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TRACE FOSSILS OF FORT HAYS LIMESTONE MEMBER OF NIOBRARA CHALK (UPPER CRETACEOUS), WEST-CENTRAL KANSAS

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TRACE FOSSILS OF FORT HAYS LIMESTONE MEMBER OF NIOBRARA CHALK (UPPER CRETACEOUS), WEST-CENTRAL KANSAS[1]

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[1] Contribution number 196 from the University of Georgia Marine Institute, Sapelo Island, Georgia 31327.

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ABSTRACT

Trace fossils are abundant and diverse, though poorly preserved, in the Fort Hays Limestone Member of the Niobrara Chalk. In west-central Kansas this trace-fossil fauna, which has not been studied previously, consists of at least 20 taxonomic and ethologic variants distributed among approximately 13 genera or morphologic forms. Named genera include *Asterosoma, Chondrites, Laevicyclus, Planolites, Teichichnus, Thalassinoides, Trichichnus* (FREY, n. gen.), *Zoophycos,* and possibly *Arthrophycus.* Forms which cannot be assigned readily to distinctive trace-fossil genera include cylindrical shafts, mechanically filled burrows, and various calcite-, pyrite-, and limonite-filled tubular burrows. About 35 per cent of these taxa or forms represent feeding burrows or combined feeding-dwelling burrows, and 65 per cent represent dwelling structures. Tracks, trails, and other surficial traces were not observed.

The distribution and abundance of several of these trace fossils are correlative with distinct lithotypes, and the composition of individual assemblages changes gradually stratigraphically upward. Yet none of the trace fossils were observed above a bed of chalk in the lower few feet of the overlying Smoky Hill Chalk Member of the Niobrara.

Evidence indicates that 1) except for brief influxes of terrigenous detritus, the carbonate muds of the Fort Hays accumulated slowly, 2) the substrate was soft and yielding to considerable depth, and remained so until late in diagenesis, 3) both the sediments and the overlying water were well aerated, 4) currents capable of substrate scour and shell fragment transport were common, especially during early episodes of Fort Hays deposition, 5) sediments accumulated initially in relatively shallow water, which deepened gradually with successive intervals of time, and 6) the overall depositional environment was more favorable to fossil organisms than is suggested by the diversity of preserved tests and shells. The dearth of trace fossils in the overlying Smoky Hill Member reflects the inception of a different depositional regimen, including increased deposition of terrigenous detritus and more poorly oxygenated sediments.

ZUSAMMENFASSUNG

Der Fort Hays-Kalk in der Niobrara-Kreide des westlichen Mittel-Kansas ist reich an verschiedenartigen Spurenfossilien, die allerdings kümmerlich erhalten sind. Diese bisher unbearbeitete Ichnofauna enthält mindestens 20 taxonomische und ethologische Varianten, die sich auf schätzungsweise 13 Gattungen oder morphologische Formen verteilen. Folgende Ichnogenera kommen vor: *Asterosoma, Chondrites, Laevicyclus, Planolites, Teichichnus, Thalassinoides, Trichichnus* (n. gen.), *Zoophycos,* und möglicherweise *Arthrophycus.* Zu den Formen, die nicht ohne weiteres bestimmten Ichnogenera zugeordnet werden können, gehören zylindrische Schachtbauten, mechanisch verfüllte Gänge und verschiedene mit Kalkspat, Pyrit, und Limonit ausgefüllte röhrenförmige Gangbauten. Ungefähr 35% dieser Taxa oder Formen sind Fressgänge oder kombinierte Fress-Wohn-Gänge; 65% sind Wohnbauten. Fortbewegungsspuren und -fährten und andere Oberflächenspuren wurden nicht beobachtet.

Bei mehreren dieser Spurenfossilien stehen Verbreitung und Häufigkeit in Wechselbeziehung zu bestimmten Lithotypen. Die Zusammensetzung der einzelnen Spurenvergesellschaftungen ändert sich allmählich von unten nach oben im Profil. Oberhalb einer in den tieferen Partien der hangenden Smoky Hill-Kreideschichten (ebenfalls Niobrara-Kreide) gelegenen Kreidebank verschwinden die Spurenfossilien.

Der ichnologische Befund führt zu folgenden Schlüssen:

1. Die Karbonatschlämme des Fort Hays-Kalkes wurden langsam abgelagert, abgesehen von kurzzeitigen Einschwemmungen von terrigenem Detritus.
2. Das Substrat war bis zu einer beträchtlichen Bodentiefe weich und plastisch und blieb in diesem Zustand bis zu einem fortgeschrittenen Stadium der Diagenese.
3. Die Sedimente und das bedeckende Wasser waren recht kohlensäurereich.
4. Oft traten Strömungsenergien auf, durch die das Substrat aufgewirbelt und biogene

Hartteile transportiert werden konnten, besonders im Beginn der Sedimentation des Fort Hays-Kalkes.
5. Anfangs wurden die Sedimente in verhältnismässig flachem Wasser abgelagert; dann wurde das Wasser allmählich tiefer.
6. Der gesamte Ablagerungsbereich war als Lebensraum für fossile Organismen recht günstig, wie das die Arten- und Individuenzahl der erhaltenen biogenen Hartteile vermuten lassen.

Das Fehlen von Spurenfossilien in den hangenden Smoky Hill-Schichten spiegelt den Beginn eines neuen Ablagerungsregimes wieder, mit verstärkter Sedimentation von terrigenem Detritus und mit schlechterer Durchlüftung der Sedimente.

INTRODUCTION

PURPOSE AND SCOPE

In the Fort Hays Limestone Member of the Niobrara Chalk (Upper Cretaceous), trace fossils are generally more abundant and diverse than the remainder of the macrofossil assemblage. These trace fossils, although scarcely mentioned in previous literature, are thus too prominent to be excluded from paleontological and paleo-ecological studies of the Niobrara in Kansas.

Trace fossils are treated traditionally either as sedimentary structures or as paleontologic entities. When the distribution of characteristic structures is mapped, for example, trace fossils may be useful facies indicators (e.g., Howard, 1966); or, when studied from the standpoint of morphologic diversity, trace fossils shed some light on the problem of the "incomplete fossil record" (e.g., Rhoads, 1966). In the present study I have attempted to integrate these two approaches and to glean from the trace fossil assemblage as much information as possible on ethologic and taxonomic diversity and on physical and biologic parameters of the depositional environment.

Because the success of such studies depends mostly upon the amount of time devoted to individual stratigraphic sections, the work was restricted to a small geographic area having excellent exposures (Fig. 1; Appendix 1); Fort Hays exposures along Smoky Hill River in southern Trego County, Kansas, were found to be especially good. In addition to the Fort Hays, the lower few feet of the overlying Smoky Hill Chalk Member (Appendix 2) were studied in order to interpret the transitional change from Fort Hays to Smoky Hill deposition. Most of the field work was done during the summer of 1967.

This paper constitutes part of a more embracive study on the stratigraphy, paleontology, and paleoecology of the Fort Hays Member in west-central Kansas. The remainder of the study is being published separately (Frey, in preparation).

STRATIGRAPHY

The Niobrara Chalk, which is well represented in the Western Interior Region of the United States (Cobban & Reeside, 1952; Reeside, 1957), underlies approximately the northwestern one-fifth of Kansas (Merriam, 1963, fig. 19). In Western Kansas the Niobrara disconformably overlies the Carlile Shale (Hattin, 1962, p. 88-92) and, where uneroded, conformably underlies the Pierre Shale (Table 1). These and subjacent formations were deposited during two major marine transgressive-regressive phases, the Greenhorn and Niobrara marine cycles, each named for deposits reflecting maximum transgression during that cycle (Hattin, 1964; Kauffman, 1967).

Because of abrupt changes in lithology, the contact between the Codell Sandstone Member of the Carlile (Table 1) and the Fort Hays Limestone Member of the Niobrara is sharp and striking (see Pl. 7, fig. 7). The Fort Hays-Smoky Hill contact, on the other hand, is fully gradational and therefore less distinct; positioning of this contact has varied among authors (Runnels & Dubins, 1949, p. 6-7). (See Appendix 2.)

Subsurface thickness of the Fort Hays in Kansas ranges from about 40 to 90 feet, averaging about 50 feet, and the thickness of the Smoky Hill ranges from about 400 to more than 650 feet, probably averaging 550 feet (Merriam, 1957, p. 14, fig. 1, pl. 1-3). Similar thicknesses of the Fort Hays have been reported along its Kansas outcrop belt (Runnels & Dubins, 1949, p. 5). No exposure of the Smoky Hill in Kansas is stratigraphically complete; only one composite section has been published (Russell, 1929), and in this synthesis no actual bedding measurements or field locations are indicated.

The Fort Hays in Kansas consists essentially of thick to very thick beds[1] of chalky limestone separated by very

[1] Terms pertaining to stratification are those given by Dunbar & Rodgers (1957, p. 97-98). Color designations refer to wetted rocks and are based upon the color chart by Goddard *et al.* (1948).

TABLE 1.—*Stratigraphic Units in Upper Part* of Gulfian Series, Western Kansas.*
(Adapted from HATTIN, 1965, table 1.)

FORMATION	MEMBER	APPROXIMATE THICKNESS (FT.)	DOMINANT LITHOLOGY
Pierre Shale	Weskan Shale	170	Shale, dark gray, bentonitic; clay-ironstone and limestone concretions, phosphate nodules.
	Sharon Springs Shale	155	Shale, dark gray, bentonitic; limestone and calcareous septarian concretions, phosphate nodules.
Niobrara Chalk	Smoky Hill Chalk	560-620	Shaly chalk, olive gray to grayish orange and yellowish gray, bentonitic; limonite nodules.
	Fort Hays Limestone	55-80	Chalky limestone, light olive gray to pale grayish orange and yellowish gray.
	Codell Sandstone	0-30	Sandstone and siltstone, quartzose, light olive gray; shaly, calcareous locally.
Carlile Shale	Blue Hill Shale	170-185	Shale, dark gray, silty near top; calcareous and clay-ironstone concretions.
	Fairport Chalk	90-120	Shaly chalk, olive gray, laminated, bentonitic, having beds of chalky limestone and marly chalk.

* Middle Turonian through Campanian.

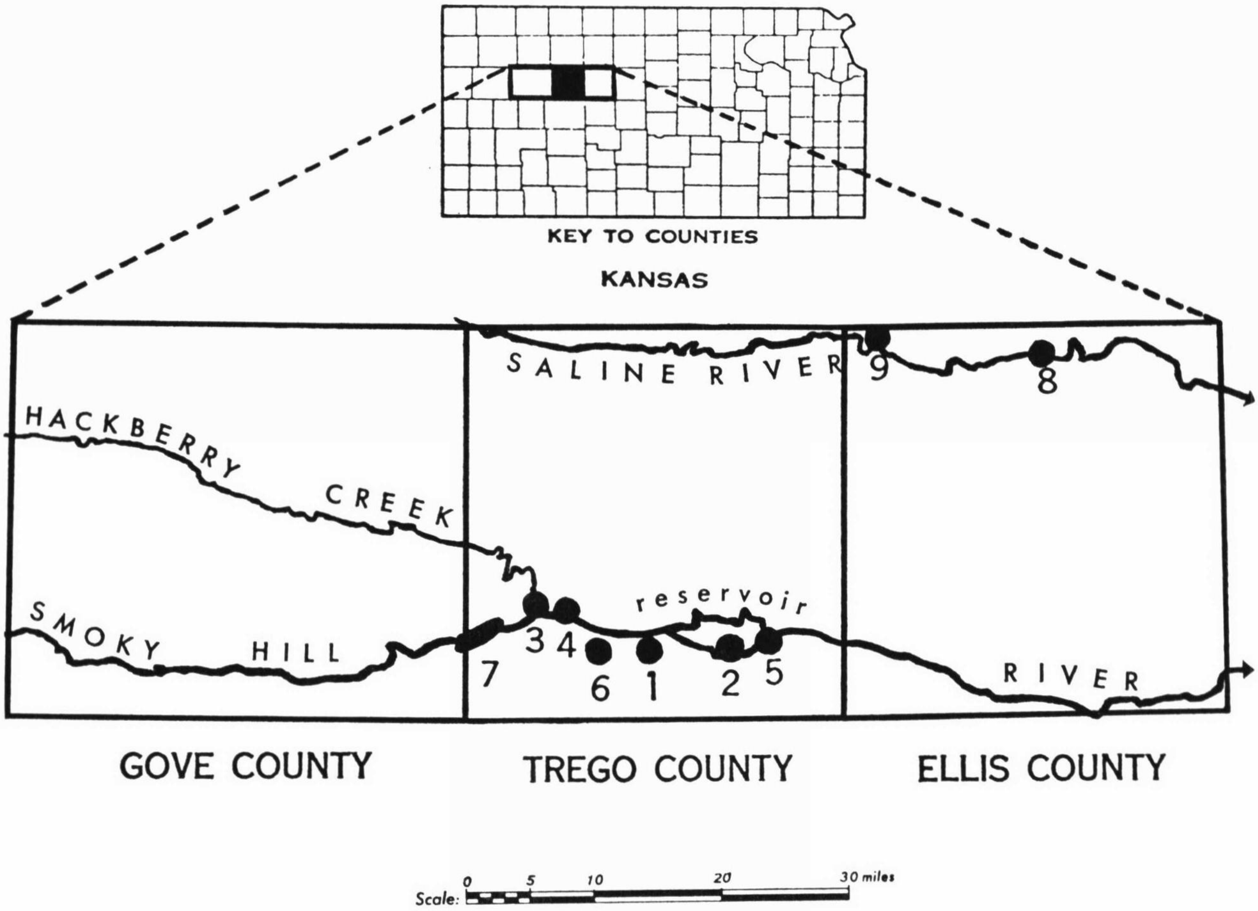

FIG. 1. Locations of Fort Hays exposures examined in west-central Kansas (see Appendix 1 for township and range locations).

