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CONTENTS

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Contents

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Sedimentary Features and Paleoenvironment of the Dakota Sandstone (Early Upper Cretaceous) Near Hanksville, Utah*

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ABSTRACT.—The Dakota Sandstone, as exposed six miles west of Hanksville, Utah, is divisible into five main rock bodies which were depositionally controlled by fluvial to open-marine processes. Regressive and transgressive phases of deposition are in evidence.

Environments interpreted to have existed in the study area are: distributary or tributary channel, point bar, natural levee, splay, marsh, swamp, beach or barrier beach, oyster bank, tidal channel, tidal flat and open marine.

A fluvial system formed a clastic wedge which was probably deposited in an embayment along the western shore of the Mancos Sea. Upon abandonment of the distributary system marine sands were driven over the land, possibly by storms. A regressive forebeach structure was formed. Upon minor subsidence the sea moved over the beach. With continued transgression an oyster bank grew profusely on the inundated beach. Further transgression allowed the deposition of deep marine shales over the oysters.

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*A thesis presented to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree Master of Science, July 1972.

INTRODUCTION

Upper Cretaceous rocks exposed in eastern and central Utah represent a series of near-shore transgressive and regressive environments along the margin of the Mancos Sea (Spieker and Reeside, 1925; Spieker, 1931; Young, 1955). The Dakota Sandstone is part of this series and in the study area is a thin, prograding clastic wedge at the base of the Tununk Member of the Mancos Shale. The Dakota Sandstone within the area of the study consists of a thin sequence of lenticular, cross-bedded sandstone; conglomerate; carbonaceous shale; and shaly coal that were deposited under a variety of depositional environments within a deltaic filling of a small embayment along the western margin of the Upper Cretaceous Mancos Sea. Sedimentary, paleontological, and spatial relationships of lithologies permit documentation and interpretation of numerous environments of deposition. Stratigraphic variation and lateral and vertical facies relationships indicate both depositional and destructional phases of coastal, possibly deltaic, deposition like the pattern described by Masters (1967), Coleman, Gagliano, and Morgan (1969), Davies, Ethridge, and Berg (1971), Visher (1972), and Fisher et al. (1971).

PREVIOUS WORK

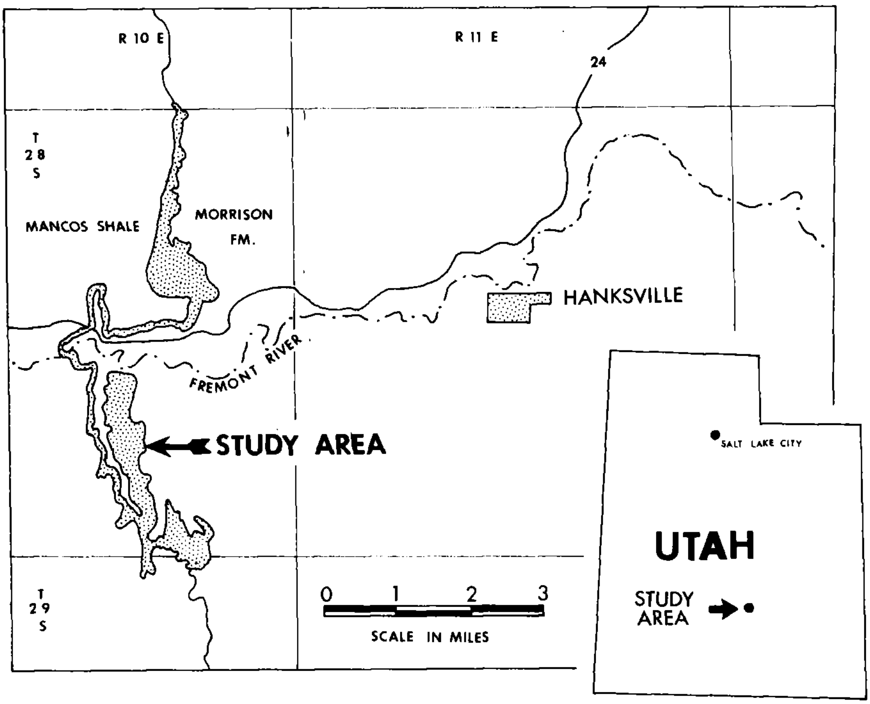
The Dakota Sandstone was named by Meek and Hayden (1861, p. 419) for the basal member of the Cretaceous System exposed in bluffs along the Missouri River, near the town of Dakota, Nebraska.

The Dakota Sandstone has been described in adjacent areas by many authors over the last century (Meek and Hayden, 1868; Gilbert, 1877; Dutton, 1880; Gilluly, 1929; Gregory and Moore, 1931; Hunt, Averitt, and Riller, 1953; Bissell, 1954; Van deGraff, 1963), but detailed work in paleodepositional environments is wanting.

Dutton's (1880) and Gilbert's (1877) work laid the foundation for study of the Dakota Sandstone in central Utah. Gilbert's report (1877) on the Henry Mountains structural basin described, in some detail, the intrusive rocks, geography, geology, and geomorphology. Hunt et al. (1953) mapped the greater Henry Mountain basin and did general stratigraphy on the region. Hunt measured and published sections at fifteen widely spaced localities and listed four mollusks from the formation. Elsewhere, Gregory and Anderson (1939) measured sections of the Dakota Sandstone within the Capital Reef area but published no detailed data relating to paleoenvironmental interpretations. Gilluly and Reeside (1928) and Gilluly (1929) mapped the Dakota Sandstone in the San Rafael Swell. Richardson (1909) determined the Dakota Sandstone, as exposed near Woodside, Utah, to be early Late Cretaceous through fossil plant identification.

LOCATION AND GEOLOGIC SETTING

The Dakota Sandstone within the study area crops out north and south of the Fremont River, six miles west of Hanksville, Utah (Text-fig. 1). The



TEXT-FIGURE 1.—Index map, showing location of study area; large arrow points to stippled outcrop of Dakota Sandstone.

outcrops studied strike north and south and lie entirely within T. 28 and 29 S., R. 10 E. Utah Highway 24 is paved through the center of the area. Several unimproved dirt roads allow ready access to much of the study area.

The area was chosen as a study location because (1) an ash bed which overlies the Dakota Sandstone defines a time line, (2) extensive beds of *Gryphaea newberryi* overlie the Dakota Sandstone, (3) the area has been little affected by post-depositional deformation, (4) the Dakota Sandstone here is a small isolated lens at the base of the marine Mancos Shale, and (5) fine exposures allow documentation of lateral and vertical facies relationships across the formation.

The Dakota Sandstone occurs directly below the Tununk Member of the Mancos Shale and was deposited unconformably across the bevelled Cedar Mountain Formation or Brushy Basin Member of the Morrison Formation. The Dakota Formation within the area of study is on the northeast flank of the Henry Mountain structural basin.

METHODS

Twenty-one generalized sections were measured along the outcrop to provide control for drawings of relationships of rock bodies. Description, identification, and documentation of these rock bodies were accomplished through sketches, samples, and photographs and with notes taken on a portable cassette tape recorder. Correlation of depositional units and biostratigraphic units was documented by walking out each unit.

Thin sections were made of each major lithology. All samples required impregnation and were treated with 3-M Scotchcast electrical resin #3, a two-part thermosetting electrical epoxy resin. Samples were impregnated in a vacuum oven and allowed to set overnight prior to cutting. Composition and grain size were determined by counting three hundred points per thin section under the petrographic microscope. Sorting and roundness were determined by visual inspection of four areas on each slide, using the petrographic microscope. Percentages of 14 compositional parameters were determined for each thin section.

Preliminary geochemical analyses were made using an atomic absorption spectrophotometer equipped with a strip-chart recorder. Samples analyzed are from three closely spaced sections. Each sample was analyzed for total Ca, Na, Mg, Sr, Al, Fe, and K.

NOMENCLATURE

Descriptive grain-size terminology used is the modified Wentworth grade-scale proposed by Dunbar and Rogers (1957, p. 161). Descriptive bedding terms are those suggested by McKee and Weir (1963, p. 383, Table 2). Compositional descriptive terms are modified after Krynine (1957).

ACKNOWLEDGMENTS

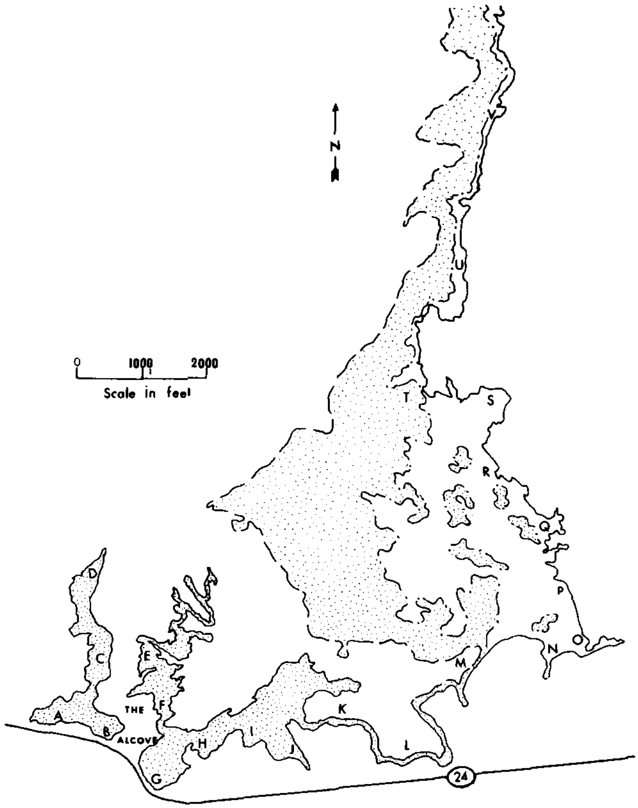
I am indebted to many people who assisted me in differing ways. Specific recognition must go to my wife, Bobbie, who labored to keep the family intact throughout the thesis experience and aided in the work in many ways. I am indebted to J. K. Rigby and W. K. Hamblin, who gave constantly their advice and encouragement. Thanks also go to Wilson Lima and John Cranor, who assisted by doing preliminary geochemical work, and to Don Newman, who assisted in the field. Financial support was provided by grants from the Society of the Sigma Xi and Brigham Young University Geology Graduate Research Fund, and by a Marathon Oil Company fellowship award.

