a), *H. amabilis* (c), *H. delrioensis* (s), *Heterohelix globulosa* (r).	1.4
11.	Bentonite and septarian concretions; bentonite 1.0-foot thick, very light-gray, weathers dark yellowish-orange, minute grains of biotite? throughout, very slightly silty; concretions, in upper part and projecting above bentonite bed, up to 4 feet across, dusky yellow to nearly white with brecciated appearance, coarsely crystalline calcite and septaria limonitic when weathered. *Fossils:* in concretions, *Ostrea beloiti* (c), *Inoceramus rutherfordi* (r).	1.4
10.	Shale, medium to medium dark-gray, upper parts mostly weathered dark yellowish-orange, basal part blocky, upper part thinly laminated, weathers flaky, stained by limonite on joints and bedding planes, moderately to very silty in lower part, very sandy in upper part with sand occurring as light olive-gray laminae or very thin layers, some of which are thinly laminated; sand, soft, mostly argillaceous, composed chiefly of quartz silt and very fine sand; alunite nodules, 0.1-foot thick, lie 0.6 foot below top. *Fossils:* in shale, *Inoceramus rutherfordi?* (juvenile) (r), *Ostrea beloiti* (s), *Borissiakoceras* sp. (r), *Reophax minuta* (c), *?Hedbergella brittonensis* (r); in sandstone, *Ostrea beloiti* (c), scalpellid plate (r), fish remains.	3.7
9.	Siltstone, weathered dark yellowish-orange, single discontinuous bed, thinly laminated to gently cross-laminated, mostly poorly cemented, friable, composed chiefly of quartz grains, argillaceous, limonitic.	0.2
8.	Shale, light olive-gray (5Y7/2) to medium dark-gray, mostly partly weathered to medium brownish-gray, mottled where partly weathered, soft and plastic when wet, blocky, irregularly fissile, weathers flaky, all moderately to very silty, unit streaked throughout with thin laminae and lenses or thinly laminated thin beds of quartz silt or very fine sand, specks of carbonaceous matter common throughout, jarosite stains on joints and bedding planes, limonite concentrated in a few very thin layers, large selenite crystals common throughout; bentonite, dark yellowish-orange to moderate yellowish-brown, 0.08-foot thick, lies 0.7 foot above base of unit. *Fossils:* in shale above bentonite, *Pleisiacanthoceras amphibolum* (r), *Borissiakoceras reesidei* (s), *Ostrea beloiti* (r), *Inoceramus sp.* (s), *Reophax minuta* (a), *Hedbergella brittonensis* (r), *H. amabilis* (s), *H.* sp. (r), *Ammobaculoides plummerae* (r), *Trochammina rainwateri* (s); in shale below bentonite, *Reophax minuta* (c); in sandstone, *Ostrea beloiti* (s).	12.7
7.	Sandstone, light olive-gray (5Y6/1) to greenish-gray, thin to very thin-bedded, in part very thinly and evenly laminated, composed chiefly of very fine quartz grains, alternating well-cemented and argillaceous poorly cemented layers, all specked with carbonaceous matter, very thin shale partings throughout; bentonite, light olive-gray (5Y6/1) to greenish-gray, 0.08-foot thick, lies 0.2 foot above base. *Fossils: Inoceramus* sp. (s), *Callistina lamarensis* (s), fish remains.	1.7
6.	Shale, medium-gray, blocky, irregularly fissile, weathers flaky, moderately silty throughout, numerous very thin layers of very fine quartz sand scattered throughout, specks of carbonaceous matter common, partly stained by jarosite and limonite on	

Unit	Thickness, feet
joints and bedding planes, many large selenite crystals, especially in upper 0.1 foot; sandstone, light olive-gray, weathers yellowish-gray (5Y7/2), thinly laminated, jarositic in harder layers; one resistant sandstone bed, 0.1-foot thick, ripple-marked, lies 7.5 feet above base; bentonite, light-gray 0.05-foot thick, lies 1.7 feet above base. *Fossils:* in lower 7.5 feet of shale, *Callistina lamarensis* (r), fish remains, *Reophax minuta* (a), *R. pepperensis* (r), *Ammobaculoides plummerae* (s), *Trochammina rainwateri* (r); in upper 3.8 feet of shale, *Inoceramus* (prisms), *Reophax minuta* (a), *R. pepperensis* (s), *Ammobaculoides plummerae* (c), *Verneuilinoides perplexus* (c), *Trochammina rainwateri* (s), *Hedbergella delrioensis* (r), grass microfossils; in sandstone, *Callistina lamarensis* (c), worm? castings.	11.3
Total thickness of Graneros Shale.	33.8
Rests conformably on:	