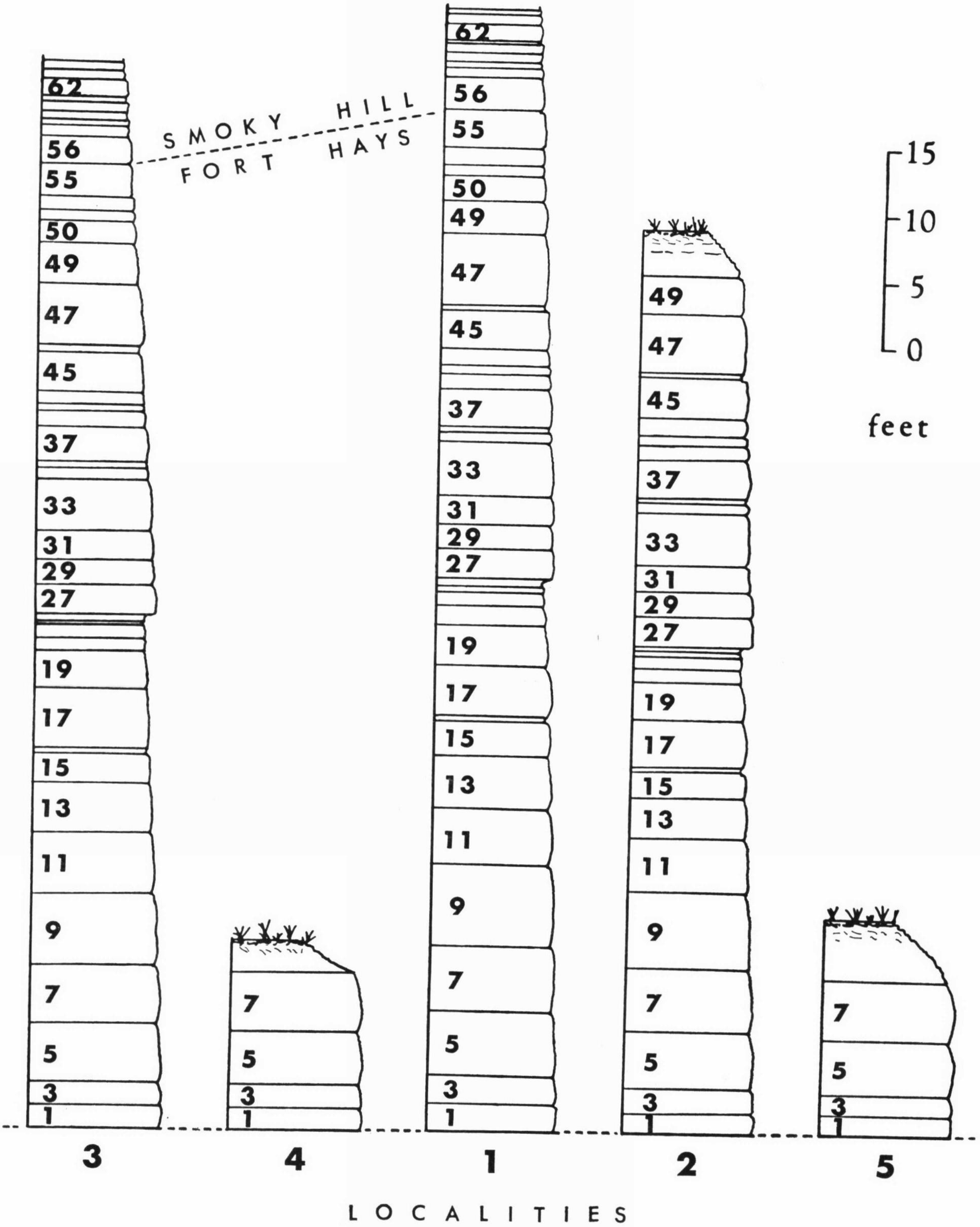

FIG. 2. Diagram of stratigraphic sections measured in Trego County, Kansas. Sections may be correlated on a bed-by-bed basis throughout the county, hence each bed was given a constant numerical designation. (Numbers for thin beds are not indicated here.) Sections are described in Appendix 2.

thin to thin beds of chalky shale (Pl. 1, fig. 1). The chalky limestone is light gray or medium gray where fresh and is yellowish gray, pale orange, or yellowish orange where weathered. Chalky shales are olive-black to dark-gray where fresh and light olive-gray and yellowish gray where weathered.

The Smoky Hill consists chiefly of shaly chalk but also contains numerous beds of chalk and bentonite. Shaly chalk is olive-gray to light olive-gray, and it may be speckled by nearly white spheroidal pellets (HATTIN, 1965, p. 21). The chalk ordinarily weathers to various shades of grayish or yellowish orange or yellowish gray.

Smoky Hill strata contain larger quantities of terrigenous detritus, iron sulfide, and organic matter than the Fort Hays. Inorganic and biogenic sedimentary structures (Pl. 1, fig. 2-5) are much more abundant in the Fort Hays.

CORRELATION OF FORT HAYS EXPOSURES

Strata of the Fort Hays exposed along Smoky Hill River in Trego County (Fig. 1) are remarkably uniform and laterally persistent (Pl. 1, fig. 1), as are strata in the lower few feet of the Smoky Hill Member. Among these strata are numerous key marker beds or groups of beds, hence each exposure of the Fort Hays in Trego County may be correlated on a bed-by-bed basis (Fig. 2). Each bed studied in Trego County, where the Fort Hays attains its approximate maximum thickness along the Kansas outcrop belt, was therefore given a standard numerical designation (Appendix 2). These numbered bedding units are referred to frequently in subsequent parts of the paper.

Strata of the Fort Hays examined in Ellis County (Fig. 1) are also uniform and laterally persistent, but these bedding units could not be correlated exactly with those in Trego County. The Fort Hays at Locs. 8 and 9 is considerably thinner and contains fewer total beds than in Trego County. The only exception is the group of beds comprised by units 39 through 47 (Appendix 2), which were traced from the eastern border of Gove County (loc. 7) to the north-central part of Ellis County (loc. 8), a linear distance of approximately 50 miles.

PETROLOGY

In the area studied, strata of the Fort Hays consist almost entirely of four intergradational lithologies: chalk, chalky limestone, shaly chalk, and chalky shale (Table 2). Very thin bentonites and irregular bentonitic, shaly lenses constitute an insignificant fraction of the total volume of rock. Calcarenite is represented by rare small lenses of shell debris and disaggregated *Inoceramus* prisms (inoceramite).

Except for macroinvertebrate fossils and calcarenite, the chalks and chalky limestones are remarkably uniform in texture (HATTIN, 1965, fig. 6.8). The average composition of these two lithotypes, based upon point counts of petrographic thin sections from loc. 3 (FREY, in preparation), are: matrix (63 percent), microfossils (22 percent), pelecypod fragments (11 percent), iron compounds (2 percent), and miscellaneous constituents (2 percent). Electron micrographs show that the matrix consists chiefly of coccolith debris. The bulk of the microfossils are globular-chambered planktonic foraminiferans. Pelecypod fragments consist mostly of *Inoceramus*, but *Pycnodonte* is also represented. The iron compounds are made up of various forms of authigenic iron sulfide and iron oxide. Stratigraphic variation among these constituents is slight.

TABLE 2.—*Lithologies Comprising Fort Hays Member.*

MAJOR LITHOTYPE	PERCENT (BY VOLUME) OF TOTAL ROCK
Chalk: very soft, friable, low-density micrite made up mostly of cryptocrystalline to microcrystalline grains of calcium carbonate, including nannoplankton remains and planktonic foraminiferal tests	3.7
Chalky limestone: differs from chalk chiefly in being slightly harder and less friable; however, it is substantially softer and less dense than typical Paleozoic micrites. Breaks with conchoidal fracture	90.2
Chalky shale: consists predominantly of clay minerals and fine-grained argillaceous detritus, containing subordinate quantities of chalk. Commonly thinly laminated; breaks with blocky fracture where fresh but has moderately good to good fissility where weathered	3.5
Shaly chalk: essentially intermediate between chalk and chalky shale, but chalky components are more abundant than terrigenous detritus. Usually thinly laminated to laminated and typically contains very thin shale partings	2.5

The calcium carbonate content of chalks and chalky limestones of this member, except for the basal bed, ranges from 88.7 to 98.2 percent (RUNNELS & DUBINS, 1949, p. 9-10, 14-16, table 2, 4-6). The basal bed of the Fort Hays contains considerable detritus reworked from the Carlile Shale. Insoluble residues among chalky shales typically amount to about 60 or 70 percent of a sample (FREY, in preparation).

PALEONTOLOGY

Eleven macroinvertebrate species were found in the Fort Hays (FREY, in preparation): bryozoan *Pyripora* sp., serpulids *Serpula* sp. cf. *S. semicoalita* and *Serpula* sp., and pelecypods *Pycnodonte aucella, P. congesta, Inoceramus* sp. cf. *I. erectus, I. deformis, I. browni, Inoceramus* sp. aff. *I. platinus, Inoceramus (Volviceramus) grandis,* and tubes of *Gastrochaena.* Of these, only two are abundant and widespread: *P. congesta* and *I. deformis. P. aucella* is common locally in the basal Fort Hays, and *I. (V.) grandis* is common in the uppermost part of the member. In the lower part of the Smoky Hill only *I. (V.) grandis, I. platinus,* and *P. congesta* are abundant. Shells bored by acrothoracican barnacles and clionid sponges were observed in both members.[1] The macroinvertebrates constitute assemblages N and Z of KAUFFMAN (1967, p. 112-133).

The microfauna of the Fort Hays consists predominantly of planktonic foraminifers, especially *Heterohelix* and *Hedbergella*. Several additional genera, most of them quite rare, were recorded by LOETTERLE (1937).

Vertebrate fossils among the rocks studied consist mostly of shark teeth and fish scales, both of which are common locally, and a few bone fragments. Higher in the section the Smoky Hill is noted for its well-preserved marine and flying reptiles (WILLISTON, 1898).

Coccolithophorids are diverse and extremely abundant (REZAK & BURKHOLDER, 1958). Other plant fossils consist of rare logs or fragments of wood, some of it coalified.

The presence of *Inoceramus deformis*, *I. browni*, and *I. (V.) grandis* in the Fort Hays indicates that sediments of this member were deposited during Coniacian time (KAUFFMAN, 1966, table 1).

[1] Although shell borings are in fact trace fossils, description and interpretation of those observed in the Niobrara have been omitted from the present report, because the origin and paleoecological significance of these particular structures ally them more closely with the preserved macroinvertebrate assemblage.

ACKNOWLEDGMENTS

I am indebted to DONALD E. HATTIN, Indiana University, who called my attention to the need for a detailed study of Fort Hays ichnology and paleoecology, and who offered valuable assistance, suggestions, and constructive criticisms throughout the study. JAMES D. HOWARD, University of Georgia Marine Institute, visited me in the field and subsequently reviewed my ichnological data; I am grateful for his help in the initial documentation of certain trace fossils. WALTER HÄNTZSCHEL, Geologisches Staatsinstitut, Hamburg, Germany, reviewed part of the manuscript and offered helpful comments. I thank GÜNTHER HERTWECK, Senckenberg Institut, Wilhelmshaven, Germany, for translating the abstract into German.

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I also wish to thank the various landowners in Kansas who gave me permission to examine rocks exposed on their farms and ranches.

TRACE FOSSILS (ICHNOLOGY)

GENERAL STATEMENT

Trace fossils represent animal activity or behavior rather than actual body remains and are therefore difficult to classify (HÄNTZSCHEL, 1962, p. *W*178-*W*181; SEILACHER, 1964a, 1964b). Because of vagaries in modes of preservation, many of the problems in identification and classification of trace fossils are compounded. [Terminology used is explained by HÄNTZSCHEL (1962).]