DESCRIPTION OF ROCK UNITS

Dakota Sandstone

The Dakota Sandstone, as exposed west of Hanksville, Utah, is wedge shaped in its gross aspect, pinching out to the north and south and thinning as it goes subsurface to the west and to the erosional edge on the east. The Dakota Sandstone is conformably overlain by a thin bentonitic ash at the base of the fissile blue gray shale of the Tununk Member of the marine Mancos Shale. Nonmarine, variegated Cedar Mountain Formation unconformably underlies the Dakota Sandstone.

Within the area of study the Dakota Sandstone consists of conglomerate, sandstone, shaly coal, coal, and carbonaceous sandstone. It is convenient to describe the Dakota Sandstone in terms of what appear to be natural lithologic subdivisions. Five major rock units recognized in the Dakota Sandstone within the study area are informally designated as members or facies. These are, from the bottom up, (1) congomerate facies; (2) lower sandstone facies; (3)



TEXT-FIGURE 2.—Outcrop map of the area studied; dashed line is contact of Mancos Shale and Dakota Sandstone; stippled area identifies *Gryphaea* beds; alternating dots and dashes show approximate boundary of the upper sandstone and the stripped-back *Gryphaea* beds; solid line indicates the base of the formation at the cliff edge of the Dakota Sandstone; letters are reference points for text discussion.

carbonaceous facies, all three included in the lower member; (4) an upper sandstone member, and (5) a *Gryphaea* member.

Gryphaea Member

The informal *Gryphaea* member consists of poorly consolidated, light to dark gray, sandy beds containing abundant *Gryphaea newberryi* (Pl. 2, fig. 4; Pl. 8, figs. 1, 2). It conformably overlies the upper sandstone member of the Dakota Sandstone in the study area. Rocks of the *Gryphaea* member are less resistant than the underlying sandstone and produce a gray, shell-strewn slope at the top of the Dakota Sandstone. In a fresh vertical exposure, poorly defined cross-beds dip four to eight degrees to the west. Nearly all the valves are dissociated. An upward decrease in shell fragmentation and in amount of quartz sand is seen in most exposures. A marked decrease in *Gryphaea* size, accompanying a gradual increase of grain size of associated sediments from medium quartz sand to coarse sand and fine pebbles, can be seen on the thinning edges of the Dakota Sandstone to the north and south. A light tan bentonitic ash, 12 to 14 inches thick, immediately overlies the beds. *Gryphaea* are not found above the ash in the study area. Above the ash is the blue gray shale of the Tununk Member of the Mancos Shale.

Maximum thickness of the *Gryphaea* member is five feet three inches near the center of the area at point K (Text-fig. 2). Rocks of this member thin to a few inches thick on the north and south edges of the Dakota Sandstone in the studied exposures. Thinning can also be seen to the east and west of the central portion of the area, at points A and M. Where the underlying upper sandstone member is absent, *Gryphaea* become so scarce that beds of the Tununk Member of the Mancos Shale rest on Cedar Mountain beds.

Fossils other than *Gryphaea newberryi* are uncommon, but the following are found in the *Gryphaea* member: *Exogyra costagyra* (?) (Pl. 8, figs. 3, 5), two species of *Inoceramus,* and an unidentified pectinoid (Text-fig. 3E F). *Gryphaea newberryi* is by far the most common bivalve, making up nearly all of the fossils found. Vertical full-relief burrows are preserved in the lower medium- to fine-grained sandy part of the *Gryphaea* member. Burrowing organisms may be responsible in part for some of the fragmentation.

Upper Sandstone Member

The informal upper sandstone member is composed of a well-sorted, medium- to fine-grained ($+2$ to $+3$ Phi), light tan, quartz sandstone which forms the massive upper cliff of the Dakota Sandstone. This sandstone is composed of subangular to well-rounded, well-sorted grains, and is the cleanest sandstone in the section (Pl. 1, fig. 1). Grain size generally increases upward within the sandstone. The upper sandstone grades vertically and laterally into the *Gryphaea* member with an arbitrary boundary drawn at the irregular surface where the poorly consolidated *Gryphaea* beds first appear (Pl. 3, fig. 2). The upper sandstone member is a linear, convex-upward, sandstone body, as is seen in north-south and east-west cross sections (Pl. 4), and is formed of up to 30 individual, shinglelike sandstone beds 8 to 14 inches thick at any one section (Pl. 3, fig. 5).

EXPLANATION OF PLATE 1

PHOTOMICROGRAPHS
(All 10x crossed nicols)

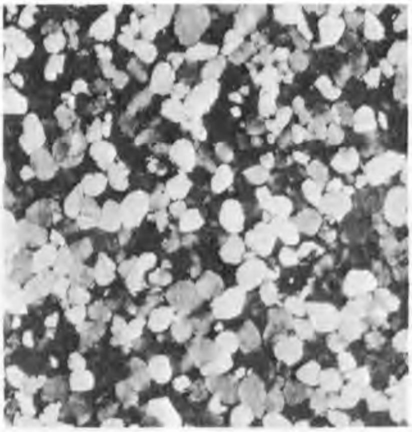
FIG. 1.—Thin section of upper sandstone from the middle of general measured section 3, showing well-sorted, well-rounded, medium-grained sandstone.

FIG. 2—Thin section of lower portion of the lower sandstone facies, showing an angular, poorly sorted sandstone.

FIG. 3.—Thin section of carbonaceous sandstone lens; fine grained and angular. Poor sorting is typical of this unit.

FIG. 4.—Thin section of the finer matrix in the conglomerate from general measured section 2; shows igneous rocks, and finer matrix; poor sorting.

FIG. 5.—Thin section of the upper portion of the lower sandstone from general measured section 3.



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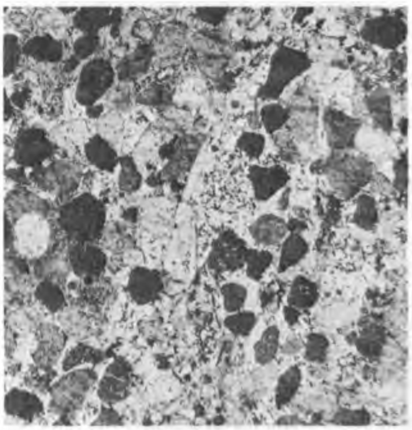

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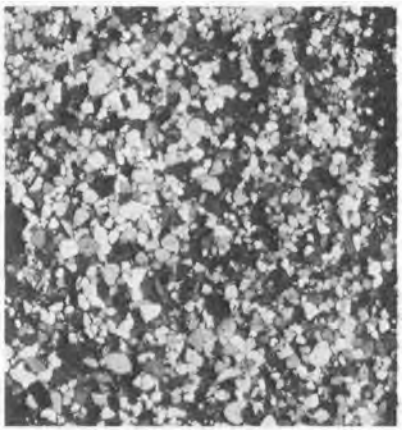

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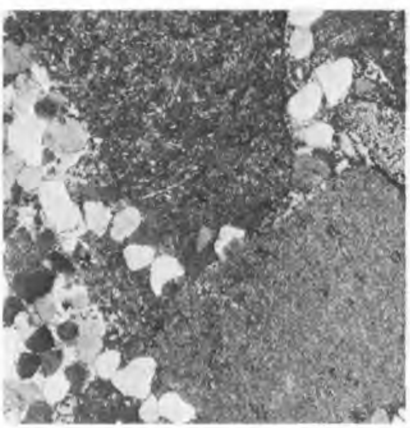

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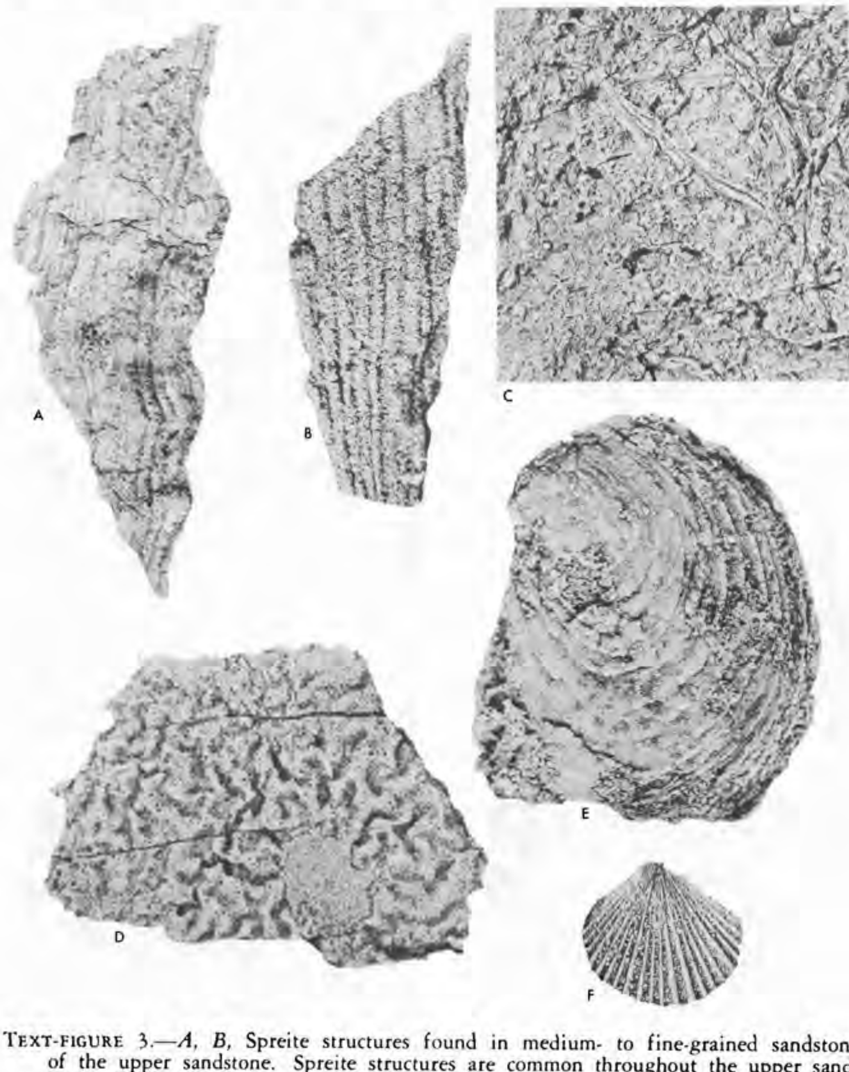
PLATE 1