DAKOTA FORMATION

Unit	Thickness, feet
5. Sandstone, partly weathered moderate yellowish-brown, medium-bedded, weathers to thin irregular beds, moderately well-cemented, resistant, composed chiefly of medium to very fine quartz sand, finely micaceous, carbonaceous, slightly argillaceous in upper 0.5 foot, limonitic, contains numerous clay galls. *Fossils: Callistina?* sp. (r).	2.4
4. Sandstone and very sandy shale, sandstone light olive-gray weathering dark yellowish-orange, medium-bedded, argillaceous, poorly cemented, friable, in part tightly cemented by limonite in layers that weather very dusky red, composed chiefly of medium to very fine quartz sand, carbonaceous throughout; shale medium dark-gray, plastic when wet, very thinly laminated where most sandy, stained in part by jarosite; exposure rusty red from high concentration of limonite. *Fossils:* worm? burrows.	2.3
3. Shale, medium dark-gray, soft and plastic when wet, thinly laminated, irregularly fissile, weathers flaky, moderately to very silty, alternating in lower 0.8 foot with shale, olive-gray, fissile, very finely quartz sandy, carbonaceous, with many very thin layers of sandstone which is medium light-gray, thinly laminated, composed chiefly of fine to very fine quartz grains, carbonaceous and micaceous; upper 0.8 foot of unit interbedded with very thin layers of sand, light olive-gray (5Y5/2), composed chiefly of fine to very fine quartz grains. *Fossils: Trochammina rainwateri, Ammobaculoides* cf. *plummerae*, grass microfossils.	2.6
2. Siltstone, dark-gray to medium light-gray, weathers medium brownish-gray, one thick bed, thinly and irregularly laminated, poorly cemented, friable, composed chiefly of coarse quartz silt and very fine sand, carbonaceous throughout, micaceous, partly stained by jarosite and limonite, streaked with dark-gray shale. *Fossils:* reed molds in upper part.	2.1
1. Lignite and shale; lignite, black, hard, brittle, vitreous, grading upward into shale, dark-gray, soft, irregularly fissile, silty, carbonaceous.	0.85
Measured thickness of Dakota Formation.	10.25
Total thickness of measured section.	45.70

KEY SECTION 3.

Road cut on east side of Kansas Highway 14 approximately 1 mile north of Lincoln, Kansas.

Locality 12. SW SW sec. 30, T 11 S, R 7 W.

GREENHORN LIMESTONE

Lincoln Limestone Member

Unit	Thickness, feet
13. Limestone, skeletal and chalky, poorly exposed, all weathered dark yellowish-orange, punky, thin-bedded, not resistant, composed chiefly of shell debris and very fine quartz sand, or chalk. *Fossils: Inoceramus* sp., fish remains.	1.0
Measured thickness of Greenhorn Limestone.	1.0
Rests with sharp contact on:	

GRANEROS SHALE

Unit	Thickness, feet
12. Shale, medium dark-gray, weathers dark yellowish-orange, plastic when wet, irregularly fissile, moderately to very silty throughout. *Fossils: Inoceramus* (prisms), fish remains, *Hedbergella delrioensis* (a), *Heterohelix globulosa* (c).	0.5
11. Bentonite, pale yellowish-green to nearly white, slightly silty, with very fine grains of biotite, unit ranges up to 0.5 foot in thickness.	0.2
10. Shale, olive-gray, in part medium dark-gray mottled with pale yellowish-brown, blocky and irregularly to evenly fissile, weathers flaky, slightly to very quartz silty, very finely sandy at base, specked throughout with carbonaceous matter, jarosite and some limonite staining on joints and bedding planes, scattered large selenite crystals; interbeds of quartz sand and silt, especially near top, mostly light olive-gray (5Y6/1). *Fossils: Inoceramus rutherfordi* (juvenile) (r), *Ostrea beloiti* (r), *Borissiakoceras reesidei* (r), fish remains, *Reophax minuta* (a).	7.9
9. Sandstone, mostly weathered dark yellowish-orange, mottled, transitional with adjacent units, one bed, weathers blocky to platy, moderately well-cemented, dolomitic, composed chiefly of very fine quartz sand and silt, limonitic. *Fossils: Ostrea beloiti* (s), *Inoceramus* (prism molds), fish remains.	0.8
8. Shale, light olive-gray (5Y6/1) to dark olive-gray, weathers dark yellowish-orange, blocky and irregularly fissile where least sandy, weathers flaky, specked with carbonaceous matter, slightly to very sandy with numerous thin and very thin beds and laminae of fine and very fine quartz sand and silt, more sandy at top of unit, specked with carbonaceous matter; sand mostly	