Most ichnological studies have been restricted to rocks composed of siliceous silt or sand. Two main reasons for this trend are discernible. First, biogenic sedimentary structures are more apt to weather in relief among siliceous rocks than among carbonates; trace fossils are thus more conspicuous and easier to study in siliceous rocks. Second, skeletal remains are ordinarily much more diverse and better preserved in carbonates than in siliceous rocks (where the ichnofauna commonly represents all or most of the preserved organic community); among carbonate rocks paleoecologists have therefore devoted proportionately more attention to preserved tests and shells than to trace fossils.

As shown by BROMLEY (1967) and KENNEDY (1967), trace fossils in chalk rocks, although difficult to study, are capable of yielding important paleontological and paleoecological information and therefore cannot reasonably be excluded from such investigations. This is especially true of the ichnofauna of the Fort Hays, and it is probably also true of other kinds of carbonate rocks (e.g., SHROCK, 1935). Furthermore, because lebensspuren cannot ordinarily be reworked or transported, they are more intimately associated with the immediate depositional environment than tests or shells possibly derived from another environment through current transport or stratigraphic reworking (FREY, 1970b).

MODES OF PRESERVATION

The ichnofauna of the rocks reported here apparently consists almost exclusively of chalk- or mineral-filled burrows preserved in full relief (*see* SEILACHER, 1964a, chart 1; 1964b, fig. 1). The chalk-filled burrows are ubiquitous and profuse; they consist of simple cylindrical shafts, irregularly branching burrow systems, and spreiten structures.[1] Mineral-filled burrows are less abundant but are by no means rare; they consist mostly of simple or bifurcated cylindrical shafts. Tracks, trails, and resting and grazing traces, if ever present, have since been obliterated.

The preponderance of chalk-filled burrows in the Fort Hays and in the lower part of the Smoky Hill are irregular, highly variable structures that may be ascribed to particular genera or forms only through careful study. They are typically exposed as more or less obscure biodeformational structures.

[1] These structures consist of genetically related, parallel or concentric individual burrows, generally strung between two supporting or trunk burrows, like the "web of a duck's foot" (BATHER, 1927, p. 128).

The only Fort Hays and Smoky Hill trace fossils that consistently weather out are pyrite-, limonite-, and calcite-filled tubular burrows. Spreiten structures (Pl. 2, fig. 4) are generally more apt to weather in relief than other kinds of chalk-filled burrows, but none of the chalk-filled burrows ordinarily weather out intact; such burrows are more typically obscured by juxtaposed lenses of inoceramite (disaggregated *Inoceramus* prisms), patches of more resistant chalk, or the burrows of other genera (Pl. 1, fig. 4-5; Pl. 2, fig. 1). In places the cores of horizontal burrow systems are weathered to form small cavities in the rock (Pl. 1, fig. 2), resembling the "cavity preservation" of Bromley (1967, pl. 7a); in many instances, however, the cavity configuration does not seem to correlate exactly with the burrow systems present, and some of the cavities may represent gnawings or borings by Recent fossorial animals that inhabit fractures and crevices in the rock.

Most Fort Hays and Smoky Hill trace fossils must be studied in places where the color of the burrow infilling contrasts with that of the adjacent rock. These differences in color are related chiefly to outcrop weathering; in either extremely fresh or heavily weathered rocks the burrows are inconspicuous, whereas in slightly weathered rocks they are more or less distinct. The best surfaces to examine are: 1) rocks subject to active, small-scale exfoliation during winter freeze-and-thaw; 2) bedrock floors in gullies or arroyos that are abraded periodically by alluvial particles; or 3) solution-etched rock surfaces. Excellent two-dimensional views of burrows are seen often in such places; these are adequate for the study of most burrows, but three-dimensional views or etched surfaces are needed especially for the study of branching burrow systems and spreiten structures.

TECHNIQUES

Unless the color contrast mentioned above is sharp and striking, the chalk-filled burrows remain difficult to study and photograph. Water stains on rock surfaces may also be confusing. A helpful practice in such instances is to outline the periphery of the trace fossil by felt-tipped pen (Pl. 2, fig. 2). Furthermore, by tracing the outline of the structure one is more apt to look closely and critically at an otherwise "nondescript" burrow.

An alternative or supplementary technique is to wet the rock surface with water, which usually enhances burrow details; a canteen and paint brush were regularly carried into the field for this purpose.

Staining techniques and the use of luminescence or ultra-violet radiation, as mentioned by Bromley (1967, p. 166, 168), were not attempted. X-radiography of Fort Hays rocks has been generally unsuccessful because of nearly negligible density contrasts between burrow and matrix (D. F. Merriam, 1967, personal communication). Additional studies on this aspect of Fort Hays ichnology are planned, however.

The size and linear density of burrows was established by the line-transect method (Pl. 2, fig. 6). Burrow size was measured perpendicular to the long axis of the burrow at the point where the cord traversed the burrow. A standard transect length was not used because of variations in area among exposures containing measurable burrows; density data were nevertheless converted to an equivalent standard length.

CONVENTIONS IN TAXONOMY

In general the trace fossils of the Fort Hays are too poorly preserved to be identified at subgeneric levels. Furthermore, the use of specific names for trace fossils is often questionable, considering the extreme ethologic variability exhibited among certain groups. Species names have thus been assigned only to a few of the more distinct structures, although differences between genetically related structures are described in as much detail as possible.

SYSTEMATIC DESCRIPTIONS

Genus ASTEROSOMA von Otto, 1854

[*Asterosoma* Von Otto, 1854, p. 15]

Diagnosis.—Star-shaped structures having an elevated center; rays are bulbous, tapered distally, and wrinkled longitudinally (adapted from Häntzschel, 1962, p. *W*184).

The genus *Cylindrichnus* was introduced informally in a thesis by Toots (1962, p. 64-65), who designated *C. concentricus* as the type species (p. 65-68; pl. 5, fig. 4, 7). Howard (1966, p. 45, fig. 10) has since published Toots' concept of *C. concentricus*, and this work preceded Bandel's (1967, p. 6-7, pl. 3, fig. 2; pl. 4, fig. 1, 5; fig. 2.2) use of the name *Cylindrichnus* for an altogether different trace fossil. Subsequent work, however (J. D. Howard, 1968, personal communication), has shown that *C. concentricus* in the Upper Cretaceous of Utah and Wyoming is fully gradational with both the "helicoid funnel" (Howard, 1966, p. 43, fig. 7) and *Asterosoma*. Present nomenclature is thus in a state of flux and is analogous to the paleobotanist's use of different generic names for component parts of the same plant.

Although the ethological variants *Cylindrichnus concentricus* and "helicoid funnel" are evidently subordinate to the original genus *Asterosoma*, I did not observe "classical" specimens of *Asterosoma* (Häntzschel, 1962, fig. 111,2) in the Fort Hays, nor was I able to demonstrate an interrelationship between *C. concentricus* and the "helicoid funnel." This difficulty is probably due in part to poor preservation of lebensspuren in the Niobrara of Kansas, relative to those in siliceous sands of Utah and Wyoming, yet it possibly also reflects significant ethological and environmental differences. For these reasons, and because of the fundamental distinctiveness of specimens observed in the Fort Hays, the form names "*Cylin-*

drichnus concentricus" and "helicoid funnel" are retained informally.

ASTEROSOMA FORM "CYLINDRICHNUS CONCENTRICUS" (Howard, 1966)

Figure 3,*A;* Plate 2, figure 5; Plate 3, figures 1-2

Diagnosis.—Long, cylindrical or infrequently branched burrows, vertical or inclined to bedding; burrow wall commonly poorly preserved, consisting of multiple, concentric layers. Infilled with detrital sediment. (Adapted from Toots, 1962, p. 65-68; Howard, 1966, p. 45, and 1968, personal communication.)

Burrows of this type are scattered through most of the Fort Hays and, because they commonly tend to weather in relief, are among the more conspicuous trace fossils studied.

Fort Hays specimens of this form are very similar to those described by Toots (1962, p. 65-68; pl. 5, fig. 4, 7) and Howard (1966, p. 45, fig. 10). The burrows are unbranched and are straight to weakly curved; they are typically vertical or steeply inclined to bedding. Burrow dimensions are somewhat variable within a single specimen. The burrows range in diameter from 0.5 to 1.5 cm., but are more commonly about 0.6 to 1.0 cm. Maximum length was not established, but incomplete specimens up to 30 cm. long were found. The burrows are circular to ovate in transverse section. The walls consist of two or more thin, irregular, concentric layers surrounding a central, sediment-filled core. The diameter of this core is one-third to one-half that of the burrow exterior. Minute transverse striae or laminae were detected in the core of a few specimens. The burrow walls in most specimens have been partly or wholly replaced by pyrite, rarely by calcite. Unaltered burrow walls (Pl. 2, fig. 5) are usually lighter in color than the surrounding rock.

Fort Hays specimens differ from those studied by Toots (1962, p. 65) primarily in wall texture and composition; in specimens from the Mesaverde Formation the walls consist of alternate layers of coarser- and finer-grained sediment, which grade imperceptibly into both the burrow infilling and the adjacent substrate. Particles of different grain size were not available to the Fort Hays organism, and the wall layering is detected primarily by concentrically layered discontinuities in texture or fabric; these discontinuities seem to have acted as loci for concentration of diagenetic minerals and probably represent mucus laid down by the organism. Unlike *"Cylindrichnus concentricus"* from the Panther Sandstone of Utah (Howard, 1966, p. 45), Fort Hays forms are rarely oriented at low angles to bedding.

"Cylindrichnus concentricus" is found through most of the Fort Hays but is seldom abundant. It seems to be patchily distributed, both laterally and vertically in the section; very few specimens were found above Unit 39.

Asterosoma consists of one or more feeding burrows that radiate from a central dwelling burrow, of which *"Cylindrichnus concentricus"* is an example. The concentricity of these burrow walls is evidently related to the organisms' activities in maintaining a domicile. Toots (1962, p. 66), following the experimental work by Reineck (1957, 1958), noted that certain pelecypods and annelids maintain their burrows by compacting the burrow walls; if sediment is washed into such burrows, the organisms push it into the walls and plaster it in place with mucus. Periodic influx of sediments thus results in a multilayered wall, successive layers being shoved outward so that the size of the burrow interior remains more or less constant.

The shrimp *Callianassa* may also produce a multilayered burrow wall (Schäfer, 1962, p. 353); thus some of the Fort Hays specimens identified in transverse section as *"Cylindrichnus concentricus"* might conceivably be the vertical shafts of small *Thalassinoides.*

Where the concentricity of burrow walls in *"Cylindrichnus concentricus"* is poorly developed or absent, the burrows grade into the "rod-shaped burrows" of Howard (1966, p. 50-51, fig. 17), which are also a form of *Asterosoma* (J. D. Howard, 1969, personal communication). Certain burrows from the Fort Hays, designated herein as "cylindrical shafts," are probably equivalent to these "rod-shaped burrows," as explained below.

ASTEROSOMA FORM "HELICOID FUNNEL" (Howard, 1966)

Diagnosis.—Broad, oval to funnel-shaped spreiten structures passing both upward and downward into cylindrical stems; funnel walls consist of closely appressed whorls arranged in a low helicoid. Sediment in core of funnel weakly to intensely disturbed, displaying gneiss-like texture in certain specimens. Two or more funnels may be linked in irregular series. (Adapted from Howard, 1966, p. 43.)

"Helicoid funnels" are among the more abundant and widely distributed trace fossils in the Fort Hays. In general they are poorly preserved, however, and are easily overlooked except where the color of the burrow cast contrasts with that of the adjacent rock. Only rarely do the spreiten structures weather in relief so that individual burrows may be studied in detail. Two varieties seem to be present, although further work may show eventually that these are intergradational.

"HELICOID FUNNEL" TYPE A (Howard, 1966)

Figure 3,*C;* Plate 2, figures 6-7; Plate 3, figure 6

As illustrated by Howard (1966, fig. 7), the "helicoid funnel" may be either low and oval, in which case the burrow core is intensely bioturbated, or large and distinctly funnel-shaped, in which case the burrow core is somewhat less bioturbated. Although Howard did not stress the differences between these two forms, they seem to be morphologically distinct in the Fort Hays and are therefore designated as types A and B, respectively.

Type A consists typically of a small oval funnel that is joined both above and below by small cylindrical shafts.