Individual sandstone beds, where well exposed, can be seen to climb from the base to the top of the ledge-forming sequence. An individual shingle-like sedimentary unit consists of an upper, intensively burrowed part, a few inches thick, where all or most sedimentary structures are destroyed; and a lower, moderately burrowed, thicker part where some original depositional



TEXT-FIGURE 3.—*A, B,* Spreite structures found in medium- to fine-grained sandstone of the upper sandstone. Spreite structures are common throughout the upper sandstone, BYU 2057, 2053. *C.* Repichnia burrows in fine to very fine, carbonaceous sandstone of the upper sandstone member on the eastern exposed edge at point O (Text-fig. 2), BYU 2055. *D,* Domichnia burrow with tunnels radiating on the central protective tube found in a middle layer of the upper sandstone on the eastern exposure near point O (Text-fig. 2), BYU 2051. *E,* Inoceramus, common in the basal pebbly sandstone throughout the study area. F, An unidentified pecten found infrequently throughout the upper sandstone in the study area, 1x, BYU 2058.

structures are preserved. The upper burrowed part frequently contains increased silt and clay that may have helped to form a shaly zone a few inches thick. This shaly zone is repeated six to eight times in the basal portion of the upper sandstone in the central part of the outcrop between points I and O (Text-fig. 2) but is not well expressed in western exposures.

A basal, pebble-bearing sandstone occurs at the base of the sheetlike sandstone. It contains *Exogyra* and poorly preserved *Inoceramus*. Pebbly sandstone is repeated in thin beds and lenses up to three feet above the base of the sandstone. Clay galls, coal fragments, and rare petrified wood fragments are infrequently found within the basal pebble-bearing sandstone. Pebbles are of quartz, quartzite, chert, and igneous rock fragments.

The upper sandstone is well exposed in sinuous cliffs from the northeastern exposed edge north of point V to the westernmost exposure west of The Alcove at point A (Text-fig. 2). The Dakota Sandstone cliffs are exposed for 14 miles in a north-south direction and for $2\frac{1}{2}$ miles east-west (Text-fig. 1). The upper sandstone pinches out to the north and south and thins in western exposures. It thins to only a few feet on the eroded eastern edge of the exposure belt. Maximum thickness of the upper sandstone occurs almost at the center of the east-west exposed section, near point K (Text-fig. 2). The upper sandstone thins to less than two feet in the northeastern part of the study area, but less than one mile to the south it thickens to 12 feet in lenses up to 350 feet wide where individual beds dip into the lens centers, indicating depositional filling of depressions. Shinglelike cross-beds in central exposures near The Alcove and near the eastern exposed edge dip two to five degrees southeast. Locally, beds may be horizontal or have a variable dip direction.

Low angle (8 to 12 degrees), parallel to subparallel, cross-laminae are common in beds of the lower part of the upper sandstone (Pl. 4, fig. 16). Bedding disturbed by burrowing is commonly seen in the lower part of individual sandstone beds (Pl. 5, figs. 1, 2). Original depositional structures are poorly preserved in the middle and are usually destroyed in the upper parts of individual beds in the upper sandstone. Multiple sets of trough cross-bedding, 6 to 18 inches thick, are present at the northern and southern exposures of the Dakota Sandstone where the *Gryphaea* member has been stripped back. Lens-shaped cross-beds are also locally present. Both interference and oscillation ripple marks are present in these sandstone beds (Pl. 5, fig. 4). Large-scale oscillation ripples, 19 to 20 centimeters between crests, and 5 centimeters high have been observed on float blocks at the base of the upper sandstone. Reworking of rippled surfaces by burrows is common (Pl. 5, fig. 4). Megaripples, although rare, have been observed on the northeastern exposed edge.

Trace fossils, which are common in this facies and which occur frequently and abundantly, have destroyed all original depositional structures. Vertical full-relief, smooth tubes up to 15 centimeters in diameter and $2\frac{1}{2}$ meters in length are common throughout the upper sandstone but are particularly concentrated within the basal third of the sandstone. Full relief, smooth-tubed burrows with upward-branching side tubes, forming conical burrows in cross section, are common in the lower third of the sandstone as well. *Thalassinoides* burrows, 1 to 3 centimeters in diameter, are found as convex hyporeliefs on the bottom of bedding planes (Pl. 6, fig. 3). Vertical exposures of cross sections of many *Thalassinoides* also appear to be more abundant within the basal third of the sandstone (Pl. 5, fig. 5). Sparse, poorly preserved chevron trails, and *Ophiomorpha*-like burrows are infrequently preserved as convex hyporelief features both on bedding planes, predominantly in the lower third of the sandstone. Large and small plug-shaped burrows, with U-shaped bases, 5 to 18 centimeters in diameter and from 7 to 32 centimeters long, occur throughout the upper sandstone. Trace fossils similar to *Cylindrichnus reptilis*, 1 to 3 centimeters in diameter, are found near the base of the sandstone in a silty, clayey layer (Pl. 6, fig. 6). Labyrinth casts of tightly interwoven burrows are preserved as convex hyporeliefs on the basal surfaces of beds (Pl. 6, fig. 3). *Asterosoma*-like burrows are present locally as convex hyporeliefs along with *Thalassinoides* on the basal surface of bedding planes. Helicoid funnels occur at the lower contact with the coal and carbonaceous sandstone and penetrate into the underlying carbonaceous rocks to a depth of at least one meter. Their total length cannot be determined. Both horizontal and vertical *Arthrophycus*-like burrows are also present in these beds (Pl. 6, fig. 4). In the same beds large, horizontal burrows with a diameter of 7 centimeters occur rarely as convex hyporeliefs on the bottoms of bedding planes. Brush and prod marks are present but are more rare.

Contact of the upper sandstone and the underlying lower carbonaceous facies is abrupt. Some scouring of the carbonaceous facies by currents prior to deposition of the upper sandstone is evidenced by truncated beds and the appearance of coal fragments in the basal pebble-bearing sandstone of the upper member.

Lower Member

Coal and Carbonaceous Sandstone Facies

Thin beds of low-grade bituminous coal (Pl. 2, fig. 6), which grade downward into shaly coal, overlie a thicker silty and shaly carbonaceous unit which has abundant thin and undulatory sandstone lenses throughout (Pl. 2, figs. 3, 5). The low-grade bituminous, shaly coal and carbonaceous sandstone are less resistant than the overlying upper sandstone and underlying fluvial deposits, and form an indentation in the profile of the formation. The shaly coal and carbonaceous sandstone weather to a steep slope. Quartz sand of $+4$ to $+3$ Phi size is the major nonorganic constituent in these beds, but macerated plant material makes up 40 to 50 percent of the shaly carbonaceous layers. Reed and grasslike plant impressions are common in the macerated organic layers, but none are preserved well enough to be identified. Petrified wood

EXPLANATION OF PLATE 2

GENERAL LITHOLOGIES OF THE DAKOTA SANDSTONE

FIG. 1.—View of V-shaped, cone-in-cone, vertical burrows and thin bedding in the upper sandstone near the center of the exposure at point K (Text-fig. 2)

FIG. 2.—Conglomerate overlain by cross-bedded coarse sandstone of a channel exposed on the eastern edge of the study area, near point S (Text-fig 2).

FIG. 3.—View of shaly coal lithology in the carbonaceous facies.

FIG. 4—View of *Gryphaea newberryi* bed which overlies the upper sandstone.

FIG. 5.—Undulatory sandstone lenses and carbonaceous layers of the lower portion of the carbonaceous facies

FIG. 6.—Thin coal grading downward into the shaly coal within the carbonaceous facies.

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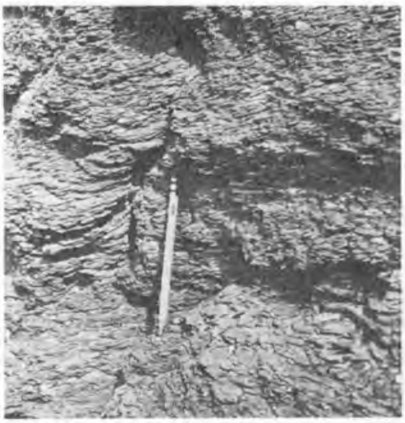

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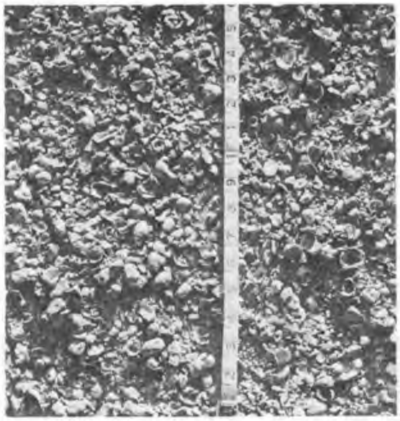

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PLATE 2

is common throughout the center of the exposure, between points I and O (Text-fig. 2). Many petrified wood fragments are strewn along the carbonaceous slope; seven large logs were found to be in place in the shaly coal. The largest log is nearly 12 feet long and 24 inches in diameter (Pl. 5, fig. 6). Longitudinal, transverse, and radial sections were cut from each of six separate logs. All were identified as angiosperms because of the presence of vessels. Fibers and questionably identified tracheids were seen, but pitting of walls was not preserved. Growth rings up to three-eights of an inch wide are present but are poorly preserved in most specimens.

The bituminous coal reaches a maximum of three feet eight inches thick near a small drift in the center of the outcrop belt at point K (Text-fig. 2) and forms a broad, thin, convex-downward lens with the maximum thickness near the geometric center of the lens, nearly centered between two channel deposits. The coal pinches out laterally where the carbonaceous siltstone and sandstone are thicker.