Unit		Thickness, feet
	weathered dark yellowish-orange, poorly to well-cemented, some well-cemented beds thinly laminated weathering to very thin platy float; limonitic septarian concretions up to 0.7-foot wide lie 0.8 foot above base. *Fossils:* fish remains, *Reophax minuta* (c), *Verneuilinoides perplexus* (s), *Trochammina rainwateri* (s).	3.7
7.	Shale, medium dark-gray, weathers medium brownish-gray to olive-gray, blocky and irregularly fissile, weathers flaky, very slightly silty throughout with very thin laminae and lenses of very fine quartz sand or silt, abundant specks of carbonaceous matter, jarosite and some limonite staining along joints and bedding. *Fossils:* fish remains, *Reophax minuta* (c).	1.5
6.	Bentonite, grayish-orange, weathers dark yellowish-orange, thins laterally to 0.01 foot.	0.03
5.	Shale, like that in unit 4 but with numerous laminae and thin laminae of very fine quartz sand and silt; laminae are light olive-gray, jarosite-stained. *Fossils: Inoceramus* sp. (s), fish remains, *Reophax minuta* (c), *R. pepperensis* (r), *Ammobaculoides plummerae* (s), *Trochammina rainwateri* (r), carbonized plant fragments.	0.9
4.	Shale, medium dark-gray, weathers medium brownish-gray to olive-gray, blocky and irregularly fissile, weathers flaky, very slightly silty throughout with very thin laminae and lenses of very fine quartz sand or silt, abundant specks of carbonaceous matter, jarosite and some limonite stains on joints and bedding planes, some coarsely granular gypsum. *Fossils:* fish remains, *Reophax minuta* (c), *Verneuilinoides perplexus* (r).	7.2
3.	Sandstone, light olive-gray, weathers dark yellowish-orange with limonite and jarosite stains, poorly to moderately well-cemented, friable, harder layers resistant, composed chiefly of fine to very fine grains of quartz, specked with carbonaceous matter.	0.6
2.	Shale, olive-gray (5Y4/1), medium dark-gray, grading upward to light olive-gray (5Y6/1), soft and plastic when wet, blocky, irregularly fissile, sparse specks of carbonaceous matter, stained throughout by jarosite and, in streaks, by limonite, granular gypsum common locally, basal 0.5 foot stained dark yellowish-orange by limonite. *Fossils:* fish tooth, *Trochammina rainwateri* (a), *Ammobaculites* cf. *A. bergquisti* (s), *Hedbergella delrioensis* (r).	3.0
	Total thickness of Graneros Shale.	26.33
	Rests conformably on:	

DAKOTA FORMATION

Unit		Thickness, feet
1.	Sandstone, weathered dark yellowish-orange, thick-bedded, poorly to moderately well-cemented, friable, composed dominantly of fine to very fine grains of quartz, limonitic.	1.0
	Measured thickness of Dakota Formation.	1.0
	Total thickness of measured section.	28.33

KEY SECTION 4.

Road cut on U.S. Highway 36 approximately 3 miles south and 1 mile east of Haddam, Kansas.

Locality 16. SW sec. 1 and NW sec. 12, T 3 S, R 1 E.

GRANEROS SHALE

Unit		Thickness, feet
8.	Shale, dark-gray, mostly partially weathered medium light-gray to light olive-gray (5Y6/1), soft and plastic when wet, blocky and irregularly fissile, moderately to very silty throughout, scattered thin laminae of light, olive-gray very fine quartz sand or silt, unit partially stained dark yellowish-orange by limonite, lower 0.2 foot interlaminated with bentonite like that in unit 7; sandstone laminae in lower 2 feet moderately well-cemented, resistant, weathers to platy float.	6.0+
7.	Bentonite, yellowish-gray (5Y7/2) to grayish-yellow (5Y8/4), weathers dark yellowish-orange owing to limonite stain, slightly silty.	0.7
6.	Shale, medium dark-gray, partially weathered to medium brownish-gray along joints and bedding planes, basal 0.3 foot dark yellowish-brown, blocky and irregularly fissile, very finely quartz sandy, weathers flaky, stained by jarosite and some limonite on joints and bedding planes, specked with carbonaceous matter throughout, selenite crystals common in some layers; sandstone, light olive-gray, one very thin bed, moderately well-cemented, composed chiefly of fine- to very fine-grained quartz, lies at top of unit. *Fossils:* in shale, *Inoceramus rutherfordi?* (juveniles) (s), *Ammobaculites* cf. *A. bergquisti* (s); in sandstone, *Inoceramus* (prism and fragment molds), *Ostrea beloiti* (s).	6.6
5.	Sandstone, light olive-gray (5Y6/1), limonite-stained to light-brown color (5YR5/6) in upper foot, mostly noncemented, poorly cemented at top, thin- to thick-bedded, composed chiefly of fine and very fine quartz sand, lower part slightly argillaceous. *Fossils: Callistina lamarensis* (a), *Exogyra columbella?* (s), carbonized plant fragments.	2.8
4.	Shale, olive-gray, blocky and irregularly fissile, weathers flaky, abundantly streaked by light olive-gray (5Y6/1) laminae and thin laminae of very fine quartz sand and silt, specked with carbonaceous matter, all beds stained by jarosite and limonite on joints and bedding planes, transitional into unit 5. *Fossils: Trochammina rainwateri* (c), *Ammobaculites* cf. *A. bergquisti* (c), *A. impexus, Trochamminoides apricarius* (r), carbonized plant fragments.	2.1
3.	Shale, medium dark-gray, weathers medium olive-gray to olive-gray, soft and plastic when wet, blocky and irregularly fissile, weathers flaky, slightly to moderately silty	

Unit		Thickness, feet
	throughout, thin laminae and lenses of very fine quartz sand or silt scattered throughout but more numerous near top, specks of carbonaceous matter common, upper foot limonite-stained, some jarosite stains, very thin, relatively hard layers of limonitized shale scattered throughout, especially common in upper half, large selenite crystals common throughout, pyrite nodules common just above middle, strong taste of melanterite in more sandy upper part. *Fossils: Ammobaculites impexus* (r).	10.1
2.	Shale and sandstone; similar to unit 1, shale predominates, sandstone limonitic. *Fossils: Trochammina rainwateri* (c), *Ammobaculites* cf. *A. bergquisti* (r).	0.7
	Measured thickness of Graneros Shale.	29+
	Rests conformably on:	

DAKOTA FORMATION

Unit		Thickness, feet
1.	Sandstone and shale; sandstone pale yellowish-brown, partly weathered, soft and plastic, argillaceous, composed chiefly of very fine quartz sand and silt, finely micaceous, specked with carbonaceous matter, jarosite-stained, limonitic and more resistant at top; shale, 1.0-foot thick, medium brownish-gray, soft and plastic when wet, blocky, slightly silty, specked with carbonaceous matter. *Fossils: Trochammina rainwateri* (a).	3.2
	Measured thickness of Dakota Formation.	3.2
	Total thickness of measured section.	32.2+

KEY SECTION 5.