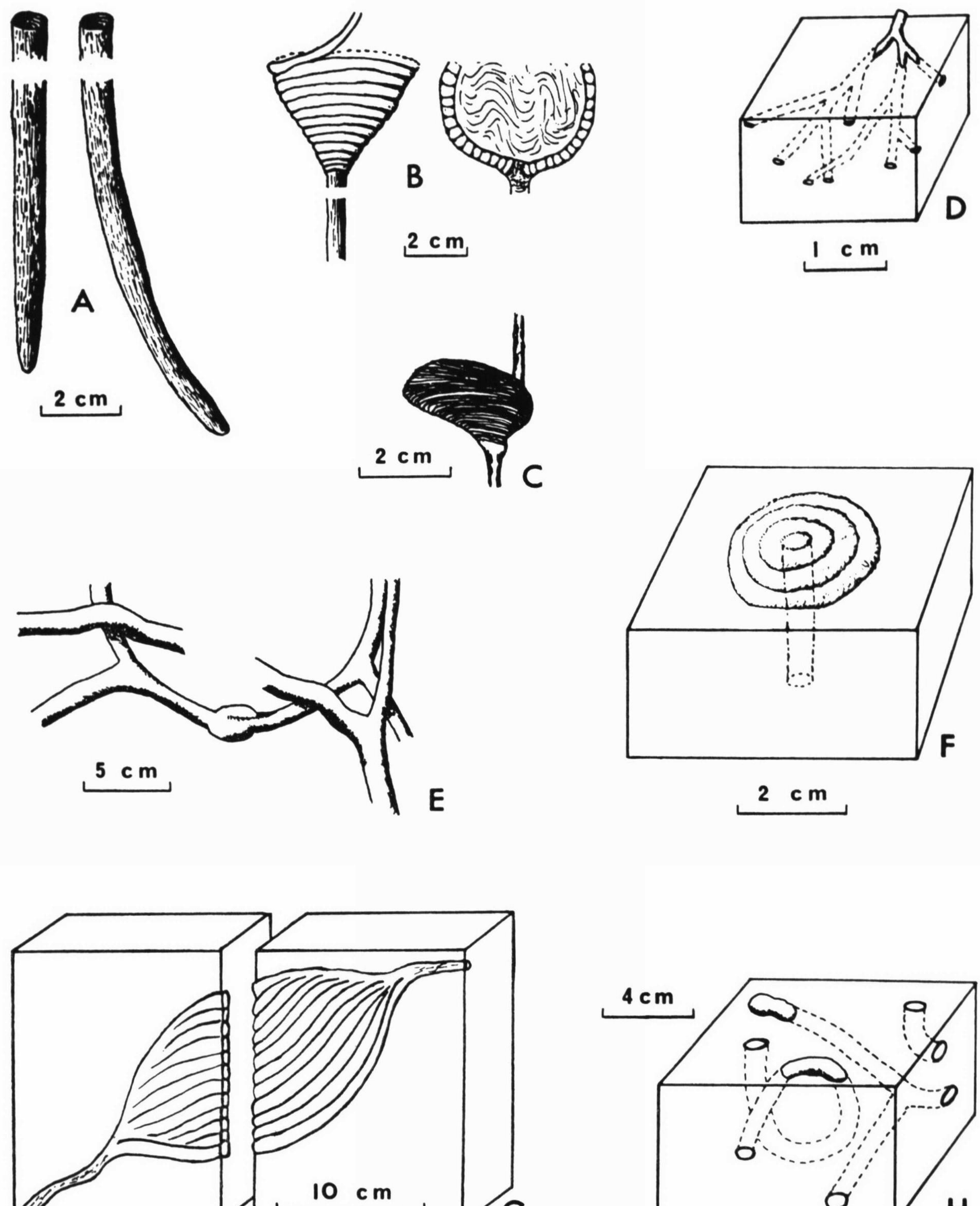

FIG. 3. Diagrammatic reconstructions of trace fossils from the Fort Hays Member.——*A. Asterosoma* form "*Cylindrichnus concentricus.*" ——*B. Asterosoma* form "helicoid funnel" Type B.——*C. Asterosoma* form "helicoid funnel" Type A.——*D. Chondrites* sp.——*E. Thalassinoides* sp.——*F. Laevicyclus* sp.——*G. Teichichnus* sp.——*H. Planolites* sp.

Several funnels may be linked by such shafts. The shafts are nearly straight but vary considerably in length and orientation; where funnels are sparse they are vertical (Pl. 2, fig. 7) but where funnels are crowded together the shafts may be oriented at almost any angle (Pl. 2, fig. 6). Individual whorls of the spreite are irregular and may overlap or truncate previous whorls. The diameter of these whorls was not established but is presumably comparable to the diameter of the shafts. The funnels are 3 to 9 cm. across, typically 4 to 5 cm., and their height is generally about one-half of their breadth. Shafts range in diameter from 0.3 to 1.1 cm., but most are about 0.5 cm.; the largest shaft seen had a length of more than 17 cm.

The lack of diagenetic minerals associated with the spreite indicates that this sediment-ingesting "worm" did not expend much mucus on the whorls of the funnel, although it apparently reinforced the walls of the shafts to some extent.

The type-A funnel ranges throughout the Fort Hays but is more abundant in the lower part of the member. It possibly ranges as high as Unit 62 (Smoky Hill Member). A maximum density of 11 burrows per meter (horizontal transect) was found in Unit 7, Loc. 1. Densities gradually decline stratigraphically upward from Unit 9, and only isolated specimens were found in the upper one-half to one-third of the member.

In many places the funnels are concentrated within particular stratigraphic zones (Pl. 2, fig. 6) suggesting a response to rate of deposition; such zones are usually bounded by changes in lithology or texture.

"HELICOID FUNNEL" TYPE B (Howard, 1966)

Figure 3,*B;* Plate 2, figure 3; Plate 3, figures 3, 5

The type-B funnel may be cone-shaped (Pl. 3, fig. 5) or crudely circular in outline (Pl. 2, fig. 3; Pl. 3, fig. 3). The maximum diameter of these funnels ranges from 3 to 20 cm., most specimens being 5 or 6 cm. across. The breadth of the funnel is variable relative to its height. Individual whorls of the spreite are of approximately the same diameter as the shaft, which is 0.5 to 1.3 cm., averaging about 0.8 cm. Shaft and whorl dimensions may vary within the same specimen. Dorsal shafts (Pl. 3, fig. 5) are seen less commonly in the type-B funnel than in type A, and they are also less consistent in size and orientation.

Pyrite was found in the shaft of one specimen but did not seem to be a replacement of the burrow core; the specimen was evidently penetrated by a burrow of a different kind, and the pyrite was concentrated in the latter.

Type-B funnels are patchily distributed and are usually sparse. A density of 9 funnels per meter (horizontal transect) was found locally in Unit 47, Loc. 1, but this density is atypical. Unlike type A, this funnel was not found in the lower two-thirds of the Fort Hays, and it apparently does not range into the base of the Smoky Hill. Locally the funnels are concentrated within distinct stratigraphic zones (Pl. 3, fig. 3).

Although the overall dimensions of types A and B are generally similar, the two funnels are consistently dissimilar in other respects. Among specimens found in the Fort Hays, type A is always oval and wider than tall, whereas type B is typically cone-shaped to circular, or if elliptical, its height almost invariably exceeds its width. A full intergradation between the two types could not be established.

Fort Hays specimens of both types are smaller than many of those studied by Howard (1966, p. 43), and the whorls lack the alternating layers of coarse- and fine-grained sediment reported by him. Such sediment was not generally present in the Fort Hays depositional environment.

According to Howard (1968, personal communication), the shafts associated with the "helicoid funnel" grade into *"Cylindrichnus concentricus."*

Genus CHONDRITES Sternberg, 1833

[*Chondrites* Sternberg, 1833, p. 25]

Diagnosis.—Very plantlike, regularly ramifying burrow structures which neither closely contact each other nor anastomose (effected by phobotaxis[1]); system consists essentially of branched horizontal components which rise gradually toward a vertical centrum. Burrows are circular in transverse section and have smooth walls. Burrow diameter remains constant within a single burrow system but varies considerably among different systems. Branching pattern is dendritic and commonly very regular, but lacks symmetry other than a radial tendency; several orders of branching may be present, the more distal of which tend to be pinnate. Systems usually are infilled with detrital sediment but may contain transversely oriented ellipsoidal fecal pellets. (Adapted from Simpson, 1957; Häntzschel, 1962, p. *W*187-*W*188, and 1965, p. 21-22.)

Except for *Planolites, Chondrites* may be the most widespread trace fossil in the Fort Hays and in the lower few beds of the Smoky Hill. However, the structure is conspicuous only where the burrow cast is lighter in color than the adjacent rock; it does not weather in relief. Complete horizontal parts of the burrow systems are almost nowhere seen because the bedding surfaces available for study are typically highly weathered. Thus, although most of the small, horizontal or gently inclined, chalk-filled burrows of the Fort Hays may be referred to this genus, specific morphological details are extremely diffi-

[1] Term used by Rudolf Richter (1927, *Die fossilen Fährten und Bauten der Würmer, ein Überlick über ihre biologischen Grundformen und deren geologische Bedeutung:* Paläont. Zeitschr., v. 9, p. 193-235) to describe the behavior of a burrowing animal which, upon encountering another burrow made previously by itself or by another individual of the same species, detects the presence of that burrow through some chemical sense and deliberately avoids penetrating it; the animal either retreats or changes the direction of its burrowing. According to Richter, such behavior enhances an animal's efficiency in exploiting space available in the substrate.

cult to evaluate. Because of apparent consistency in burrow configuration, only one species is thought to be present.

CHONDRITES sp.

Figure 3,*D;* Plate 2, figure 6; Plate 3, figure 4; Plate 5, figure 3; Plate 8, figure 13

Individual burrows range in diameter from 0.8 to 2.0 mm., most being about 1.0 to 1.5 mm. Within a burrow system and also within a given stratum the burrow diameter tends to be more or less constant. The burrows are typically straight in plan view but may be weakly curved in vertical view. Branching is at acute angles and without apparent symmetry; at least second-order branches are present. Vertically oriented burrows are circular in transverse section; horizontal burrows may be nearly circular to strongly elliptical, depending upon compaction of containing strata. The burrow walls are distinct and unornamented, and the burrow core consists of structureless chalky sediment.

In vertical section this species strongly resembles *Chondrites* sp. KENNEDY (1967, pl. 2, fig. 2-4) from the Lower Chalk of England; the two are also generally similar in plan view (KENNEDY, pl. 9, fig. 1). Unlike *Chondrites* sp. KENNEDY (p. 149-150), however, the Fort Hays species was not found in felted, intertwined mats on the bottom surface of *Thalassinoides.*

Chondrites sp. is scattered to locally profuse in beds of chalk and chalky limestone throughout the Fort Hays and the lower few feet of the Smoky Hill. Densities of 2 to 3 burrows per centimeter (horizontal transect) are common. It is also found in beds of somewhat shaly chalk, but is apparently absent from other beds of shaly chalk and all beds of chalky shale. At the base of Unit 1, and possibly in other places, it commonly penetrates *Arthrophycus*-like and thalassinoid burrows, as does *Chondrites* sp. KENNEDY.

Chondrites is interpreted as a feeding burrow, possibly made by the proboscis of a sipunculoid worm (SIMPSON, 1957, p. 487-488) or, less plausibly, by an animal having many tentacles (TAYLOR, 1967, p. 21). Whether the structure was passively infilled at some later time or was filled penecontemporaneously with burrow construction remains debatable. FERGUSON (1965) suggested that the withdrawal of a proboscis from the burrow would create a vacuum that would, in turn, cause detrital sediment to be sucked into the burrow. However, the burrow filling may also consist of fecal pellets (HÄNTZSCHEL, 1960, p. 98); in order to reconcile FERGUSON's mechanism in this instance, one must assume that the debris surrounding the central burrow opening consisted almost entirely of fecal pellets, most of which were subsequently removed by currents. Furthermore, certain specimens have a laminated infilling, which suggests that the sediments filtered periodically into partly open burrows (TAYLOR, 1967, p. 19-21). SCOTT (1970, p. 87) described briefly some *Chondrites* specimens from the Kiowa Formation (Lower Cretaceous) of Kansas that were found in the micrite fillings of some *Gryphaea* valves; these burrows have important ethological and sedimentological implications and should be studied in greater detail.

Unlike specimens of this trace fossil from the septarian clay of Germany (HÄNTZSCHEL, 1960, p. 98) and the Alpine Flysch (SIMPSON, 1957, p. 479), pyritic burrow linings were not observed in specimens of *Chondrites* sp. from the Fort Hays; this suggests that the organism did not line its burrows with appreciable quantities of organic matter.

None of the trace fossils associated with *Chondrites* sp. in the Fort Hays suggest locomotor movements by the *Chondrites* organism, as postulated for *Cylindrites* by SIMPSON (1957) and for "circular and kidney-shaped burrow swellings" by TAYLOR (1967), although this is conceivably the result of poor preservation of burrows in the Fort Hays.

Genus LAEVICYCLUS Quenstedt, 1879

[*Laevicyclus* QUENSTEDT, 1879, p. 577]

DIAGNOSIS.—Vertical, approximately cylindrical shafts, penetrated by central canal; upper end of shaft surrounded by series of concentric, circular or elliptical furrows excavated on bedding surfaces. Diameter of shaft variable within a single specimen. (Adapted from HÄNTZSCHEL, 1962, p. *W*201, and 1965, p. 51.)