The lower carbonaceous siltsone and sandstone are laterally equivalent to the lower sandstone facies. Carbonaceous sandstone interfingers with the lower sandstone near the westernmost exposure at point A, as well as north of The Alcove at point E, east of The Alcove at point I, near point M by the eastern edge, and on the eastern edge at point O (Text-fig. 2). In good exposures one can trace individual sand lenses laterally from their asymptotic relationship at the top of the carbonaceous unit, down an initially steep dip (8 to 10 degrees), to where they level off as they approach the nearly flat center of the basin. This relationship occurs at all exposed edges of these carbonaceous lenses.

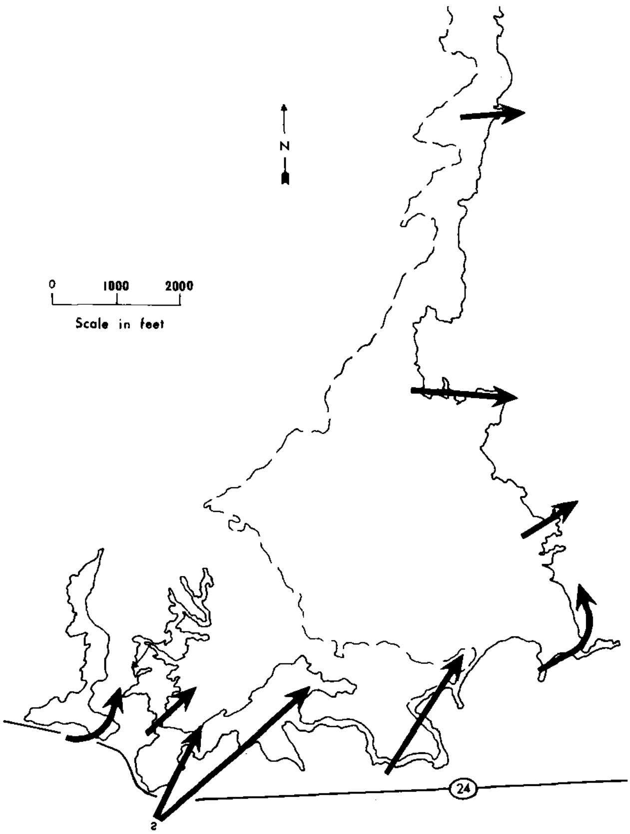
Narrow and thin flat-bottomed sandstone lenses occur frequently near the center of the broad carbonaceous lenses. Micro-cross-bedding and parallel and wavy lamination occur within these thin sandstone lenses. Trough and parallel laminations dominate in the internal structures of the thicker lenses.

Current ripple marks and rib and furrow structures are abundant, although poorly preserved, in the carbonaceous clastic units. Rooting impressions (Pl. 9, fig. 16) are common but are rarely well preserved because the carbonaceous units are weathered easily. Small piercement structures are abundant. Locally, small scour-and-fill structures are common. Changes in dip direction of successively overlying cross sets within the carbonaceous unit can be seen east of The Alcove, to the right of point G (Text-fig. 2).

Lower Sandstone Facies

The lower sandstone facies consists of cross-bedded, fine- to very fine-grained ($+1$ to $+5$ Phi) quartz siltstone and sandstone that erode to form the lower sandstone ledges in the study area. Small lenses of coarse sandstone and fine-pebble conglomerate are also locally common. Upper portions of this rock unit are laterally equivalent to the carbonaceous facies but elsewhere are overlain by the carbonaceous rocks or the upper sandstone. The lower sandstone, in gross aspect, occurs in large convex-upward lenses with channeled or flat bases. The thickest lower sandstone lens is 17 feet thick at point K (Text-fig. 2), near the center of the exposure.

In any given lens, beds of this sandstone dip away on both sides from the thickest central portion in a shingled fashion. Bedding thins upward and grades laterally into carbonaceous rocks. Trough and tabular cross-



TEXT-FIGURE 4.—Outcrop map, showing location and general paleocurrent direction of channels of the lower sandstone. Arrows show general position and major current direction of channels.

bedding is common in rocks of this facies. Current ripples, migrating megaripples or sand waves, and oscillation ripples are common. Current ripples decrease in size upward and laterally. Climbing ripple laminae are frequently seen in the lower sandstone. Evidence of soft sediment deformation, although rare, is preserved in eastern exposures near points N, O, and P (Text-fig. 2) where beds of this facies dip more steeply. Cross-bedding directions within the upper, burrowed siltstone, which locally caps the lower sandstone facies, take on bimodal characteristics normal to highly oblique to the major current directions for the lower channeled sandstone. Megaripples, decreasing in amplitude in the regionally landward direction, occur in association with soft-sediment deformational structures in the upper part of the lower sandstone (Pl. 3, fig. 1).

A well-exposed, flat-bottomed, but convex-upward lens occurs directly north of The Alcove at point E (Text-fig. 2), where the relationship between the lower sandstone and carbonaceous rocks can be seen easily. Lower sandstone rocks were deposited vertically at the expense of the carbonaceous facies (Pl. 9, Panel section). Bedding decreases in thickness upward in this exposure, and thin beds interfinger laterally with the carbonaceous rocks. The upper, very thin-bedded sandstone, in beds less than two inches thick, is current rippled and characteristically contains parallel and wavy laminations and rib and furrow structures. Small-scale scour and fill is common. Coarse-grained sandstone and pebble-conglomerate beds less than two feet thick form the inner core of the lens. These beds grade to finer-textured rocks laterally and vertically, and part laterally into the thin-bedded units. This lens is underlain by carbonaceous sandstone and shaly siltstone. Where a channeled conglomerate base is found to underlie the lower sandstone, it has an abrupt contact, and it partially interfingers, with the coarse conglomerate. Such interfingering was not observed in the flat-bottomed lenses.

Another well-exposed relationship between the lower carbonaceous sandstone and the underlying channeled conglomerate is west of The Alcove, between points A and B (Text-fig. 2; Pl. 3, fig. 3; Pl. 8, fig 1). Sandstone beds in this exposure override the conglomeratic sandstone at a low angle and become asymptotic to the conglomerate. Sand waves or megaripples are common and may represent transverse bars. Bedding decreases in thickness upward. Trough and tabular cross-bedding dominate the lower portion of this exposure of the lower sandstone, while parallel and horizontal laminations dominate the upper surface. The frequency of occurrence of ripple marks increases upward.

Conglomerate Facies

The conglomerate facies consists of lenses of loosely consolidated, subrounded to rounded, fine pebbles to coarse cobbles of quartz, quartzite, chert, basalt, diorite, and other igneous rocks. These lenses form steep slopes or ledges where not blanketed by slope wash from above. Rocks of this facies are channeled into the Cedar Mountain Formation, as evidenced by the admixture of clay galls with the basal conglomerate, and by the truncation of the Cedar Mountain beds. Thicker occurrences of the lower sandstone and conglomerate facies coincide with the occurrence of the sandstone directly above the conglomerate lenses.

Rocks of this facies generally have a deeply convex-downward base in southern and western exposures, but a nearly flat base is common in

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EXPLANATION OF PLATE 3

FIELD VIEW OF THE DAKOTA SANDSTONE

FIG. 1.—Megaripples (decreasing in amplitude to the west) and disturbed bedding (in the upper part of the lower sandstone) on the eastern edge of the study area at point O (Text-fig. 2).

FIG. 2.—Gradational nature of the contact of the *Gryphaea* and upper sandstone members. Point J (Text-fig. 2).

FIG. 3.—View of point-bar sequence overriding channel gravel on the southwest side of The Alcove at point A (Text-fig. 2).

FIG. 4.—Sandstone beds of the upper sandstone dipping into a channel on the northeast edge of the exposure at point U (Text-fig. 2).

FIG. 5.—View of the upper sandstone and overlying *Gryphaea* beds, beneath Tununk Shale, west of point K (Text-fig. 3).

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PLATE 3

lenses on the exposed eastern edge of the formation. The conglomerate lenses decrease in grain size from west to east. Small sandstone lenses are dispersed throughout the member. Petrified wood is the main fossil material found in the conglomerate.

Cross-bedding is common but not well expressed in the conglomerate, and graded bedding is common and well expressed. Abrupt upward increase in pebble size of an overlying conglomerate set alternating between fine- to medium-grained sandstone is frequently seen. The upper contact between the lower sandstone and the conglomerate facies is abrupt in some places but gradational in others.

Cedar Mountain Formation

Variegated beds of the Cedar Mountain Formation are unconformably overlain by all lithologic divisions of the Dakota Sandstone in the study area. The Cedar Mountain Formation includes the variegated beds between the Buckhorn Conglomerate and the Dakota Sandstone (Stokes, 1944). Near the type section at Cedar Mountain, Emery County, Utah, Stokes (1944) noted a gradation of the Cedar Mountain Formation into the Dakota Sandstone, but in the study area the units have a sharp boundary. Stokes (1944, p. 981) suggested that the Cedar Mountain Formation was at least partially derived from reworking of the Brushy Basin Member of the Morrison Formation.

Channels within the Cedar Mountain Formation may have been related initially to the Dakota Sandstone fluvial channels. It is speculated that these channels may represent upper alluvial-plain channels of an earlier system.

TRACE FOSSILS

Palichnology is the study of trace fossils, tracks, trails, and burrows that result from the activity of organisms on and within sediments and that therefore indicate where organisms have lived. The organism which produced the trail may not be preserved with the impression. Diagenesis destroys body fossils but often enhances preservation of trace fossils. Seilacher (1946) and Hantzchel (1962), among others, show that trace fossils can be grouped into facies according to environments preferred by the animals.

EXPLANATION OF PLATE 5

FOSSILS IN THE DAKOTA SANDSTONE

FIG. 1.—Laminae disturbed by burrowing in the upper sandstone member. Cone-in-cone structure indicates an attempt to keep up with rapid sedimentation.

FIG. 2.—Laminae disturbed by burrowing in the upper sandstone member.

FIG. 3.—Horizontal view of branching burrows at the top of the lower sandstone facies.

FIG. 4.—Interference ripples superimposed on oscillation ripples and burrowed on the upper surface (upper sandstone member). Small arrow is pointing to the upward end of an *Arenicolites* burrow

FIG. 5.—Side view of horizontal termination of burrows in the upper sandstone Ends are about dime-size.