Gullied slope and road cut on south side of east-west county road approximately ½ mile south and 1 mile east of Hanston, Kansas.

Locality 20. NE NW sec. 25, T 22 S, R 22 W.

GREENHORN LIMESTONE

Lincoln Limestone Member

Unit		Thickness, feet
17.	Limestone, skeletal, light olive-gray (5Y6/1), weathers grayish-orange, thin to very thin-bedded, well-cemented, resistant, composed dominantly of *Inoceramus* prisms and shell fragments with some quartz sand, petroliferous odor when fresh. *Fossils: Ostrea* sp., *Inoceramus* sp., fish remains.	2.0
	Measured thickness of Greenhorn Limestone.	2.0
	Rests with sharp contact on:	

GRANEROS SHALE

Unit		Thickness, feet
16.	Shale, medium light-gray, partly weathered light-gray, blocky and fissile, weathers flaky, moderately quartz silty, weakly calcareous throughout, chalky in upper 0.1 foot, sparsely specked with carbonaceous matter, stained by jarosite and limonite. *Fossils: Inoceramus* sp. (prisms), *Hedbergella delrioensis* (a), *H. brittonensis* (c), *H. planispira* (r), *Trochammina?* sp. (r), unidentified calcareous foraminifer (r).	0.8
15.	Bentonite, pale greenish-yellow, slightly silty.	0.07
14.	Sandstone, light olive-gray (5Y6/1), weathers dark yellowish-orange, thin-bedded, poorly cemented and friable, well cemented by limonite in middle part, flakes of carbonaceous matter common. *Fossils:* fish remains, *Hedbergella delrioensis* (c).	1.1
13.	Clay, bentonitic, medium light-gray to light-gray, very silty.	0.25
12.	Sandstone, dark yellowish-orange, cemented by limonite, relatively resistant, composed chiefly of fine quartz grains, contains chunks of carbonaceous matter. *Fossils:* fish remains.	0.25
11.	Shale, medium dark-gray, dries medium light-gray, blocky and fissile, weathers flaky, interbedded with numerous thin laminae of very fine-grained quartz sand and silt, stained by jarosite and some limonite. *Fossils: Callistina lamarensis* (s), *Inoceramus* sp. (s), fish remains, *Reophax minuta* (a), *Hedbergella delrioensis* (c), *Ammobaculoides plummerae* (c), *Ammodiscus planus* (r), tintinnids (s).	14.4
10.	Sandstone, dark yellowish-orange, thinly and irregularly bedded, moderately well-cemented, relatively resistant, friable, composed dominantly of very fine-grained quartz sand and silt, characterized by molds of pelecypods. *Fossils: Callistina lamarensis* (a), *Exogyra columbella* (c), *Discinisca* sp. (s), *Trochammina rainwateri* (r), *Reophax minuta* (c).	1.1
9.	Shale, medium dark-gray, dries medium light-gray, blocky and evenly fissile, weathers flaky, slightly silty to silty, stained throughout by jarosite and limonite, unit contains scattered thin laminae of very fine-grained quartz sand or silt. *Fossils: Callistina lamarensis* (r), *Inoceramus* (prism), *Reophax minuta* (c), *R. pepperensis* (s), *Trochammina rainwateri* (s), *Trochamminoides apricarius* (r), *Verneuilinoides perplexus* (r), *Ammobaculoides? plummerae* (r).	7.4
8.	Sandstone and claystone, dark yellowish-orange, limonitic throughout; upper part of unit is sandstone, poorly cemented, friable, composed chiefly of fine and very fine quartz grains. *Fossils: Reophax minuta* (c), *Trochammina rainwateri* (c), *Verneuilinoides perplexus* (c), *Ammobaculoides plummerae* (r).	0.1
7.	Shale, medium dark-gray, dries medium light-gray, blocky and fissile, weathers flaky, silty to very silty, sparse laminae of very fine quartz sand, specks of carbonaceous matter common, jarosite and limonite stains on joints and bedding planes throughout, selenite common as isolated crystals and crystalline masses. *Fossils:* fish remains, *Trochammina rainwateri* (c), *Reophax minuta* (c), *R. pepperensis* (r), *Verneuilinoides perplexus* (c), *Trochamminoides apricarius* (s).	6.0
	Total thickness of Graneros Shale.	31.5
	Rests conformably on:	