Laevicyclus is conspicuous in the Fort Hays only where the concentric circles are etched in relief on weathered bedding surfaces, and the vertical shafts are seen only where the color of the burrow cast is different from that of the adjacent rock. These two conditions are rarely fulfilled by a single slab of rock, hence one must rely largely upon incompletely preserved specimens for study.

LAEVICYCLUS sp.

Figure 3,*F;* Plate 4, figures 2-3

The length of the vertical shaft was not established in *Laevicyclus* sp., but probably does not exceed a few centimeters. The few shafts seen were uniformly about 0.6 to 0.7 cm. in diameter. The upper end of each shaft is "capped" by a thin, horizontal lens of sediment that is slightly larger in diameter than the shaft itself; this lens is surrounded by 2 to 3 low, circular ridges of sediment. The circlets are strikingly concentric, although their gross outline may be slightly ellipsoidal. Maximum diameters of nonelliptical specimens (in cm.) are indicated below; a conspicuous modal peak is not present.

Measurements of Laevicyclus *sp. from Fort Hays Member*

NUMBER	RANGE	MEDIAN	MEAN	STANDARD DEVIATION
11	3.1	2.8	2.9	0.88

The central canal that penetrates the shaft was not positively identified in *Laevicyclus* sp.

Specimens were found most commonly at lithologic interfaces. The shafts almost invariably lie within chalk or chalky limestone, whereas the circles are typically found within, or immediately subjacent to, the overlying shale unit. In the thin transitional zone between Units 1 and 2 at Loc. 4, a density of more than 30 specimens per square meter (horizontal quadrat) was found; a comparable population was seen at the same stratigraphic level at Loc. 5. The trace fossil is extremely rare in stratigraphically higher beds, however, and was not noted above Unit 25.

Laevicyclus has been interpreted variously as a coral, as an organism of unknown affinities, as an inorganic structure produced by gas exhalations and pressure on interstitial water, and as a trace fossil (HÄNTZSCHEL, 1962, p. *W*201). The abundance of *Laevicyclus* sp. at lithologic interfaces in the Fort Hays seemingly supports the idea of an inorganic origin, that is, overloading of watery carbonate muds by rapid influx of terrigenous clays. The clayey strata of the Fort Hays are too thin to have added appreciable weight, however. Furthermore, *Laevicyclus* sp. was not found in association with load casts or related phenomena, and some specimens are contained entirely within chalk or chalky limestone beds, thus opposing the possibility of physical disruption of the substrate.

Concentric markings are also produced by such things as limber, current-swept bodies (BARTHEL, 1966), but no evidence suggests that *Laevicyclus* sp. of the Fort Hays was formed in this way.

SEILACHER (1953a) compared *Laevicyclus* with dwelling- and feeding-structures produced by the Recent polychaete *Scolecolepis squamata*. This worm occupies a vertical, cylindrical dwelling burrow and searches for food by scraping the adjacent substrate with its two long tentacles. In turbulent waters the tentacles trail down-current and produce V-like or irregular surficial markings, but in calmer waters the tentacles are raked in a circular path around the burrow opening, leaving concentric furrows and ridges in the substrate surface (SEILACHER, 1953a, fig. 4). (The ellipsoidal structures associated with *Laevicyclus* sp. of the Fort Hays are thus conceivably the result of weak currents, although the long axes of such specimens generally reflect a random rather than preferred orientation.)

The only objection to *Scolecolepis* as a possible explanation for *Laevicyclus* sp. of the Fort Hays is that the circlets are well preserved locally, whereas tracks, trails, and resting traces are conspicuously absent from the same beds; if conditions favored preservation of *Scolecolepis'* delicate scrape marks, then other kinds of impressions should have been preserved as well. Similar objections were raised by KEMPER (1968, p. 79-80), who concluded that the real nature and origin of *Laevicyclus* remains unclear.

Genus PLANOLITES Nicholson, 1873

[*Planolites* NICHOLSON, 1873, p. 289]

DIAGNOSIS.—Irregular, horizontal or inclined burrows, generally about 1 cm. in diameter, filled by sediment passing through a vermiform organism's alimentary canal; burrows meander and undulate more or less randomly, and may branch. (Adapted from NICHOLSON, 1873; HOWELL, 1943a, p. 17; HÄNTZSCHEL, 1962, p. *W*210, and 1965, p. 72.)

Burrows of this general type are undoubtedly the most abundant and widespread trace fossils in the Fort Hays and the lower few beds of the Smoky Hill. They are conspicuous on almost every fresh exposure of rock, and locally they weather in relief. Subtle differences exist among certain populations, yet such burrows are so irregular that elaboration of these differences is difficult; practically any attempt to identify species is futile. When seen only as biodeformational structures, *Planolites* may also be confused with other trace fossils. Except for their considerably smaller size, several other chalk-filled burrows in the Fort Hays resemble *Planolites* and are probably related to it.

PLANOLITES sp.

Figure 3,*H;* Plate 3, figure 4; Plate 4, figures 4-5; Plate 5, figures 1, 3

Burrows of the *Planolites* type range in diameter from 0.5 to 1.2 cm., but most are about 0.8 cm. in diameter. Their configuration is extremely variable. The burrows may be 1) nearly straight or gently to markedly sinuous, 2) simple cylindrical shafts or rarely to frequently branching structures, and 3) oriented horizontally or inclined gently or steeply to bedding. In places the entire population is oriented similarly (Pl. 4, fig. 4) but the individual burrows are usually oriented somewhat randomly with regard to bedding. The latter situation is sometimes confusing because the "apparently" dominant burrow orientation at first seems to coincide with the plane of the rock surface, when in fact there is no particularly dominant orientation. For example, the burrows in the lower half of Plate 5, Figure 3, a vertical exposure, appear to be more or less vertically oriented, whereas those in Plate 4, Figure 5, a bedding surface, appear to be horizontally oriented; the same stratum is involved in both places, however. The confusion results from the viewer's tendency to overlook burrows exposed only in transverse section and which therefore present less surface area than those exposed in longitudinal view.

These burrows attest to a profusion of vermiform, sediment-ingesting organisms in the carbonate muds of the Fort Hays and lowermost Smoky Hill. The burrows are common in both chalky limestone and chalky shale, and individual burrows commonly cross lithologic contacts (Pl. 5, fig. 3). Although this trace fossil is sparse locally, densities of 50 to 55 burrows per meter (horizontal transect) are common in chalky limestones; densities of about half that are common locally in shales. The density and distribution of this trace fossil are not correlative with any obvious environmental parameters other than sediment composition, and this is probably an indirect reflection of the rate of sedimentation.

Planolites is apparently unique among Fort Hays trace fossils in that this genus may also be found in nonmarine deposits (SEILACHER, 1963, fig. 1).

Genus TEICHICHNUS Seilacher, 1955

[*Teichichnus* SEILACHER, 1955, p. 378]

DIAGNOSIS.—Vertical, bladelike, spreiten structures consisting of several superposed, horizontal or inclined burrows; spreiten rarely branch. Individual burrows straight or somewhat flexuous in plan view, nearly straight to broadly concave or convex in vertical view. Burrows displaced either downward (protrusive) or upward (retrusive), truncating both ends of previously formed burrows. (Adapted from SEILACHER, 1955, p. 378-379; HÄNTZSCHEL, 1962, p. *W*218, and 1965, p. 91-92.)

Although SEILACHER (1955, p. 379) intended the name *Teichichnus* to include all attenuate "wall-forming" spreiten structures, the name presently embraces a somewhat heterogeneous assortment of trace fossils, many of which seem to have little in common with *T. rectus*, the type species, other than vertically stacked individual burrows. Examples are the teichichnians figured by MÜLLER (1962, fig. 17), MARTINSSON (1965, fig. 21-28), SCHNEIDER (1962, fig. 1-3), and possibly those from the Fort Hays. The various forms presently included within this genus need critical reexamination and perhaps taxonomic redefinition.

Teichichnians are among the more characteristic and abundant trace fossils in the Fort Hays. The color of the burrow casts commonly contrasts with that of the adjacent rock, and the configuration and gross outline of a spreite periphery is usually sufficient for generic identification. In places the individual burrows weather in moderately strong relief so that spreite components may be studied in some detail. The chief problem in studying these trace fossils is that in places where the spreiten are incompletely preserved, they are easily mistaken for certain *Zoophycos* spreiten.

TEICHICHNUS sp.

Figure 3,*G;* Plate 2, figures 2, 4; Plate 3, figure 7; Plate 4, figures 1,6; Plate 5, figures 2, 4, 7; Plate 7, figure 4

Teichichnus sp. consists of protrusive spreiten that are biconvex in a vertical plane (Fig. 3,*G*). The spreiten may be oriented parallel with bedding (Pl. 2, fig. 2) but are typically inclined at a steep angle. They are almost invariably straight in plan view and are irregular in vertical view only where the burrowing organism encountered some obstacle in the substrate. Individual burrows are bowed upward in the upper part of the spreite, are nearly straight in central part, and are bowed downward in the lower part. These burrows are 0.4 to 0.9 cm. in diameter, most being 0.5 to 0.6 cm.; they inosculate at either end of the spreite to form a single trunk stem of approximately the same diameter as the individual burrows. The stem is nearly straight to weakly or markedly sinuous, and may be oriented at various angles with respect to bedding. The maximum length of such stems was not determined; the exposed parts rarely exceed 10 cm. in length, but the stems are apparently much longer. Certain clusters of spreiten suggest that two or more spreiten may arise from a single trunk stem, although clearly isolated spreiten are more common. Branching spreiten were not observed, but later-formed structures commonly penetrate earlier ones. Among well-preserved specimens the spreiten range in length from 12 to 35 cm. and in height from 4 to 27 cm.; most spreiten are 20 to 25 cm. long and 12 to 14 cm. high. Incomplete specimens suggest that certain spreiten may have attained lengths up to 45 or 50 cm., although the heights of such structures apparently remained within the range stated above.

Certain kinds of long, vertical burrows were found commonly in close association with *Teichichnus* sp. and may have been produced by the same organism. The burrows may be simple, more or less cylindrical shafts (Pl. 4, fig. 1; Pl. 5, fig. 7) or they may be broad, flat structures that seem to be spreiten composed of vertical shafts (Pl. 5, fig. 6). Part of the trunk stem of certain teichichnians (Pl. 5, fig. 2) strongly resemble the latter burrows. *Teichichnus* spreiten are sometimes found in juxtaposition with the vertical burrows (Pl. 5, fig. 7), but none of the examples observed are well preserved and it remains unclear whether such juxtaposition represents true junction or merely a cross-cutting relationship between two separate trace fossils.

Teichichnus sp. does not closely resemble any teichichnian described previously and is probably a new form. It ranges throughout the Fort Hays and is locally to consistently abundant in numerous beds, although it is generally sparse below Unit 15 and above Unit 47. Representative population densities are indicated below, each measured at Loc. 1.

Population Densities of Teichichnus *sp. at Locality 1*

UNIT	SPECIMENS/M² (VERTICAL QUADRAT)
47	6 to 7
39	9 to 10
29	2 to 3
19	5 to 6
17	2 to 3

Specimens are typically confined to beds of chalk or chalky limestone but may extend into shaly units. Differential compaction of a single spreite extending into both lithologies, such as that illustrated by MARTINSSON (1965, fig. 24,*A*), is not conspicuous in the Fort Hays. In places the specimens are concentrated along particular stratigraphic horizons (Pl. 4, fig. 1), which suggests that the population responded simultaneously to some environmental factor, probably rate of deposition. In such places the spreiten may also be oriented parallel to each other. (In a rock exposure facing a particular direction the spreiten may be seen only in cross-sectional view, whereas in an exposure of the same stratum facing a different direction the spreiten may be seen only in longitudinal view.) Such orientations were not observed commonly, however.

Seilacher (1957, p. 203-204, pl. 23, fig. 1-2) concluded that certain structures produced by the polychaete *Nereis diversicolor* in aquaria (Reineck, 1957) are Recent analogs of retrusive teichichnians such as *T. rectus*. They are possibly also analogs of protrusive teichichnians such as *Teichichnus* sp., although the activities of *N. diversicolor* seem to be considerably more diverse than those of the Fort Hays teichichnian organism. *N. diversicolor* ordinarily occupies a well-defined, rather permanent, U-shaped dwelling burrow, which may have additional branches communicating with the substrate surface. It ingests surface mud surrounding the burrow or leaves the burrow to browse upon the substrate. It may also feed upon marine plants or prey upon other worms, and it is able to secrete and use a mucoid filter-feeding apparatus. Plant fragments are commonly stored in the burrow for later feeding. (See Pettibone, 1963, p. 175-178; Bajard, 1966, fig. 7-13.)