FIG. 6.—Petrified angiosperm log in place in the carbonaceous facies near the center of the exposure between points J and K (Text-fig 2).

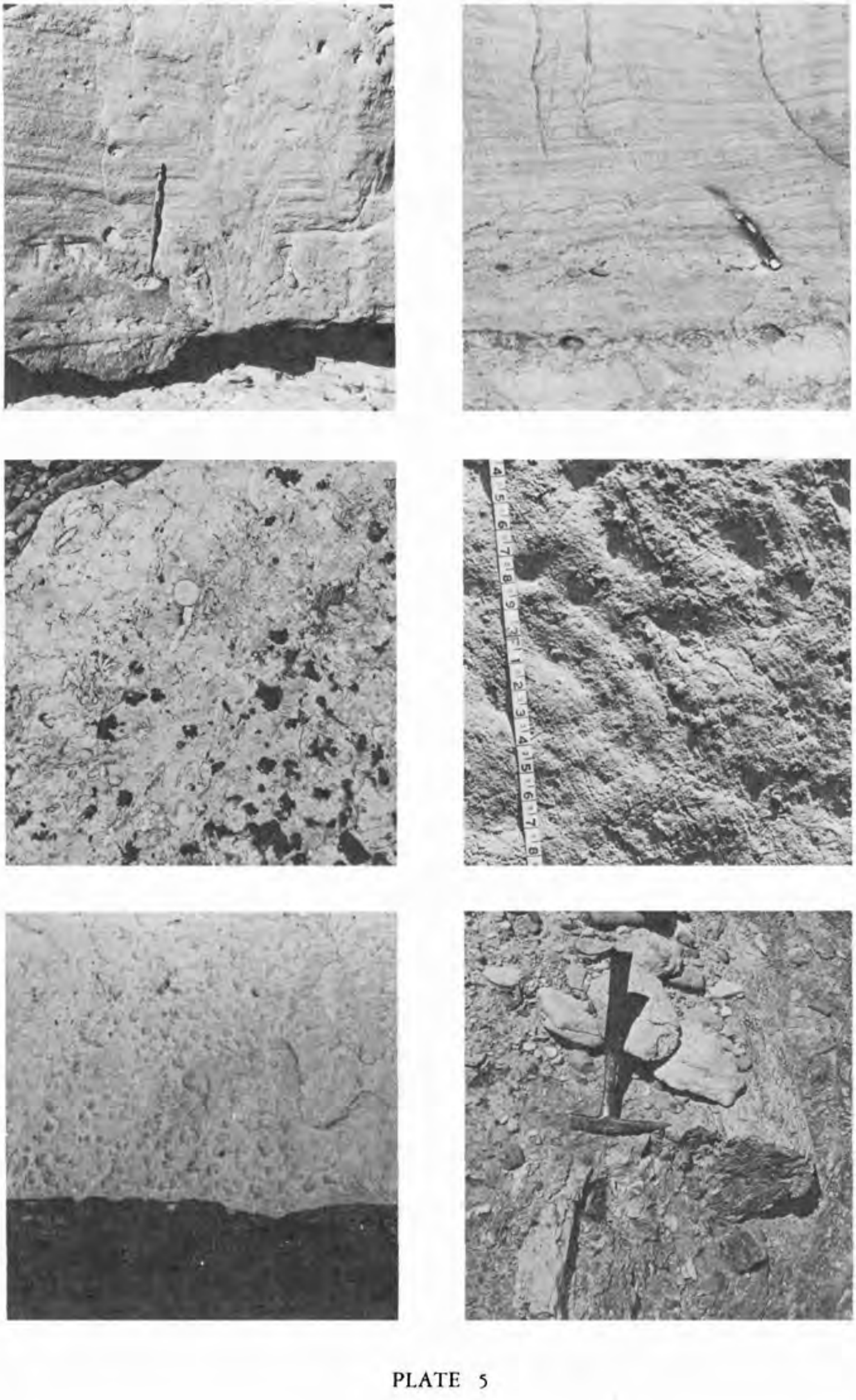


PLATE 5

An abundance of trace fossils is characteristic of the upper sandstone of the Dakota Sandstone in the study area, but such fossils are also found in the *Gryphaea* member and in the carbonaceous and lower sandstone facies.

The following classification system, proposed by Seilacher (1964), is based on function of the trace-fossil structure and is used in this paper.

Pascichnia: winding trails of vagile mud eaters which reflect a "grazing" search for food by covering a given surface more or less efficiently and avoiding double coverage.

Fodinichnia: burrows made by hemisessile deposit feeders. They reflect the search for food and at the same time fit the requirements for a permanent shelter.

Domichnia: permanent shelters dug by vagile or hemisessile animals procuring food from outside the sediment as predators, scavengers, or suspension feeders.

Cubichnia: shallow resting tracks left by vagile animals hiding temporarily in the sediment, usually sand, and obtaining their food as scavengers or suspension feeders.

Repichnia: trails of burrows left by vagile benthos during locomotion.

Trace fossils are epirelief forms if the trace is on top of a bedding plane and hyporelief if it is preserved on the base. Convex and concave are the terms used to describe the relationship to the bedding plane on which it is formed. A convex epirelief form is a positive projecting feature on the top of a bedding plane and convex hyporelief is a positive feature preserved on the base. Concave epirelief or hyporelief describe depressions.

Commonly observed trace fossils within the Dakota Sandstone are spreite (Text-fig. 3a, b), like those observed by Hantzchel (1962, p. W178). Spreite structures are common in fodinichnia. Each furrow on the spreite represents a tunnel. Each succesive tunnel, a result of lateral or vertical "mining," was accompanied by back filling or the pushing of detritus or fecal pellets into previous burrows. A sequential horizontal or vertical shifting of the tunnel or furrows forms the spreite structure. Vertical spreite indicate upward or downward movement of the animal and horizontal spreite indicate a "mining" along a nutrient lamina or layer. Spreite structures indicate that the material which was being "mined" was partially consolidated, or at least firm enough to retain the walls of the tunnel.

EXPLANATION OF PLATE 6

TRACE FOSSILS AND SEDIMENTARY STRUCTURES

FIG. 1.—Horizontal view of a single V-shaped burrow within the upper sandstone west of The Alcove at point H (Text-fig. 2).

FIG. 2.—Cross-bedding in the opposite directions, in successively overlying sets of cross-bedding exposed in the lower sandstone of a flat-bottomed, convex-upward channel north of The Alcove at point E, (Text-fig. 2).

FIG. 3.—Bedding in the upper sandstone, showing the weathering expression of the intense burrowing near the middle of the exposure near point M (Text-fig. 2).

FIG. 4.—Ripple laminae in thin-bedded natural levee deposits from north of The Alcove at point E (Text-fig. 2).

FIG. 5.—Megaripples in the point-bar sandstone which overlies channel gravels west of The Alcove at point A (Text-fig. 2).

FIG. 6.—Sole markings in lower sandstone on the eastern exposed edge, near point O (Text-fig. 2).

1

2

3

4

5

6

PLATE 6

Pascichnia

Poorly preserved convex hyporelief chevron trails occur but are rare in fine-grained sandstone of the basal portion of the upper sandstone member. Trail width varies from 7 to 10 millimeters. Most are subparallel to parallel and are associated with small thalassinid-like burrows. Apparently these forms were made as animals fed on or near the top of the sediments. These trails are shallow marine indicators (Howard, 1966 a, b, c).

Fodinichnia

Arthrophycus (Pl. 6, fig. 4) is a cylindrical burrow with a ribbed, conduitlike, pattern found as full-relief or convex hyporelief forms. These fossils are commonly 20 to 35 millimeters wide, but the length cannot be determined. Branching is rare. A slight bulge like that found in *Thalassinoides* occurs at the point of branching, when branching is seen. *Arthrophycus* occurs through a relatively wide depth range in medium- to fine-grained sandstone (Seilacher, 1964).

Asterosoma-like burrows (Pl. 6, fig. 3) are found as convex hyporeliefs in medium- to fine-grained sandstone. A series of petaloid spreite structures reflect "mining" patterns of the animals that made short excursions from a central tube. *Asterosoma*-like burrows frequently have at the top a helicoid funnel like that described by Howard (1966 a; b). They have a width of 8 to 12 centimeters in the Dakota examples (Pl. 6, fig. 4) and are thought to indicate a change in burrowing pattern, possibly a response to a fresh influx in nutrients or a change in current velocity (Mayberry, 1971). Steeply inclined and spiraled burrows are common.

Cylindrichnus reptilis was named by Bandel (Mayberry, 1971) and is like *Cylindricum linets* (Hantzchel, 1962, p. W189). The rough external texture of *Cylindrichnus* can easily be mistaken for a poorly preserved *Arthrophycus*.

Labyrinth castings (Pl. 6, fig. 3) or large areas of tightly interwoven trails or castings are frequently preserved as convex hyporeliefs on the bottom

EXPLANATION OF PLATE 7

TRACE FOSSILS IN THE DAKOTA SANDSTONE

FIG. 1.—Vertical view of plug-shaped burrows and *Thalassinoides* burrows in lower portion of the upper sandstone near the center of the exposure near point K (Text-fig. 2).

FIG. 2.—Side view of an oblique cross-section through a plug-shaped burrow common in the upper sandstone throughout the study area.

FIG. 3.—Labyrinth of burrows showing *Asterosoma, Thalassinoides,* and other burrows near the center of the exposure west of point K (Text-fig. 2).

FIG. 4.—Spindle-top *Arthrophycus*-like burrow in a carbonaceous layer near point K (Text-fig. 2).

FIG. 5.—Spiral burrowing in coal. Note the change in coarseness of burrow filling from top to bottom. This relationship is common throughout the study area where the coal and carbonaceous facies are present.

FIG. 6.—*Cylindrichnus reptilis*-like burrows loosely interwoven at the base of the upper sandstone near the center of the exposure at point M (Text-fig. 2).