Unit	Thickness, feet
DAKOTA FORMATION	
6. Shale and sandstone; shale medium dark-gray, dries medium light-gray, blocky and fissile, weathers flaky, quartz silty and sandy, interbedded with numerous very thin beds, laminae, and lenses of quartz sandstone, unit stained by jarosite and limonite, large selenite crystals common, specks and flakes of carbonaceous matter common throughout; sandstone beds limonitic, well-cemented, hold up bench, thinly laminated, some layers sole marked. *Fossils: Reophax minuta* (c), *R. pepperensis* (r), *Trochamminoides apricarius* (s), *Verneuilinoides perplexus* (r), *Trochammina rainwateri* (r), *Ammobaculoides plummerae* (r), *Hedbergella brittonensis* (s).	2.4
5. Shale and sandstone; shale dark olive-gray (5Y3/1), dries olive-gray (5Y4/1), similar to unit 3 but less sandy, most sandy beds lie at base of unit, specks of carbonaceous matter common near top. *Fossils:* fish remains.	2.5
4. Bentonite, pale greenish-yellow, stained by limonite, quartz silty.	0.15
3. Shale and sandstone; shale dark olive-gray (5Y3/1), dries olive-gray (5Y4/1), fissile, weathers flaky, quartz silty and sandy, interbedded with numerous very thin beds, laminae, cross laminae, and lenses of fine quartz sandstone, stained in part by jarosite and in upper part by limonite, tastes strongly of melanterite, selenite crystals common; sandstone light olive-gray (5Y6/1), thinly laminated and gently cross-laminated; unit contains chunks of carbonaceous matter. *Fossils: Lingula* cf. *L. subspatulata* (r), fish remains, *Reophax minuta* (s), *R. pepperensis* (r), *Verneuilinoides perplexus* (s), *Tolypammina?* sp. (r), *Ammobaculites?* (r).	3.8
2. Sandstone, yellowish-gray (5Y7/2), weathers light olive-gray (5Y5/2), thick-bedded, gently cross-bedded in upper part, weakly cemented, friable, relatively resistant, ripple-marked on upper surface, composed chiefly of fine quartz grains, stained in part by limonite, especially at top of unit, specks of carbonaceous matter common, minimum observed thickness 0.4 foot.	1.3
1. Sandstone and shale; sandstone medium light-gray, very thin-bedded and in upper part cross-laminated, poorly cemented, friable, mostly nonresistant, composed chiefly of very fine quartz grains, argillaceous, interbedded and interlaminated with medium dark-gray shale that contains numerous thin laminae and lenses of very fine-grained quartz sand; unit most sandy in upper 1.5 feet, contains much carbonaceous matter, stained locally by limonite. *Fossils: Inoceramus* (prism), carbonized wood fragment.	4.4
Measured thickness of Dakota Formation.	14.6
Total thickness of measured section.	48.1

KEY SECTION 6.

Cut bank along southern tributary to Sawlog Creek in pasture, northwest of windmill, approximately 14 miles northeast of Dodge City, Kansas.

Locality 23. Center N sec. 10, T 25 S, R 23 W.

Unit	Thickness, feet
GREENHORN LIMESTONE	
20. Soil, calcareous, not measured.	
19. Bentonite, grayish-orange, silty, badly weathered, contains nodules of alunite.	0.5
Measured thickness of Greenhorn Limestone.	0.5
GRANEROS SHALE	
18. Shale, medium-gray to medium dark-gray, soft and plastic when wet, irregularly and thinly laminated, weathers flaky, slightly silty, contains a few very thin lenses of very fine quartz sand or silt, stained on joints and bedding planes by limonite, chunks of limonite and jarosite scattered across weathered slope, lenticular layer of siltstone near base is highly limonitic. *Fossils: Inoceramus* (prisms), *Reophax pepperensis* (c), *R. minuta* (c), *Verneuilinoides perplexus* (s), *Heterohelix globulosa* (r), *Trochammina rainwateri* (r) [At Locality 24, 1⅓ miles to northeast, unit contains *Callistina lamarensis* (s), *Lingula* cf. *L. subspatulata* (s), nuculanid molds and worm? trails, *Reophax pepperensis* (c), *R. minuta* (c), *Hedbergella delrioensis* (s), *H. brittonensis* (r), *Verneuilinoides perplexus* (r), *Trochamminoides apricarius* (r)].	6.2
17. Sandstone, yellowish-gray (5Y7/2), one thin bed, moderately well-cemented, composed chiefly of fine to very fine grained quartz, stained by jarosite, upper surface limonitic. *Fossils: Callistina?* sp. (fragmentary mold).	0.15
16. Shale, medium dark-gray, lower portion partly weathered medium olive-gray (5Y5/1), soft and plastic when wet, irregularly and thinly laminated, weathers flaky, contains sparse very thin lenses of poorly consolidated jarosite-stained very fine-grained sand, specked with carbonaceous matter, contains numerous very thin lenticular plates of limonite, weathered surface has scattered chunks of jarosite. *Fossils:* worm burrows, *Trochammina rainwateri* (a), *Reophax minuta* (c), *R. pepperensis* (s), *Verneuilinoides perplexus* (c), *Trochamminoides apricarius* (s), *Hedbergella delrioensis* (r), carbonized wood fragments.	4.7
15. Shale and sandstone; shale partly weathered medium olive-gray (5Y5/1), soft and plastic when wet, thinly and irregularly laminated, weathers flaky, moderately silty, specked with abundant carbonaceous matter on some bedding planes; sandstone, thinly interbedded with shale, light olive-gray, composed chiefly of fine to very fine-grained quartz, carbonaceous. *Fossils: Reophax*	