Genus THALASSINOIDES Ehrenberg, 1944

[*Thalassinoides* Ehrenberg, 1944, p. 358]

Diagnosis.—Extensive burrow network consisting of frequently branching, dominantly horizontal burrows and rarely branching, dominantly vertical burrows. Burrows unite at branches to form polygons; branches typically Y-shaped and enlarged at point of bifurcation. Burrows cylindrical to elliptical in transverse section; usually unornamented. Burrow dimensions variable within a single system. (Adapted from Kennedy, 1967, p. 131-134; Häntzschel, 1962, p. *W*218, and 1965, p. 92.)

Thalassinoides is abundant locally in the Fort Hays, but the burrows are difficult to identify and document. Ordinarily they do not weather out in relief, and two-dimensional rock surfaces rarely impart a clear image of the burrow networks. Even where the burrows are partly exposed (Pl. 5, fig. 5), their configuration is largely obscured by juxtaposed lenses of inoceramite, patches of differentially resistant chalk, or burrows of other trace fossils (Pl. 2, fig. 1). Solution pits resembling "cavity preservation" (Bromley, 1967, pl. 7a) are seen locally (Pl. 1, fig. 2), but only rarely may these be ascribed to *Thalassinoides*. To complicate matters, some of the more plausible "thalassinoids," which are etched in recess and exhibit distinct scratch marks, are actually the runways of small rodents that inhabited fractures and crevices in the rocks. Nevertheless, two distinct thalassinoids[1] seem to be present in the Fort Hays.

[1] The term "thalassinoid" is used as an informal designation for *Thalassinoides;* the term is distinct from "thalassinidean," which is a general name for members of the decapod family Thalassinidea.

THALASSINOIDES SP. CF. T. PARADOXICUS (Woodward)

Plate 5, figure 5; Plate 6, figure 1

One of the Fort Hays thalassinoids is similar in many respects to *Thalassinoides paradoxicus* (Woodward), as described by Kennedy (1967, p. 142-148, pl. 3; 4; 8, fig. 5; 9, fig. 2; text-fig. 4, 5a-b). The burrows and burrow networks are very irregular in size and configuration. Burrows range in diameter from about 0.8 to more than 5.0 cm., and this range may be found within a single burrow system. Two or more tiers of closely spaced, dominantly horizontal burrow systems may be present, and these are interconnected by irregular, vertical or obliquely inclined burrows. Bulbous to elongate burrow enlargements are found in both horizontal and vertical components, and both bear short, dead-end burrows. Branches are characteristically Y-shaped, even in vertical components, and are usually wider at the point of bifurcation; in places the branches are pitchforklike and consist of more than two limbs. Distances between bifurcations are highly variable; diameters of offshoots may be strikingly different from those of parent trunks. Branching produces irregular, nonplanar polygons. Longitudinal striations, "scratch marks," or other burrow ornamentations were not observed.

According to Kennedy (1967, p. 142, 147), the irregular, three-dimensional branching pattern of *Thalassinoides paradoxicus* distinguishes it from other forms, and for this reason the Fort Hays specimens are assigned tentatively to that species. Better specimens are needed in order to confirm this assignment.

Because of the characteristically poor preservation of thalassinoids in the Fort Hays, the stratigraphic range of *Thalassinoides* sp. cf. *T. paradoxicus* was not determined. The trace fossil is present in the lower few beds of chalky limestone, probably even at the base of the Fort Hays (Pl. 8, fig. 9), but it is thought to be either absent or extremely rare in the upper two-thirds of the member. The burrows are apparently confined almost exclusively to beds of chalky limestone.

In British chalks *Thalassinoides paradoxicus* has been found only in association with minor erosion surfaces and sediments indicative of early lithification (Kennedy, 1967, p. 147-148). (These sedimentological conditions are related; see Bromley, 1967). It is thus noteworthy that *T.* sp. cf. *T. paradoxicus* is apparently most abundant in Unit 7 of the Fort Hays, which is characteristically cross-laminated and scoured (Pl. 1, fig. 2); furthermore, the place where the greatest concentration of these burrows was found in Unit 7 is located only a few hundred feet from a large channel also found in that Unit (Pl. 1, fig. 3). The circumstantial evidence implies that the organism preferred areas swept by moderately strong currents.

The abundance of closely spaced horizontal burrow systems shown in Plate 5, figure 5, may further represent readjustment of the original burrow network to fluctuating substrate levels. The top of the chalky limestone bed containing these burrows has been subjected to scour and fill (Pl. 1, fig. 2). If, as suggested by Bromley (1967, p. 162-163), the thalassinoid organism originally constructed its burrow system at a specific depth beneath the substrate surface, it possibly expanded the system to slightly lower or higher levels, depending on whether the substrate was being lowered or raised.

The apparent confinement of the trace fossil to the lower part of the Fort Hays suggests further that the organism may have preferred waters somewhat shallower than those present during maximum transgression of the Niobrara sea.

Because of their morphological distinctiveness and possible hydrographic implications, burrows of the *Thalassinoides paradoxicus* type show considerable promise as stratinomial guides.

THALASSINOIDES sp.

Figure 3,*E;* Plate 2, figure 1; Plate 6, figures 2-3, 9

The other Fort Hays thalassinoid observed is consistently small; it is more regularly branched than *Thalassinoides* sp. cf. *T. paradoxicus.* It consists essentially of a single network of dominantly horizontal burrows; vertical components are inconspicuous and may be absent. Burrow diameters range from 0.5 to 2.0 cm. and are somewhat variable within the same burrow system. Branching produces moderately large, planar polygons. Branches are typically Y-shaped but may also be nearly T-shaped, and are enlarged slightly at the point of bifurcation. Burrows may be straight or slightly to moderately curved. Most burrow systems are oriented nearly parallel to bedding, but some are inclined at very slight angles (Pl. 6, fig. 3). Knotlike enlargements of burrow shafts are seen but are not abundant. Burrow systems are commonly crowded together, and one burrow system may be superimposed upon another (Pl. 6, fig. 2). Except for a hint of surface ornamentation on the specimen shown in Plate 6, Figure 9, all specimens have smooth walls.

These burrow systems were everywhere found in thin chalky shales or shaly chalks separating much thicker beds of chalky limestone. The burrows are typically infilled with chalk, presumably from the overlying bed. Chalk-filled burrows usually retain considerable relief even though the shaly beds containing them have been compacted. Where infilled with mixtures of clay and chalk, the burrows have undergone considerable compaction.

The size and configuration of the burrows, especially vertical crowding of burrow systems and their apparent positioning at lithologic interfaces, make them very similar to *Thalassinoides* sp. Howard (1966, p. 48, fig. 14) from the Cretaceous of Utah. The Fort Hays specimens are also similar to *T. ornatus* Kennedy (1967, p. 141; pl. 6, fig. 4; pl. 7, fig. 6) from the Lower Chalk of England. *T. ornatus* differs chiefly in having its surfaces covered with small reticulate ridges, although poor preservation possibly obscures these structures in Fort Hays specimens. Very small thalassinoids such as those associated with *Thalassinoides* sp. Howard were not observed in the Fort Hays.

The lower stratigraphic limit of *Thalassinoides* sp. in the Fort Hays was not established. The burrows are most common in the upper one-half of the member and are found as high as the Fort Hays-Smoky Hill contact. *Thalassinoides* sp. conceivably replaces *Thalassinoides* sp. cf. *T. paradoxicus* stratigraphically upward in the section; no concrete evidence was found to indicate mutual exclusiveness, however, and *Thalassinoides* sp. possibly ranges into the lower beds of the Fort Hays.

Although thalassinoid-like pyrite nodules were reported by Bromley (1967, p. 168) from English chalk, pyrite was not found in association with either of the thalassinoids from the Fort Hays. In view of the abundance of other pyrite-lined or pyrite-filled burrows in these rocks, the walls of the original thalassinoid burrows were probably not reinforced with sufficient mucus or other organic substances to cause concentration of diagenetic sulfides. The walls were evidently not weak, however. No prediagenetic collapse features were observed and shell fragments were found commonly in the burrows, indicating that the walls remained intact during the period of time required for passive infilling by sediments.

Most ichnologists attribute *Thalassinoides* to the work of decapods. The branching pattern of horizontal burrow systems and the local enlargements found on burrow shafts are considered diagnostic. (See Fiege, 1944, p. 419-420.) Similar structures are excavated by Recent decapods, the enlargements being used by the animals to turn around inside the burrow; not all Recent decapods construct "turn arounds," however. The lack of scratch marks suggests that the organism plastered the burrow interiors with smooth sheets of mud or that the walls were worn smooth by contact with the organism's body. (See Bromley, 1967, p. 170-171.)

Bromley (1967, p. 172) and Kennedy (1967, p. 134-140) found anomuran fecal pellets associated with thalassinoid burrows in the Cretaceous of England, and the latter also found "mammillated" burrow surfaces apparently representing pellets of sediment such as those that *Callianassa major* presses into its burrow walls (Weimer & Hoyt, 1964, pl. 123, fig. 7).

The presence of actual decapod remains in thalassinoid burrows has also been reported (Kennedy, 1967, p. 132). Such associations are rare, however. Decapod body parts were not found in the Fort Hays, nor were they seen in the English chalks studied by Bromley (1967, p. 171-172) and Kennedy, (1967, p. 162). Both authors noted that dying callianassids ordinarily desert their burrows and that molts shed inside their burrows are later carried out. Furthermore, *Callianassa* apparently prefers areas having only slight sedimentation, and its exoskeleton, except for the claws used in burrowing, is thin and poorly calcified.

Two primary requisites for preservation—rapid burial and possession of hard parts—are therefore generally lacking. Under these conditions most callianassid remains are probably destroyed by scavengers. The claws are ordinarily better suited for preservation, but the thalassinoid animal of the Fort Hays, which burrowed only in soft muds, perhaps did not possess a strong, well-calcified claw. The relative abundance of well-preserved fish scales in this member indicates that strong chitinophosphatic skeletal parts were certainly capable of being preserved.

Recent members of the Thalassinidea occupy diverse habitats and are potentially valuable in paleoecological interpretations. The burrowing habits of most thalassinideans are poorly known, however, and the significance of the group as a whole is overshadowed by the relative abundance of data on intertidal or shallow-water forms. (See Bromley, 1967, p. 170-174.) Nevertheless, certain stratinomial tendencies seem to be evident.

The preference of callianassids for areas of negligible sedimentation has been noted previously. In sandy substrates, organic compounds and pellets of sediment are used to strengthen the burrow walls (e.g., see Weimer & Hoyt, 1964), whereas in fine muds the burrow walls are only rarely ornamented with pellets (e.g., see Kennedy, 1967, p. 134-140; Pearse, 1945). Walls of the latter type probably require less mucus for reinforcement (Schäfer, 1956, p. 216). Also, burrow systems excavated in sand may be less complex than those in mud (Doust, in Bromley, 1967, p. 179).

Genus TRICHICHNUS Frey, n. gen.

Type Species.—*Trichichnus linearis* Frey, n. sp.

Diagnosis.—Branched or unbranched, hairlike, cylindrical to sinuous burrows distinctly less than 1.0 mm. in diameter, oriented at various angles with respect to bedding. Burrow walls more or less distinct, commonly lined with diagenetic minerals.

Trichichnus (Gr., *trichos,* hair, and *ichnos,* footprint, track, or trail) is intended to include all very small, branched or unbranched, dominantly cylindrical or curvilinear burrows having walls that are at least moderately distinct both from adjacent sediment and the burrow filling. Distinctiveness of the burrow walls may be enhanced by organic linings, commonly altered to diagenetic sulfides. Burrows may be oriented at various angles with respect to the horizontal, but a given population may reflect a statistically preferred orientation. The trichichnid structure is taken to represent the feeding-dwelling burrow of a minute deposit-feeding (*not* sediment-ingesting) animal.

Structures of this kind are found frequently in marly and argillaceous sediments of various ages in Germany and are simply called *"Pyrit-Stengel"* (Walter Häntzschel, 1968, personal communication). A comparable informal designation, accompanied by concise description, might suffice for Niobrara specimens. On the other hand, the structures are distinct and widespread, and in the long run formal names are more convenient and less ambiguous than simple descriptive terms.

Among named trace fossils, *Trichichnus* is apt to be confused only with *Sabellarites* Dawson and *Montfortia* Lebesconte, although the burrows of both are larger in diameter than *Trichichnus.* In addition, *Sabellarites* consists of tortuous tubes having thick walls made of organically cemented detritus (Häntzschel, 1962, p. *W*215), and *Montfortia* (Lebesconte, 1886, p. 782-786, pl. 34, fig. 1-9) is more variable in size and may exhibit annulations; according to Seilacher (1956, p. 157), *Montfortia* is closely allied to *Planolites* Nicholson. *Trichichnus* is distinguished from the remainder of the mineral-filled burrows reported herein by its substantially smaller size and its considerably narrower range in morphologic variability and mode of preservation.

Trichichnus is abundant locally in the Fort Hays and in the lower few beds of the Smoky Hill. It is also present in the Greenhorn Limestone of Kansas (D. E. Hattin, 1968, personal communication). Because of pyritic and limonitic stains, the burrows are generally conspicuous in spite of their small size. The type species is the only form known among these rocks.