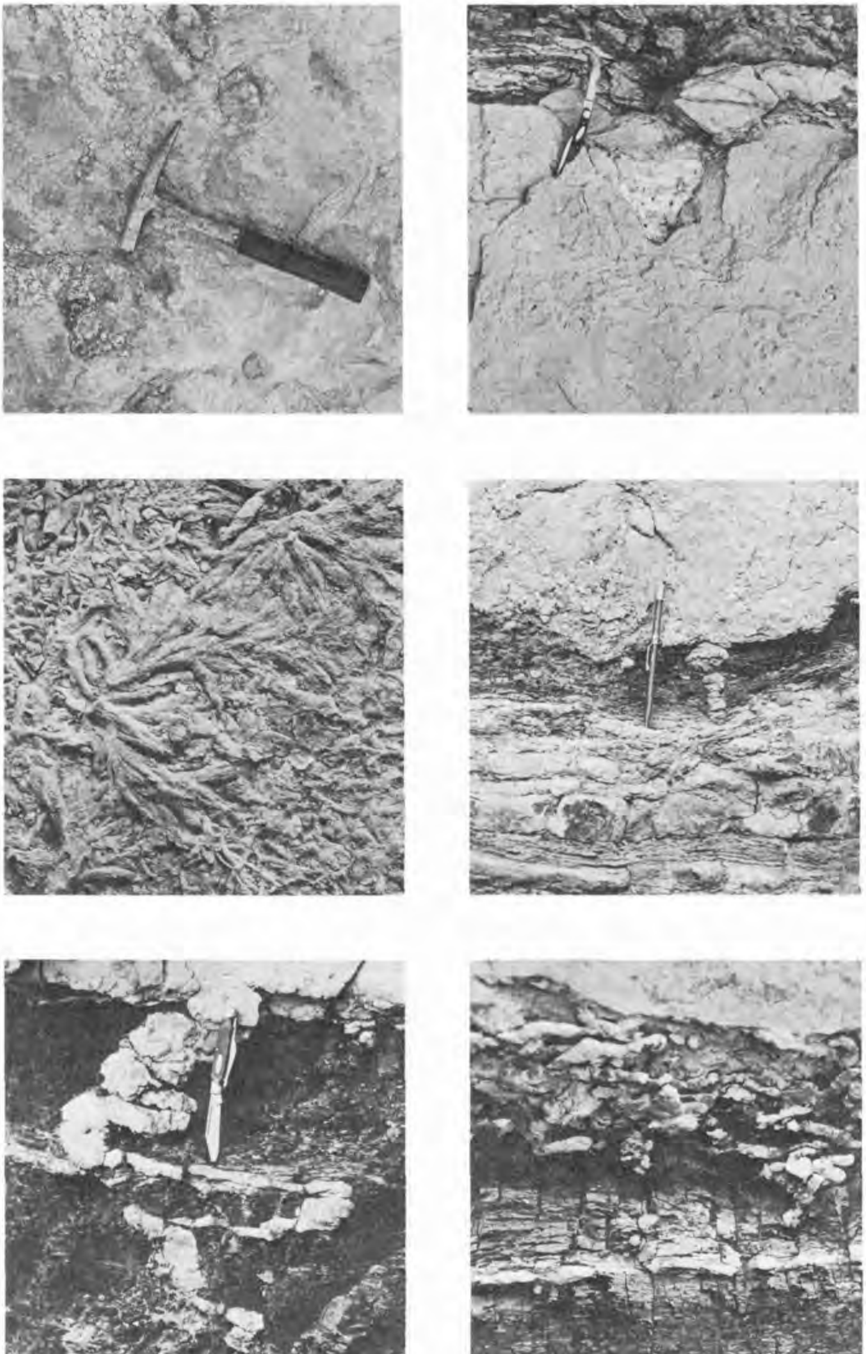
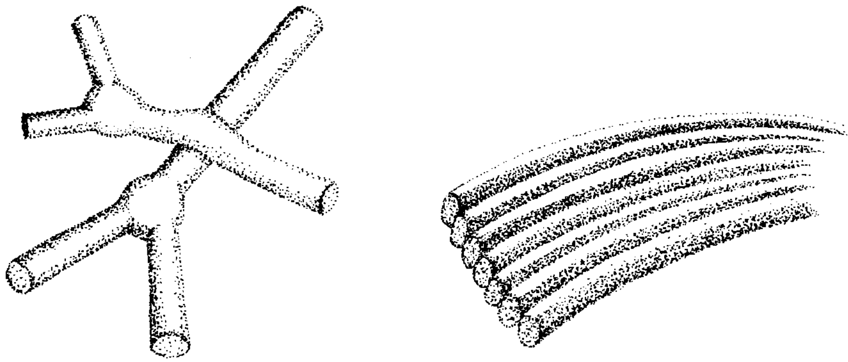


PLATE 7



A B

TEXT-FIGURE 5.—*A, Thallassinoides* Y-shaped burrows, $\frac{1}{4}$x. *B,* Spreite structure, 1x.

of bedding surfaces of medium- to fine-grained sandstone. The burrows range in diameter from 5 to 25 millimeters. Branching is common.

Convex hyporelief burrows (Pl. 6, fig. 3) preserved as branching smooth tubes are common in medium- to fine-grained silty sandstone and clays. These tubes may be small *Thalassinoides* burrows. Cross sections of these burrows are round to oval shaped, with a diameter of 4 to 10 millimeters for small ones and up to 60 millimeters for the large ones. These trails or tubes were made by detritus-feeding animals at or near the sediment-water interface in shallow, quiet water.

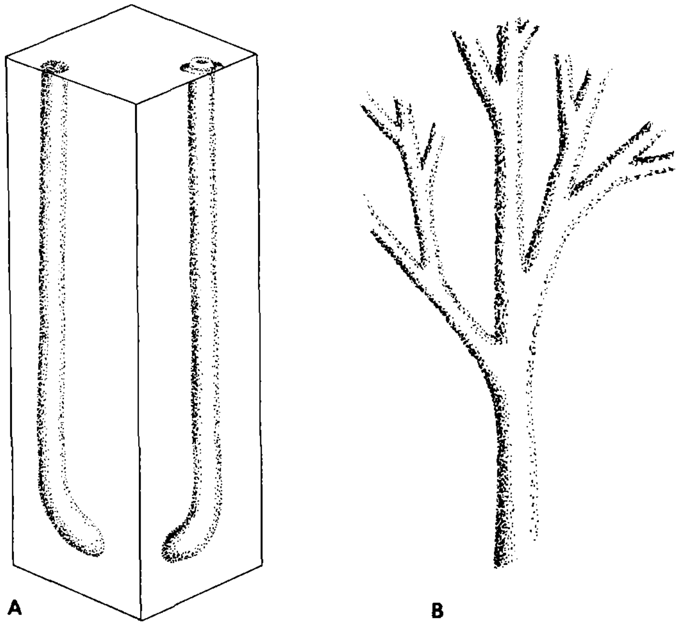
Cylindrichnus reptilis-like burrows (Pl. 6, fig. 6) occur in the formation as vertical and horizontal full-relief and frequently as convex tubes one to three centimeters in diameter. They are found in silty, medium- to fine-grained sandstone and thin-bedded carbonaceous sandstone. A loose network of interwoven burrows of indeterminable length is characteristic of these fossils. The burrows occur frequently in coal.

Thalassinoides (Pl. 6, fig. 3) is a convex hyporelief burrow and is very common in medium- to fine-grained, often silty, sandstone. Tubes are 20 to 25 millimeters in diameter and are branching in a Y-shaped pattern. Linear furrows or ridges commonly are preserved on the bottom.

Domichnia

Arenicolites is a full-relief, cylindrical, U-shaped burrow with a diameter of 7 to 10 millimeters and a length of up to $2\frac{1}{2}$ meters. Upper ends of *Arenicolites* are flat to domed with a dimple in the center (Text-fig. 4a). These fossils, which are probably the living burrows of a marine worm, indicate tidal to very shallow water environments (Seilacher, 1964, p. 311).

Giant horizontal burrows are infrequently found as convex hyporeliefs in carbonaceous silty and sandy mudstone or sandstone above the coal beds. These burrows have an apparent flattened-oval cross section and are up to 10 centimeters in diameter. The rough exterior may indicate *Ophiomorpha* bur-



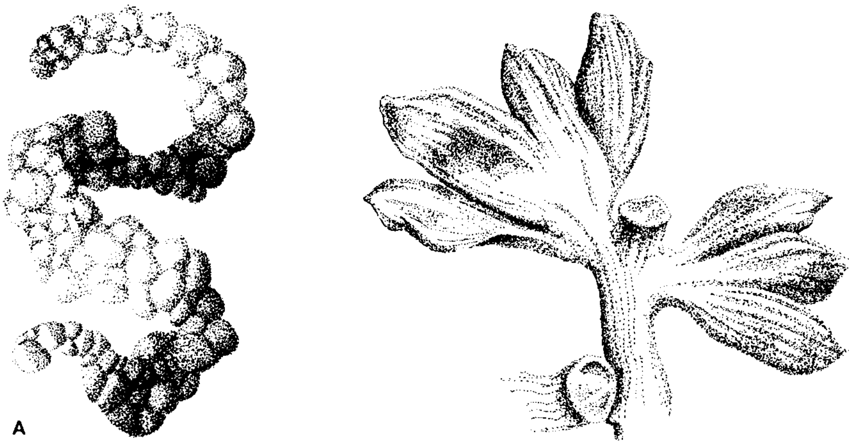
TEXT-FIGURE 6.—*A, Arenicolites* burrow, showing U-shape and upper ends, $\frac{1}{7}$x. *B,* Sketch of a vertical, full-relief upward-branching, smooth-tubed burrow, $\frac{1}{4}$x.

rows. They have a carbonaceous rind and are filled with medium- to fine-grained sandstone.

Plug-shaped burrows (Pl. 6, fig. 2) with a blunted, U-shaped bottom are very common in medium- to fine-grained sandstone. Circular upper depressions, with diameters of up to 18 centimeters, mark the position of the plugs on bedding-plane surfaces (Pl. 6, fig. 1). Their lengths vary from 10 to 35 centimeters. They are filled with fine, silty, clayey sandstone and are without visible internal structure. Apparent sharp V-shaped burrows that might be mistaken for a different variety of plug-shaped burrow are actually oblique cuts through a plug-shaped burrow. Orientation of the plug-shaped burrow is generally nearly vertical or at a slight angle from vertical. Sides of the plug-shaped burrows dip toward each other at angles of 40 to 60 degrees. A shallow marine environment for these burrows is attested to by the paleotopography of the beds in which they occur. A water depth of 10 to 15 feet is indicated.