Unit		Thickness, feet
	minuta (c), *R. pepperensis* (s), *Trochammina rainwateri* (c), *Verneuilinoides perplexus* (c), *Ammobaculites* cf. *A. bergquisti* (s), *Trochamminoides apricarius* (r).	1.0
14.	Sandstone and shale; sandstone, light olive-gray, thin- to very thin-bedded, thinly laminated, streaked with clay, composed chiefly of fine to very fine quartz, cemented by limonite, resistant, top bed thickest and most resistant, carbonaceous and glauconitic, thinly interbedded with shale like that in unit 13. *Fossils: Inoceramus* (prism), bone fragments, *Reophax minuta* (s), *R. pepperensis* (r), *Trochammina rainwateri* (r), *Verneuilinoides perplexus* (r).	1.0
13.	Shale, dark-gray, dries medium-gray to medium light-gray, irregularly laminated, weathers flaky, moderately silty, sandy near sandstone beds, specks and flakes of carbonaceous matter common, interbedded with numerous very thin beds and lenses of sandstone, stained by limonite and jarosite on joints and bedding planes, contains many large crystals of selenite; sandstone, light olive-gray, thinly laminated, fine- to very fine-grained, streaked with shale. *Fossils:* sponge spicule, fish vertebra, *Reophax minuta* (a), *R. pepperensis* (c), *Trochammina rainwateri* (c), *Verneuilinoides perplexus* (s), *Trochamminoides apricarius* (r), *Ammobaculites* cf. *A. bergquisti* (r).	4.7
12.	Sandstone, light olive-gray (5Y6/1) to olive-gray (5Y4/1), weathers dark yellowish-orange, thin- to very thin-bedded, laminated to thinly laminated, composed chiefly of fine to very fine quartz sand and silt, glauconitic, moderately well-cemented, calcareous, 0.1-foot-thick bed of very sandy dark-gray shale in upper half, shale has strong taste of melanterite. *Fossils:* in sandstone, fish remains.	0.5
11.	Shale, dark-gray, dries medium-gray, lower part light olive-gray (5Y7/2) owing to limonite stains, irregularly laminated, weathers flaky, moderately silty to very silty throughout, has strong taste of melanterite, specked with carbonaceous matter, stained by limonite along joints and bedding planes, some limonite in very thin layers parallel to bedding, fine, granular gypsum abundant on bedding planes, scattered laminae and lenses of pale olive, fine- to very fine-grained quartz sand. *Fossils:* sponge spicule?, carbonized wood fragments.	2.2
10.	Bentonite, pale grayish-yellow, slightly silty, with limonitic zone in center.	0.2
9.	Sandstone, light olive-gray (5Y6/1), weathered moderate reddish-brown (limonitic), similar to unit 7, with dark-gray laminae of flaky-weathering shale scattered throughout but especially in upper part. *Fossils:* fish remains.	0.5
8.	Shale, dark-gray, dries medium light-gray, thinly and irregularly laminated, weathers flaky, moderately silty, contains a few very thin lenses of fine- to very fine-grained light olive-gray (5Y6/1) quartz sand, strong taste of melanterite, stained by jarosite on joints and bedding planes, specked with carbonaceous matter, contains many selenite crystals up to 0.1 foot in length. *Fossils: Reophax minuta* (c), *R. pepperensis* (c), *Verneuilinoides perplexus* (s), *Trochammina rainwateri* (r), *Tolypammina?* sp. (r).	0.85
7.	Siltstone, light olive-gray (5Y6/1), very thin- to medium-bedded, thinly and irregularly laminated to gently cross-laminated, composed chiefly of quartz, finely sandy, partially stained by jarosite, streaked by and interbedded throughout with slightly silty shale; shale dark-gray, dries medium-gray, fissile, weathers flaky, strong taste of melanterite, shale especially common in upper 0.5 foot. *Fossils: Lingula* cf. *L. subspatulata* (r), fish remains, carbonized wood fragments.	1.5
6.	Shale, dark-gray, dries medium-gray, blocky and thinly, but obscurely laminated, weathers flaky, slightly silty, specked with carbonaceous matter, stained with much jarosite and limonite along joints and bedding planes, middle part with sparse very thin lenses of fine quartz sand, scattered penny-sized nodules of pyrite or marcasite. *Fossils: Inoceramus* (prism molds), fish remains, *Trochammina rainwateri* (c), *Reophax minuta* (s), *Verneuilinoides perplexus* (s), carbonized wood fragments.	4.4
5.	Clay-ironstone, olive-gray (5Y6/1), weathers moderate reddish-brown to dark yellowish-orange, hard, brittle, resistant, limonitic at top and base.	0.1
4.	Shale, dark-gray, blocky and irregularly fissile, moderately quartz silty to very sandy with thin layer of medium- to fine-grained quartz sand near top, slight taste of melanterite. *Fossils: Verneuilinoides perplexus* (a), *Trochammina rainwateri* (s), *Reophax pepperensis* (s), *Ammobaculites* cf. *A. bergquisti* (r), carbonized wood fragments.	0.65
	Total thickness of Graneros Shale.	28.7
	Rests with sharp contact on:	