TRICHICHNUS LINEARIS Frey, n. sp.

Figure 4,*A;* Plate 6, figures 5-7

Diagnosis.—Rarely branched, dominantly vertical, threadlike, cylindrical trichichnid burrows having distinct walls, commonly lined with diagenetic minerals.

Remarks.—This threadlike, cylindrical burrow is typically straight or very slightly curved, hence its species name. Branching and pronounced irregularity in the burrow shaft are rare. The walls are distinct in most specimens and consist of chalky sediment that is incompletely replaced by pyrite or, rarely, by calcite. Much of the original pyrite has been altered to limonite. The burrow core may consist of the same materials, but it is more commonly somewhat hollow and drusy. Most of the burrows are about 10 mm. in length, although lengths up to 35 mm. were seen. Burrow diameters (in mm.) are indicated below.

Measurements of Trichichnus linearis *in millimeters*

Number	Range	Median	Mean	Mode	Standard Deviation
16	0.14	0.20	0.23	0.20	0.061

The burrows are typically vertical, but a few are either inclined to bedding or are horizontal. Vertical burrows are more or less circular in transverse section, whereas inclined or horizontal burrows are elliptical because of bedding compaction.

These burrows are scattered to locally abundant in numerous beds of chalk or chalky limestone in the Fort Hays; densities of 2 to 3 specimens per centimeter (horizontal transect) are common. However, they are also extremely rare in other beds of the same lithologies. None

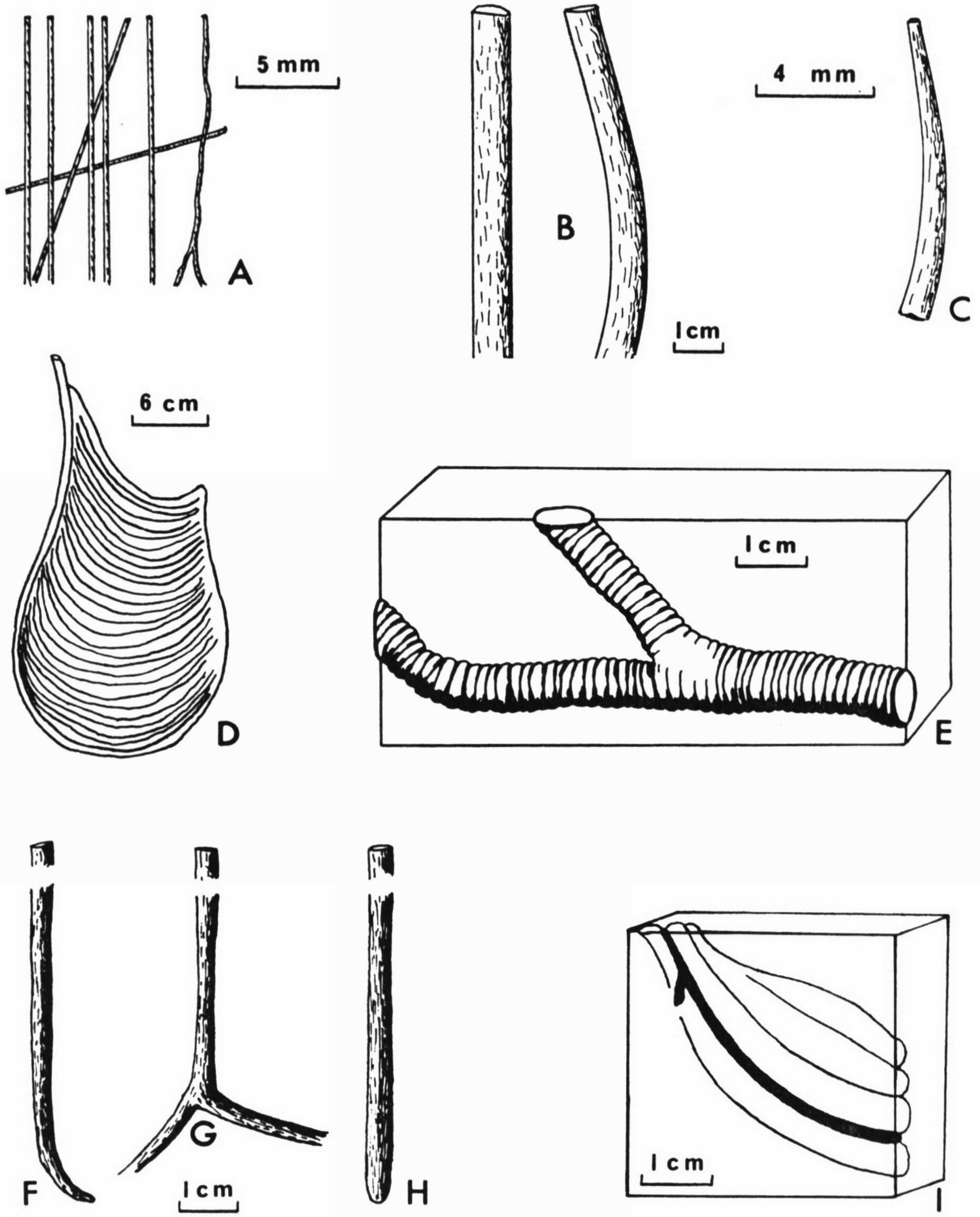

FIG. 4. Diagrammatic reconstructions of trace fossils from the Fort Hays Member.——*A*. *Trichichnus linearis*.——*B*. Cylindrical shafts. ——*C*. Scaphopod-shaped tube.——*D*. *Zoophycos* sp. A.——*E*. *Arthrophycus*-like burrow.——*F-H*. Mineral-filled burrows independent of other trace fossils. (*F* typical of calcite-filled burrows; *G* typical of pyrite- and limonite-filled burrows; *H* could be either).——*I*. Secondary mineral-filled burrow coursing along primary spreite burrows.

were found in shales. Some specimens penetrate other burrows, and the form is common in the *Arthrophycus*-like burrows at the Carlile-Niobrara contact.

Diagenetic minerals concentrated along the burrow walls suggest that the trichichnid organism lined or reinforced its burrow with an organic compound. This lining was evidently not of equal thickness or distribution because the minerals are patchily distributed in numerous specimens. The burrows were probably incompletely filled with sediment because of their small size; some of the burrow cores exhibit corrosion features, however, and part of the present porosity may be due to solution of the burrow filling. Most of the irregularities in burrow shafts probably may be attributed to the organism's attempt to avoid obstacles encountered while burrowing. The size and configuration of the burrow suggest that a minute vermiform or crustacean-like animal was responsible.

The holotype and paratypes are in the paleontological collections of the Indiana University Department of Geology. Specimen numbers are indicated in the captions for Plate 6, figures 5-7.

Genus ZOOPHYCOS Massalongo, 1855

[*Zoophycos* MASSALONGO, 1855, p. 48]

DIAGNOSIS.—Variously shaped spreiten structures comprised of numerous small, protrusive, more or less J-shaped burrows of variable length and orientation; spreiten may be tabular in shape or arranged in helicoid spirals. Part of spreite periphery delimited by last-formed burrows, which truncate distal ends of previously formed burrows. (Adapted from LESSERTISSEUR, 1955, p. 72-78; HÄNTZSCHEL, 1962, p. *W*220, and 1965, p. 98.)

This ichnogenus is plagued with excessive taxonomic splitting and contains numerous synonyms. (See HÄNTZSCHEL, 1962, p. *W*220, and 1965, p. 98; TAYLOR, 1967, p. 4-11.) One wonders, however, whether the flat, nonspiraled varieties of *Zoophycos* should be placed in synonymy with the various coiled forms. The two types reflect significant, if not basically distinct, ethological differences, and they also have different environmental implications. (See SEILACHER, 1964b, table 1.) TAYLOR (1967, p. 18-19) has suggested that the different forms be made separate species, and BISCHOFF (1968) has even suggested that the name *Zoophycos* be restricted to *Z. brianteus* (VILLA), the type species. Perhaps these differences could best be stressed, however, by invoking the taxonomic concept of subgenera; such taxonomies could thus indicate basic differences and overall similarities among the various taxa.

Zoophycos is common locally in the Fort Hays, especially in the upper part of the member, but is extremely difficult to identify and describe. Aside from the rarity of specimens in which individual burrows of the spreiten are weathered in relief, the major problem is that the spreiten structures rarely coincide with either a bedding surface or a vertical exposure. Both tabular and spiraled varieties are apparently present. Nearly complete spreiten of the former are seen occasionally on fractured rock surfaces, but spreiten of the latter are seen only in cross-sectional views. Incompletely exposed or poorly preserved vertical specimens are easily confused with *Teichichnus*.

ZOOPHYCOS sp. A

Figure 4,*D*; Plate 4, figure 5; Plate 7, figures 1, 3

This trace fossil morphologically duplicates the *Glossophycus* specimen illustrated by LESSERTISSEUR (1955, fig. 41,C). It consists of tabular spreiten 10 to 23 cm. in width; the ratio of height to width is typically about 7:5. A given spreite is straight to weakly curved in the long dimension, and the plane of the spreite is oriented at various angles with respect to bedding; most are steeply inclined, but some are nearly parallel with bedding (Pl. 4, fig. 5). The spreite consists of numerous, closely appressed, protrusive, broadly U- or J-shaped burrows 0.3 to 0.6 cm. in diameter. The burrows are generally concentric with respect to their radius of curvature, although in certain specimens they are irregular and truncate several previously formed burrows. The location of the proximal end of the radius of curvature shifts lateroventrally as successive burrows are constructed. The last-formed burrow extends downward along one edge of the spreite, truncating the distals ends of all proviously constructed burrows; the opposite side of the spreite is less distinct and is delimited by the irregularly inosculating proximal ends of individual burrows.

These structures are confined largely to beds of chalky limestone or chalk. They are most abundant in the upper part of the Fort Hays and possibly range into the lowermost part of the Smoky Hill. They were not identified positively in strata below Unit 19 and probably do not range below Unit 15. Because of difficulties in identifying particular spreiten in various cross-sectional views, population densities could not be determined. The species is thought to be considerably less abundant than *Teichichnus*, except in strata above Unit 47; here the abundance of *Zoophycos* sp. A increases, possibly in compensation for the decline of *Teichichnus* populations.

ZOOPHYCOS sp. B

Plate 7, figure 2

A low-spiraled variety of *Zoophycos*, probably somewhat like that illustrated by LESSERTISSEUR (1955, fig. 41,D) and HÄNTZSCHEL (1962, fig. 137,*2*), was also observed in the Fort Hays. Few details could be deciphered because the specimens are poorly preserved and were seen only in various cross-sectional views. No attempt was made to reconstruct the spreiten, many of which resemble the "gray bands" of *Zoophycos* in the *Schreibkreide* of Germany. (See VOIGT & HÄNTZSCHEL, 1956, pl. 15.)

Zoophycos sp. B probably ranges through most of the Fort Hays. It is abundant locally in the lower part of Unit 7.

The origin of *Zoophycos* remains open to interpretation (e.g., TAYLOR, 1967, p. 16-19). Although PLIČKA (1968) has argued that *Zoophycos* is an imprint of the prostomia of sabellid worms, specimens from the Fort Hays bear all attributes of a complicated feeding system. The same may be true even for the highly spiraled varieties (CHRISTOPH HEMLEBEN, 1968, personal communication). Most ichnologists attribute *Zoophycos* to the activities of a wormlike organism, and polychaetes have been suggested as the most likely group (BISCHOFF, 1968, and references cited therein). Certain Recent spreiten consist largely of fecal pellets (SEILACHER, 1967, pl. 1E).

Considerable environmental significance has been attached to this genus, especially regarding bathymetry. (See HÄNTZSCHEL, 1960, p. 98-99; SEILACHER, 1964b, fig. 7-8, table 1, and 1967.) In particular, the flat, non-spiraled varieties generally indicate waters below effective wave base down to bathyal depths, in areas free of turbidite sedimentation. Similar specimens are also found in shallow-water deposits, however (BANDEL, 1967, p. 9).

MISCELLANEOUS BURROWS

ARTHROPHYCUS-LIKE BURROWS

At the Carlile-Niobrara contact are several large, dominantly horizontal, chalk-filled burrows which cannot be identified easily (Pl. 7, fig. 7). They range in diameter from about 0.5 to 3.0 cm., most being between 0.8 and 1.0 cm. They consist essentially of simple cylindrical shafts but may also be branched. The latter may be enlarged at the point of bifurcation, as is commonly seen in arthropod burrows (FIEGE, 1944, p. 419-420). Vertical shafts are present in certain specimens (Pl. 8, fig. 9), and these burrows are probably *Thalassinoides* sp. cf. *T. paradoxicus*. Annulations suggestive of *Arthrophycus* HALL (HOWARD, 1966, fig. 6) are found on others, however (Pl. 7, fig. 8; Fig. 4,*E*), and are attributed tentatively to that genus. Where neither of these structural features are clearly seen, the burrows may also resemble such palaeophycids as *Palaeophycus arthrophycoides* WILCKENS (1947, pl. 9, fig. 3).