Vertically oriented smooth tubes, 5 to 10 millimeters in diameter and up to 2 meters in length, are common in clean, medium- to fine-grained sandstone. Upward branching, subhorizontal smooth tubes indicate that the animal took side excursions from the central tube, possibly along nutrient-rich laminae.

Large conical burrows (Pl. 2, fig. 1), up to 26 centimeters in diameter at the upper end and 40 millimeters at the lower end, with a V-shaped bottom, occur frequently in medium- to fine-grained sandstone. The upper surface is covered with shell fragments of *Gyrphaea newberryi,* not necessarily indicat-



TEXT-FIGURE 7.—*A,* Sketch of a spiraling burrow, showing fecal or sand balls packed into the sides of the burrow. Burrow is $1\frac{1}{2}$ inches wide and $4\frac{1}{2}$ inches long. *B,* Sketch of *Asterosoma,* showing horizontal petalloid spreite structures radiating from a nearly vertical tube. Lengths of petalloid spreite are five to seven inches.

ing what the animal ate but only that *Gryphaea* were present and were washed along the bedding surface into the burrow. A loose cone-in-cone structure, like the structures described by Seilacher (1964), indicates that the animal kept up with the rapid rate of sedimentation.

An unnamed burrow (Text-fig. 3d) was preserved as a convex hypo-relief form in medium- to fine-grained sandstone. This burrow has a central oval-shaped tube 11 millimeters in diameter at its widest point, and has a patterned burrow radiating from the central tube. At various horizons along the vertical central tube, this animal, a detritus feeder, made short excursions from a protective burrow in search of food.

Casts of vertically spiralling domichnia burrows 30 millimeters wide with closely spaced fecal or sand balls tamped into the sides were observed (Text-fig. 6a). These uncommon structures may have been attempts to fortify the burrows against a mobile substrate. These burrows are common in clean, medium- to fine-grained sandstone on the eastern edge of the lenticular sandstone facies.

EXPLANATION OF PLATE 8

FOSSILS IN THE DAKOTA SANDSTONE

(1x scale for all photos)

FIG. 1.—Right valve of *Gryphaea newberryi. Gryphaea newberryi* is the most common fossil found in *Gryphaea* member that caps the Dakota Sandstone in the study area.

FIG. 2.—Left valve of *Gryphaea newberryi.*

FIGS. 3, 5.—*Exogyra costagyra* (?) found in upper sandstone near the center of the exposure near point K (Text-fig. 2).

FIG. 4.—Ruhespuren found in fine-grained carbonaceous exposures of the upper sandstone member on the eroded eastern edge near point O (Text-fig. 2).

PLATE 8

Their occurence within shingled forebeach sandstone beds indicates a littoral environment.

Casts of bivalves in silty layers were observed. These casts were so poorly preserved that correlation with a specific type of invertebrate fossil was not possible.

Cubichnia

Ruhespuren are resting-place trace fossils preserved as concave epireliefs in fine to medium sandstone (Pl. 8, fig. 4). Traces form a circular to oval pattern with a diameter of 15 to 20 millimeters. In cross section they show a peripheral, poorly exposed trough 3 to 4 millimeters deep with transverse walls. The center of the oval has a slightly raised boss somewhat lower than the surrounding surface. The boss is 12 millimeters long and 3 to 4 millimeters wide. This form is uncommon. Howard (1966a, p. 78) suggests that they were made by "jellyfish or an animal with a similar bottom configuration." This form is indicative of a littoral to sublittoral environment.

Repichnia

Numerous burrows left as shallow depressions occur as concave epireliefs in fine to medium carbonaceous sandstone. These burrows have varying spreite-like structures paralleling the burrow. Branching is common. The width of the burrow is 1 to 5 millimeters; the length is not determinable. The plowing appearance of the burrow may indicate that the animal moved around at the sediment-water interface in partially consolidated sediments (Text-fig. 5b).

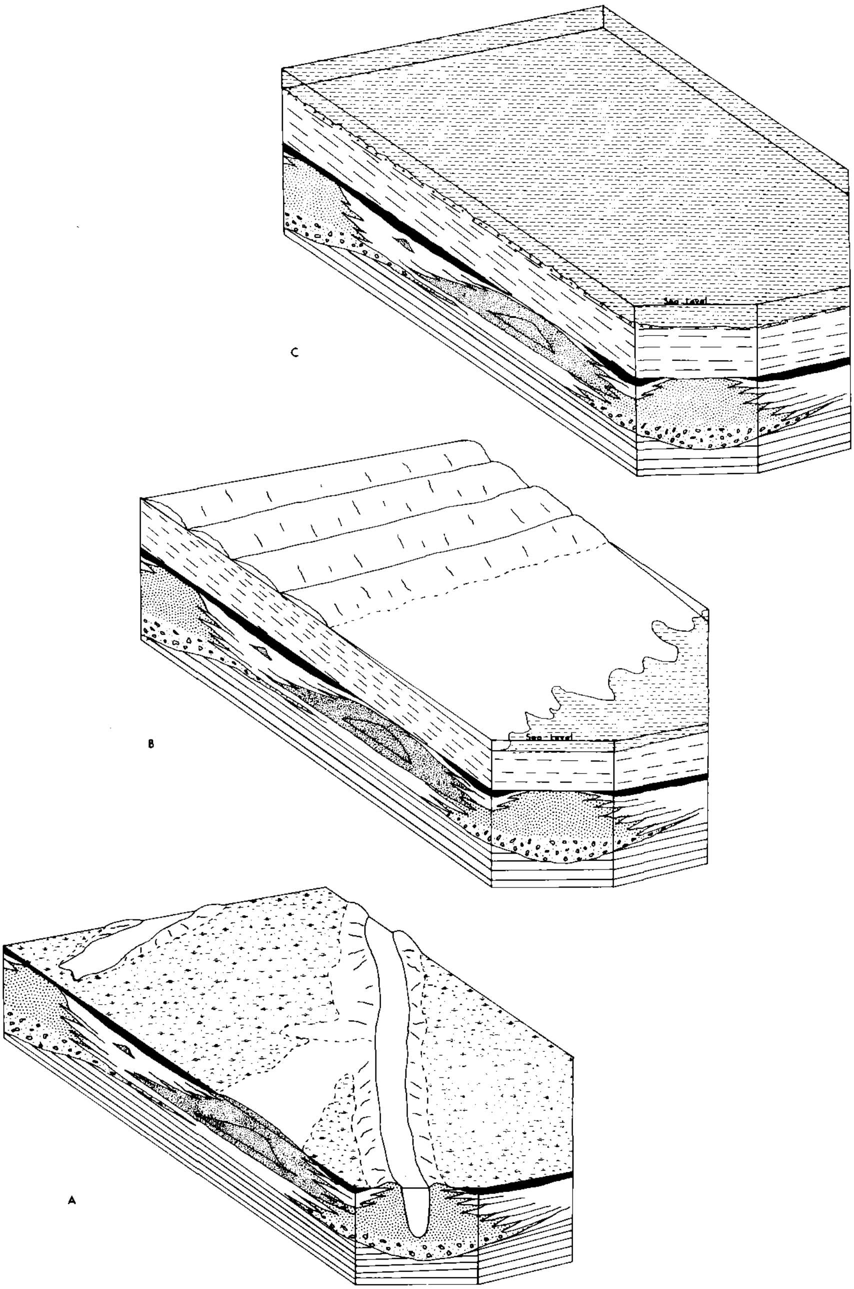
INTERPRETATION OF SEDIMENTARY ENVIRONMENTS

Conglomerate Facies

The conglomeratic rocks of the formation are interpreted to represent fluvial channel gravel, as evidenced by (1) a convex-downward channeled configuration of the lenses, (2) the truncation of underlying beds, (3) the occurrence of rounded pebbles and cobbles and of petrified wood, (4) cross-bedding with dominant unidirectional current measurements to the northeast (probably seaward), and (5) the spatial relationship of surrounding rocks, which are interpreted to be deposits of floodplain, point-bar, channel-sand, and natural levee deposits (Text-fig. 8) (Pl. 9, Panel section). It is often true in making sedimentary interpretations that two or more hypotheses may fit the available data, and it is true in the interpretation of the fluvial-channel gravels. A distributary interpretation of the fluvial-channel gravels is supported by (1) narrow natural levee deposits, (2) all channels on the western and southern exposures having a subparallel current direction and being separated by carbonaceous sandstone and coal units, (3) large point-bar deposits being unpreserved, (4) decreasing grain size toward the east, (5) decreasing channel depth and increasing channel breadth toward the east, and (6) a bifurcation east of The Alcove at point H (Text-figs. 2, 4). A tributary interpretation may also fit the data, but the author favors the former.

Lower Sandstone Facies

The lower sandstone facies represents channel and sand deposits which include point-bar, channel, splay, and natural levee deposits. Unidirectional



TEXT-FIGURE 8.—*A*, Diagrammatic interpretation of the interrelationship of interdistributary splay, abandoned-channel and active-channel deposits. *B*, interpretations of the interrelationship of fluvial system and regressive forebeach after rapid marine transgressions. *C*, Interpretation of Dakota Sandstone after minor subsidence and transgression of Mancos Sea.

current measurements corresponding to those of the channel gravel, the trough and tabular cross-bedding, and the gradational to abrupt contact with the underlying channel gravel indicate related environments for these rock bodies.

A point-bar sequence is well exposed west of The Alcove, between points A and B (Text-fig. 2). It is thought to have migrated over the lower part of the channel. A point-bar is indicated by sand waves or megaripples and trough cross-bedding at the base of the deposit, by current laminations near the top, and by small ripples at the top. Further indications are rooting impressions, an upward decrease in grain size, and a dipping of the shinglelike beds toward the center of the channel. Bedding is less than two feet thick at the bottom and decreases in thickness upward. An abrupt or interfingering contact is seen in this exposure.