DAKOTA FORMATION

Unit		Thickness, feet
3.	Sandstone and clay; sandstone light olive-gray, composed chiefly of medium- to very fine-grained quartz, streaked and mottled throughout by clay, predominates in upper part of unit; clay, dark-gray, streaked and mottled with thick to thin laminae and lentils of sand, predominates in lower part of unit. *Fossils:* grass microfossils.	3.6
2.	Clay, medium-gray, unctuous, blocky, slightly to very silty, pinches out laterally against prominence in unit below number 1. *Fossils:* carbonized plant remains.	0.8
1.	Ferruginous concretions, light olive-gray (5Y5/2), weathers dark yellowish-orange to moderate reddish-brown, highly irregular shapes, very fine-grained, sandy, laminated to gently cross-laminated, specked with carbonized plant debris, unit pinches out laterally against sandstone prominence in unit below.	0.4
	Measured thickness of Dakota Formation.	4.8
	Total thickness of measured section.	34.0

List of Localities

Measured sections are plotted on Plate 1, and the localities thereon are shown on the inset map.

1. NW sec. 35, T 12 S, R 14 W, Russell County. Road cut on east side of U.S. Highway 281, just north of the Saline River. Complete section of Graneros.
2. SW NW sec. 1, T 13 S, R 13 W, Russell County. Road cut on east side of Luray-Bunker Hill road, approximately 5½ miles north and 1 mile west of Bunker Hill. Complete section of Graneros.
3. NE NE sec. 3, T 13 S, R 11 W, Russell County. Gully and abandoned road grade on west side of north-south county road approximately 7 miles south and 1 mile east of Lucas. Complete section of Graneros.
4. NE sec. 6, T 14 S, R 10 W, Ellsworth County. Graded bank on west side of north-south county road approximately 2½ miles north of Wilson. Complete section of Graneros.
5. NE NE sec. 19 and NW NW sec. 20, T 15 S, R 15 W, Russell County. Bluff on south side of Smoky Hill River approximately 9½ miles south of Gorham. Complete section of Graneros.
6. N SE sec. 7, T 13 S, R 14 W, Russell County. Road cut on east side of Canyon road and cut bank ¼ mile west of road approximately 4½ miles northwest of Russell. Complete section of Graneros.
7. SE NE sec. 31, T 14 S, R 11 W, Russell County. Bluff on south side of Smoky Hill River approximately 3½ miles south of Dorrance. Complete section of Graneros.
8. E NW sec. 6, T 15 S, R 10 W, Ellsworth County. Graded bank and ditch on west side of north-south county road approximately 3 miles south of Wilson, Kansas. Complete section of Graneros.
9. SE SE sec. 24, T 8 S, R 6 W, Mitchell County. Road cut and ditch on west side of north-south county road approximately 3 miles south of Simpson. Complete section of Graneros.
10. SE SE sec. 24, T 9 S, R 8 W, Mitchell County. Ditch on west side of north-south county road approximately 14½ miles north of Lincoln. Section of lower Graneros.
11. NW SW sec. 30, T 10 S, R 7 W, Lincoln County. Road cut on east side of Kansas Highway 14 approximately 7½ miles north of Lincoln. Section of upper Graneros.
12. SW SW sec. 30, T 11 S, R 7 W, Lincoln County. Road cut on east side of Kansas Highway 14 approximately 1 mile north of Lincoln. Complete section of Graneros.
13. NW SW sec. 13, T 12 S, R 15 W, Russell County. Road cut on west side of north-south county road directly south of Saline River crossing. Section of lower Graneros.
14. SE NE sec. 13, T 12 S, R 15 W, Russell County. Road cuts on both side of Mallard road approximately ¼ mile west of Saline River crossing. Section of middle Graneros.
15. NW NW sec. 4, T 12 S, R 15 W, Russell County. Cut banks on small northerly tributary to Saline River approximately 1½ miles east of Fairport. Section of upper Graneros.
16. SW sec. 1 and NW sec. 12, T 3 S, R 1 E, Washington County. Road cuts on both sides of U.S. Highway 36 approximately 3 miles south and 1 mile east of Haddam. Section of Graneros, except for uppermost part.
17. SE SE sec. 12, T 11 S, R 13 W, Russell County. Bluff on south side of Wolf Creek approximately 1 mile southwest of Luray. Complete section of Graneros.
18. NE NE sec. 29, T 15 S, R 10 W, Ellsworth County. Road cut and ditch on north side of east-west county road approximately 7 miles south and 1½ miles east of Wilson. Section of upper two-thirds of Graneros.
19. NE NE sec. 12, T 25 S, R 24 W, Ford County. Exposure in pasture and road cut on west side of U.S. Highway 283 approximately 12 miles northeast of Dodge City. Section of lower Graneros.
20. NE NW sec. 25, T 22 S, R 22 W, Hodgeman County. Gullied slope and road cut on south side of east-west county road approximately ½ mile south and 1 mile east of Hanston. Complete section of Graneros.
21. SW SW sec. 26, T 15 S, R 16 W, Ellis County. Cut bank and bluff on south side of Smoky Hill River approximately 17½ miles southeast of Hays. Section of Graneros, except for uppermost part.
22. SW SW sec. 33, T 13 S, R 7 W, Lincoln County. Gullied area on upland slope approximately 12 miles south southeast of Lincoln. Section of lower Graneros.
23. C N sec. 10, T 25 S, R 23 W, Ford County. Cut bank along southern tributary to Sawlog Creek in pasture north-northwest of windmill approximately 14 miles northeast of Dodge City. Complete section of Graneros.
24. NW SW sec. 35, T 24 S, R 23 W, Hodgeman County. Road cut and ditch on east side of north-south county road approximately 12 miles south-southeast of Jetmore. Section of upper Graneros.
25. NE NE sec. 11, T 24 S, R 23 W, Hodgeman County. Graded ditch on west side of north-south county road approximately 8½ miles southeast of Jetmore. Complete section of Graneros.
26. SW NW sec. 23, T 4 S, R 6 W, Jewell County. Cut bank on east side of West Marsh Creek approximately 5½ miles northeast of Randall. Section of uppermost Graneros.
27. W NE sec. 7, T 4 S, R 2 W, Republic County. Ditch on east side of north-south county road approximately 1½ miles north of Talmo. Section of middle Graneros.
28. SE SW sec. 7, T 13 S, R 9 W, Lincoln County. Cut bank on west side of East Twin Creek approximately 5½ miles south southeast of Sylvan Grove. Section of lower two-thirds of Graneros.
29. NW NW sec. 4, T 13 S, R 9 W, Lincoln County. Ditch on east side of north-south county road approximately 5 miles southeast of Sylvan Grove. Section of upper one-third of Graneros.
30. NE SE sec. 29, T 11 S, R 9 W, Lincoln County. Cut bank off west side of north-south county road approximately 5 miles northeast of Sylvan Grove. Section of lower two-thirds of Graneros.
31. NE SE sec. 2, T 18 S, R 12 W, Barton County. Cut on north side of Missouri Pacific Railroad track approximately 4 miles west and ¾ mile south of Claflin. Section of upper two-thirds of Graneros.
32. NW NW sec. 3, T 16 S, R 10 W, Ellsworth County. Cut on east side of north-south county road approximately 7 miles north of Holyrood. Section of upper three-fourths of Graneros.
33. NE NW sec. 5, T 16 S, R 10 W, Ellsworth County. Cut banks on a small tributary to Wolf Creek approximately 7½ miles north northwest of Holyrood. Collecting locality in upper one-half of Graneros.
34. SE SE sec. 36, T 14 S, R 11 W, Russell County.

Bluff on south side of Smoky Hill River approximately 3 miles south southwest of Wilson. Collecting locality in upper one-half of Graneros.

35. SW NW sec. 13, T 13 S, R 12 W, Russell County. Cut on east side of north-south county road approximately 6 miles northeast of Bunker Hill. Collecting locality in upper one-half of Graneros.
36. SW NE sec. 23, T 14 S, R 15 W, Russell County. Cut bank on east side of Big Creek approximately 7 miles southwest of Russell. Section of upper two-thirds of Graneros.
37. NW SW sec. 25, T 14 S, R 15 W, Russell County. Cut on curve of north-south county road at south end of bridge across Smoky Hill River approximately 7 miles southwest of Russell. Section of lower Graneros.
38. SE SW sec. 5, T 3 S, R 1 E, Washington County. Cut on north side of U.S. Highway 36 approximately 3½ miles southwest of Haddam. Section of uppermost Graneros.
39. SW sec. 5, T 25 S, R 24 W, Ford County. Cut bank on south side of Sawlog Creek approximately 10 miles north and 2 miles east of Dodge City. Section of upper two-thirds of Graneros.
40. NW SW sec. 19, T 15 S, R 9 W, Ellsworth County. Cut on west side of north-south county road approximately 2 miles south southwest of Black Wolf. Section of lower one-half of Graneros.
41. NE SE sec. 11, T 24 S, R 22 W, Hodgeman County. Cut banks along intermittent stream approximately 10 miles south of Hanston. Complete section of Graneros.
42. NE SW sec. 19, T 13 S, R 9 W, Lincoln County. Cut bank on intermittent stream approximately 7 miles south-southeast of Sylvan Grove. Section of middle Graneros.
43. SE SE sec. 36, T 12 S, R 11 W, Russell County. Wilson Dam spillway excavation. Complete section of Graneros.
44. SW corner sec. 22, T 6 S, R 3 W, Cloud County. Ditch at county road intersection approximately 4 miles south and 1 mile east of Concordia. Complete section of Graneros.
45. C NW sec. 6, T 15 S, R 10 W, Ellsworth County. East wall of ravine on south side of Smoky Hill River approximately 3 miles south of Wilson. Collecting locality in upper part of Graneros.
46. NW NW sec. 18, T 13 S, R 12 W, Russell County. Ditch and graded bank on east side of Luray-Bunker Hill road approximately 3½ miles north of Bunker Hill. Section of upper two thirds of Graneros.
47. S line SE SE sec. 31, T 12 S, R 10 W, Lincoln County. Road cut on east-west county road approximately 1 mile east of Wilson Dam spillway. Collecting locality in upper one-half of Graneros.