The flat-bottomed convex-upward lens of the lower sandstone exposed north of The Alcove at point E (Text-fig. 2) is interpreted to be a splay (crevasse deposit). The flat-bottomed, coarse central core, the flaggy sandstone beds dipping to either side of the lens and interfingering with the carbonaceous units, and the nearly horizontal unchanneled carbonaceous and sandy beds beneath are evidence for this interpretation. This lens is stratigraphically younger than any of the other channel deposits exposed along the western edge of the study area.

Beds near the center of the area, such as those at points I and J (Text-fig. 2), are interpreted to be narrow natural levee deposits. Support for this interpretation is in (1) the fact that in cross section, beds dip away from the center of the channel on both sides, interfingering with the carbonaceous member, (2) the shingled nature of the beds away from the center of the channel on both sides, (3) the presence of abundant root casts and organic matter, (4) the decrease upward of bedding thickness and grain size, (5) the fact that the trough and tabular laminations at the base give way to horizontal and wavy laminations near the top, (6) the spatial relationship of the carbonaceous, conglomerate, and upper sandstone members, and (7) the geometry of the deposit.

Coal and Carbonaceous Facies

Rocks of the carbonaceous facies are interpreted as back-swamp or flood-plain deposits because of the abundance of organic matter, reedlike and grasslike impressions, petrified trees, and its occurrence in a convex-downward lens between lenses of the lower fluvial sandstone. That the upper coal lens accumulated after abandonment of the channels is evidenced by the lack of sandstone lenses and by the purity of the coal.

Upper Sandstone Member

The upper sandstone member is interpreted to consist of deposits of a barrier island or beach. This sandstone is characterized by marine fossils, intense burrowing, foreshore shingled beds regionally dipping seaward, low-angle cross-bedding, geometry, and spatial relationship with surrounding marine and nonmarine deposits. Very little matrix occurs in this well-sorted, mature, well-rounded to subrounded quartz sandstone. Upper portions of individual beds are eroded and intensively burrowed with an abundance of domichnia throughout. That sand was not deposited continuously is indicated by the upper erosional surface and by the abundant burrowing in the upper part of each bed. These individual sandstone beds may have been deposited in discrete events, such as individual storms. Depth of water in which the upper sandstone was deposited was probably never more than 10 to 15 feet and in places may have been only a few inches. Local thickenings occur in the upper sandstone along the southeastern and northwestern edges. These thickenings are interpreted to be fillings either of depressions or tide-scoured channels in the easily erodible Cedar Mountain Shale. Supporting evidence is in the cross-bed relationships, the burrowing, the dipping of beds into the depressions from both edges, and the pinching out of beds laterally along the edges of the depression.

Trace Fossils

Trace-fossil morphology is controlled more by the behavioral characteristics of the animal producing it than by the shape of the animal, by food supply, or by bathymetry. It is seldom possible in ancient rocks to associate the burrower with the burrow. A single organism may form several different burrow patterns, or several different animals may produce very similar burrows. Trace fossils are useful as long as they express a similar response to the same environment. From the standpoint of ethology and habitat, the environmental significance of trace fossils is more important than the specific identity of the trace-making organism.

Domichnia burrows are primarily protective shelters, and they indicate an environment where currents were sufficient to provide food and where sedimentation and erosion did not occur rapidly enough to be a hostile factor. Domichnia-like burrows may also have been produced by crabs and similar animals forming temporary protective shelters, and may not be permanent burrows. Horizontal burrows indicate deeper water environments where the sedimentation rate is slower and muds settle from suspension. High H_2S content in organic sediments normally would exclude bottom-dwelling organisms. To survive in the richly organic sediments, the animals must have had well-ventilated burrows (Pl. 5, fig. 5) so that excursions could be made into normally hostile environments.

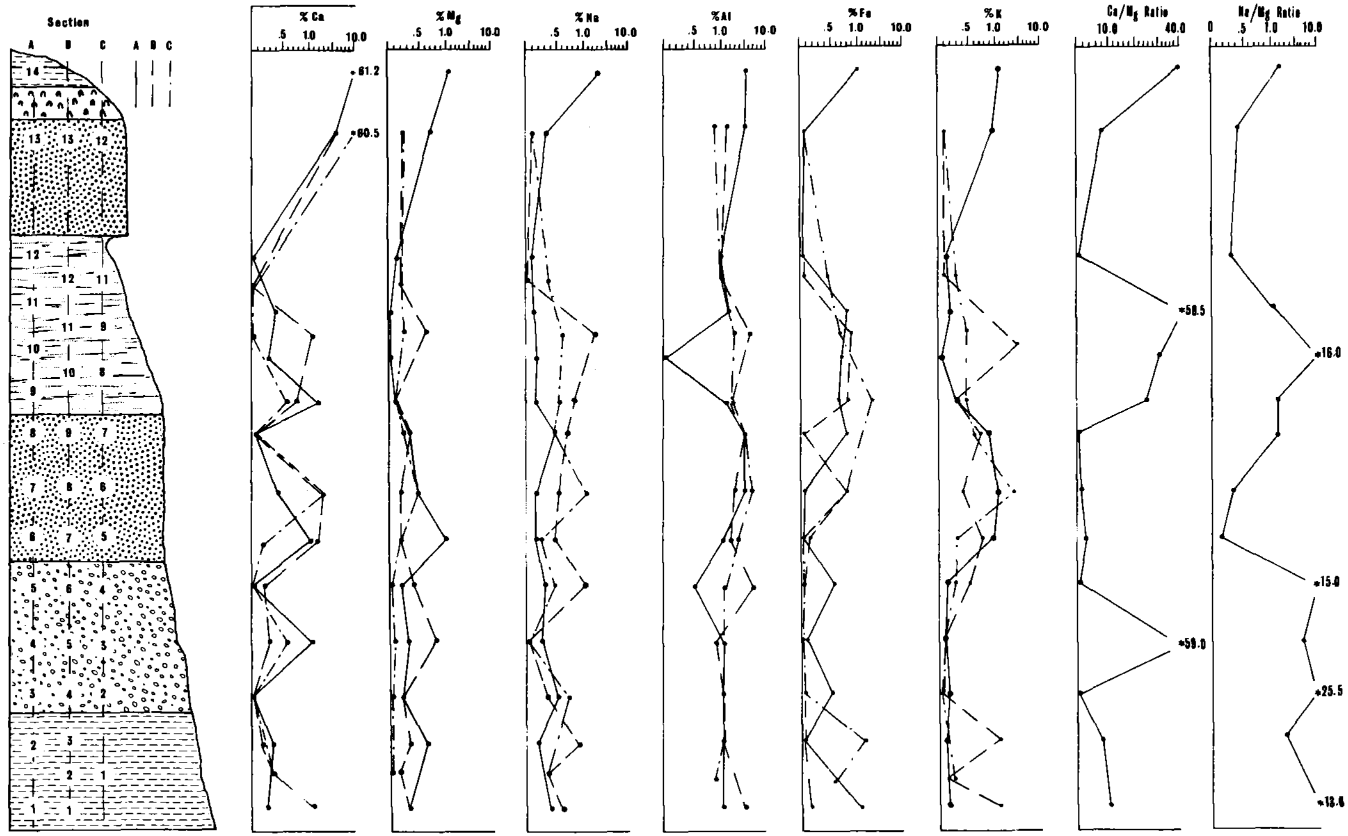
A general gradation from vertical burrows in shallow water to horizontal and patterned burrows in deeper waters is indicated for the Dakota Sandstone exposures studies. This may indicate a response to availability of food at different depths or energy levels, the presence of predators or a harsh environment, or a gradual change from faunas dominated by suspension feeders to those dominated by sediment feeders.

Not all burrows indicated a marine environment. Brackish- or fresh-water burrowers also existed in the study area, as indicated by horizontal burrows in upper silty layers of channel sandstone within the lower sandstone facies.

Minimum water depths of 1 to 15 feet are indicated by paleotopography along a single foreshore bed. A single inclined bed was deposited in varying depths of water, the shallower water being to the west (landward) and the deeper to the east (seaward).

Gryphaea Member

The mollusk *Gryphaea* is interpreted to have grown on the submerged beach sequence early in the rapid transgression of the Mancos Sea. The interpretation of the accumulation as an oyster bank is suggested by the tre-



TEXT-FIGURE 9.—Comparative geochemistry chart showing the distribution of Ca, Mg, Na, Al, Fe, and K for sections A, B, and C. Ca/Mg and Na/Mg ratios are plotted for section A only. The position of each sample is plotted to the left on a generalized lithologic section with relative positions of samples numbered vertically.

mendous abundance of *in situ* or very nearly *in situ Gryphaea newberryi.* The interpretation for the oyster bank is also indicated by whole valves and by the occurrence of some articulated *Gryphaea.*

Model

Variegated beds of the nonmarine Cedar Mountain Formation are locally cut by basal fluvial-channel gravels of the Dakota Sandstone. Elsewhere the Cedar Mountain beds are unconformably overlain by thin-bedded sandstone or shaly carbonaceous deposits of floodplain and swamp environments. Occurrence of several closely spaced, contemporaneous channels with parallel current directions, and with coal separating them, indicates that the channels were probably part of a distributary system with related backswamp deposits. The channel system was abandoned and buried by sandstone and shale of a rapid marine transgression. Initial transgression probably reworked channel gravel and sand deposits and deposited them as a transgressive basal pebble-bearing sandstone at the base of a regressive barrier or beach deposit. The latter is suggested by seaward-dipping sandstone beds in an imbricate forebeach arrangement, and the occurrence of marine fossils throughout the sandstone. With minor subsidence a second marine transgression occurred, submerging the barrier sandstone and initiating occupation of the area by *Gryphaea newberryi.* These osyters formed a bank that was buried by a thin volcanic-ash deposit and then by fissile blue gray marine Tununk Shale.

APPENDIX

Remarks on Geochemistry

Geochemical analyses of 40 samples for Ca, Mg, Na, Al, Fe, K, and Sr from three closely spaced sections were completed to see whether a marine-nonmarine boundary and clastic subenvironments could be delineated. After an evaluation of data it became apparent that without further knowledge of elemental concentrations in the mineral phases present, data are of little value. Extensive thin-section and microprobe work to determine mineral-phase concentrations should be completed prior to further whole-rock analyses. In a clastic environment, however, this may not be practicable because the mineral phases are extremely abundant and are as varied as the environments from which the rock was derived.

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