All of these structures apparently represent dominantly horizontal burrow systems that were passively filled with chalky sediment. In the Fort Hays these burrows are typically indistinct, but in the top of the Carlile Shale their color is in striking contrast with that of the dark shales or siltstones. Annulated specimens were not found above Unit 1. Total burrow density at the base of Unit 1 is tabulated below.

Measurements (mm.) of Arthrophycus-*like and Other Burrows at Carlile-Niobrara Contact*

LOCALITY	BURROWS PER METER	N	RANGE	MEAN	MEDIAN	MODE	STANDARD DEVIATION
2	40.3	16	26.5	8.5	7.5	-	6.5
1	23.4	20	7.0	7.0	7.0	6.5,7.5	2.0
4	36.4	10	22.5	9.5	9.0	-	6.5
3	40.2	27	14.5	6.5	5.0	1.5,9.5	5.0

At several places in Trego County the top of the Carlile Shale has been eroded to form small channels, which are filled with Fort Hays sediments (FREY, in preparation). The contact between these two types of sediment is extremely sharp, and burrows like those tabulated above are conspicuously absent from such places. The burrowing organisms evidently could not tolerate currents capable of scouring channel strutcures.

Pre-Niobrara burrows are also present in the Carlile, thus one must determine whether a particular specimen actually extends downward from the Fort Hays or is confined to the Carlile. The latter are frequently smaller in size, and many are vertically oriented *Skolithos*-like burrows. Most of the pre-Niobrara burrows in the uppermost part of the Carlile are hollow, probably because they were never completely filled with sediment.

Burrows near the top of a formation that contain sediment derived from the overlying formation are commonly cited as evidence for diastem or unconformity. This is suggested by the Carlile-Niobrara burrows and is supported by other evidence (FREY, in preparation).

SCAPHOPOD-SHAPED TUBES

Small *Dentalium*-shaped tubes (Pl. 8, fig. 1; Fig. 4,*C*) are abundant locally in the basal part of the Fort Hays. The tubes are oriented vertically, large-end-down. They range in maximum diameter from 0.6 to 1.3 mm., most being about 1 mm., and taper gradually to a comparatively much smaller upper end. The tubes rarely exceed a length of 16 mm.; most are about 10 mm. in length. Tube walls are distinct and consist of microcrystalline calcite. The tubes are infilled with chalky sediment; the cores are approximately one-half the outside diameter of the tube.

These tubes were found only in Units 1 and 3. At Loc. 1 the tubes are locally very abundant in Unit 1, but ordinarily they are scattered to rare.

The configuration of the tubes suggests that they might have been formed by a deposit-feeding polychaete such as *Pectinaria* (GORDON, 1966, fig. 1). The tubes constructed by this polychaete consist mostly of detrital particles and function as a veritable exoskeleton; the worm moves bodily through the substrate but feeds with the larger end of the tube facing downward.

MECHANICALLY FILLED BURROWS

Several large burrows in the Fort Hays are filled with mechanically derived shell fragments (Pl. 8, fig. 2-3). These burrows are typically 2.5 to 4.5 cm. in diameter and are 9 to 10 cm. in length. They are subcylindrical, straight to weakly curved, and inclined at angles of 45 to 55 degrees to bedding. The burrow walls are irregular and ordinarily are indistinguishable from surrounding sediment.

None of the coarse material found in the burrows represents a lining; the structures simply acted as sediment traps and were passively filled with shell debris and other detritus. Except where tabular fragments are stacked up (Pl. 8, fig. 2), the shell debris is oriented more or less randomly. The shell fragments, most of which are pieces of *Inoceramus* valves, are usually much smaller than the diameter of the burrow in which they are found. Pore spaces among the fragments are filled in with chalky sediment, and in some burrows the quantity of fragmentary material is diluted by considerable amounts of such sediment.

These burrows were found only in Units 6 through 9, and the specimens invariably extended upward from a thin shaly unit into the lower part of an overlying chalky limestone bed (e.g., Pl. 8, fig. 2). Such burrows are rare, although it is probable that in many instances they were filled with chalky sediment instead of shell debris and are now indistinguishable from the adjacent rock. The greatest population density, 3 burrows per meter (horizontal transect), was found locally at the base of Unit 7, Loc. 5.

The size and orientation of the burrows suggest a possible decapod or octopod origin, but no supporting evidence was discovered.

CYLINDRICAL SHAFTS

Cylindrical burrows generally resembling the genus *"Cylindrichnus,"* as conceived by Toots (1962, p. 64-65), are scattered through the Fort Hays (Pl. 7, fig. 4-6; Fig. 4,*B*).

This structure is typically a simple, vertical or steeply inclined burrow which may lack distinct, smooth walls. In many specimens the material constituting the burrow wall grades into the surrounding sediment, and it may also be indistinguishable from the sediment infilling the burrow. Burrow dimensions are somewhat variable within the same specimen, which may be straight, gently curved, or slightly undulatory. The burrow core is rarely distinct, unless replaced by diagenetic sulfides (Pl. 7, fig. 5), and the core is only slightly smaller in diameter than the burrow itself. The burrows range in diameter from 0.4 to 1.0 cm., and some are at least 40 cm. in length.

The abundance and distribution of this burrow type in the Fort Hays is similar to that of *Asterosoma* form *"Cylindrichnus concentricus,"* although the two are not necessarily found together. Indeed, certain of the cylindrical shafts seem to represent *"Cylindrichnus concentricus"* specimens in which wall layering was not formed or is not preserved; such burrows are thus equivalent to the "rod-shaped burrows" of Howard (1966, p. 50-51, fig. 17), which are a form of *Asterosoma* (J. D. Howard, 1969, personal communication). Branching specimens were not observed in the Fort Hays, however.

Some of the Fort Hays specimens might also be attributed to *Skolithos, Tigillites,* or *Monocraterion,* but assigning burrows to these genera is often excessively interpretative (see Hallam & Swett, 1966; Boyd, 1966, p. 52). Furthermore, Fort Hays burrows are not closely crowded, not annulated, and not associated with funnels of the *Tigillites* or *Monocraterion* type.

MINERAL-FILLED BURROWS

Mineral-filled burrows and burrows having mineral-replaced walls, or both, are among the most conspicuous and abundant trace fossils in the Fort Hays. Such burrows range throughout the member, and some are found in the lower part of the Smoky Hill. They are abundant locally and are seldom absent from a given stratum.

The burrows are partly to entirely replaced by pyrite, limonite, calcite, or mixtures of these minerals. Chalky sediment is commonly present in the burrow cores. The minerals and sediment may be found in almost every possible combination: 1) burrows and burrow casts consisting of nearly pure calcite, pyrite, limonite, or various mixtures of these; 2) pyrite or limonite tubes having cores of calcite, chalky sediment, or mixtures of these; and 3) calcite tubes having cores of pyrite, limonite, chalky sediment, or mixtures of these. In spite of the complete gradation between the burrows, however, the intermediate forms are considerably less abundant than the "end members" of relatively pure pyrite, limonite, and calcite.

The range in configuration of the burrows is almost equally variable, yet most fall within one of four major groups: 1) mineral replacement of the burrows of trace fossils described previously (e.g., Pl. 3, fig. 1-2, 6; Pl. 6, fig. 5-7, 9; Pl. 7, fig. 5; Pl. 8, fig. 1), 2) mineral-filled burrows independent of other trace fossils, 3) feeding burrows penetrating and coursing along other trace fossils, and 4) burrows associated with pelecypod valves. The following discussion is concerned with only the last three categories.

MINERAL-FILLED BURROWS INDEPENDENT OF OTHER TRACE FOSSILS

This category consists of a heterogeneous suite of burrows and is taxonomically, if not ethologically, artificial. Part of this artificiality is eliminated by the erection of two subgroups, based upon burrow preservation and configuration. The boundary between the subgroups is perhaps not as distinct as the following descriptions would imply, however, and a few Fort Hays specimens could fit into either subgroup.

Calcite-filled Burrows.—These burrows (Pl. 8, fig. 4-5; Fig. 4,*F,H*) consist typically of microcrystalline calcite tubes that are filled with fine-to medium-crystalline spar. The cylindrical tubes may be incompletely filled, in which case the core consists of drusy calcite or mixtures of this and chalky sediment. Only rarely are the tubes completely filled with chalk. Pyrite or limonite may be found in either the tube walls or the core, but these minerals are not common. The tube walls are ordinarily distinct but may be slightly gradational with the chalky sediment surrounding or infilling the tube. Although the tubes may be weakly sinuous, most are nearly straight; among curved tubes, the curved part is found typically near the base (Pl. 8, fig. 4), producing a J-shaped tube. Branching tubes were not observed. Practically all specimens are oriented vertically. Tube dimensions are slightly variable within a single specimen, although this variation is generally negligible. The tube diameters rarely exceed 0.6 cm. and most tubes are 0.2 to 0.3 cm. in diameter. Maximum length was not established; a few incomplete specimens are more than 30 cm. long.

Such tubes apparently represent more or less permanent burrows that were passively filled with sediment. The burrow walls were evidently strong; in spite of the many drusy, incompletely filled burrows, none of them exhibit collapse features. The slight sinuosity observed in certain specimens is possibly the result of compaction of beds. The composition of the organic substance reinforcing the walls must have been unsuited for the concentration of diagenetic sulfides; although pyrite- or limonite-filled burrows may be found in association with the calcite-filled ones, the latter rarely contain appreciable quantities of pyrite or limonite. The organism possibly lined its burrow with relatively large quantities of carbonate mud and cemented it in place with comparatively minor amounts of mucus; diagenetic alteration of such structures would be largely a matter of carbonate recrystallization.

The calcite-filled burrows are scattered throughout the Fort Hays and are found locally as high as Unit 62 (Smoky Hill). They are seldom found in abundance, however, and are absent in numerous beds, particularly shales. The greatest population density, 18 burrows per meter (horizontal transect), was found in Unit 45, Loc. 3.

The overall configuration and composition of the burrows suggests that they might have been constructed by a polychaete such as *Clymenella*. Species of this worm occupy cylindrical, straight to broadly J-shaped, sandy tubes (Pl. 8, fig. 6); the worms feed at the lower end of the structure, and the length and orientation of the tube is somewhat correlative with the distance between the sediment-water interface and some subsurface layer containing abundant organic debris. The composition of the inorganic part of the tube depends largely upon the kind of detritus available in the organism's habitat; quartzose sand is used along the southeastern Atlantic coast but carbonate grains are used in the Florida Keys and Caribbean. (See Mangum, 1962, 1964.)

This burrow form generally resembles *"Cylindrichnus"* (Howard, 1966), *Tigillites* Rouault, and *Skolithos* Haldeman (Howell, 1943a, p. 6-12, 14), but it has a distinct wall, is neither annulated nor associated with tigillited funnels, and is nowhere extremely closely crowded. If one concedes that *Skolithos* need not be restricted to burrows in sandstones, then this name most nearly applies to most of the vertical calcite-filled burrows of the Fort Hays. Tubes like those shown in Plate 8, figure 4, also resemble such serpulids as *Longitubus lineatus* (Howell, 1943b, pl. 20, fig. 9-21) but are not of skeletal origin; transverse striations or growth lines were not detected in Fort Hays specimens.

Pyrite- and Limonite-filled Burrows.—In many respects these burrows (Pl. 3, fig. 5; Pl. 6, fig. 4; Pl. 8, fig. 7, 10-11; Fig. 4,*G,H*) are similar to those described above, but the pyrite- and limonite-filled burrows are generally more abundant, have a wider range in size and orientation, and may be branched. In shaly zones they are almost invariably horizontal, whereas in beds of chalk or chalky limestone they may be oriented at various angles; even in chalky beds, however, groups of burrows tend to be either vertical or horizontal, not randomly inclined. Most of the burrows are simple cylindrical structures, but a few are markedly irregular (Pl. 8, fig. 7) and certain specimens are branched (Pl. 8, fig. 11). Burrows up to 22 cm. in length were found, although most seem to be much shorter; the burrows are seen typically as small fragments (Pl. 6, fig. 4) left clinging to weathered rock surfaces. They range in diameter from less than 0.1 cm. to about 0.7 cm.; unlike the calcite-filled burrows, the diameters of the pyrite- and limonite-filled burrows are multimodal. In shale beds the horizontal burrows are generally about 0.1 cm. in diameter, whereas in chalky limestones they are typically 0.1 to 0.3 cm. in diameter. Vertical or inclined burrows range in diameter from 0.1 cm. up to about 0.7 cm., but most are between 0.1 and 0.4 cm. Burrow dimensions in each category tend to be more or less constant within a given stratum. The walls of the burrows consist typically of pyrite, limonite, or mixtures of them. Most of the pyrite is finely crystalline, although cubes up to about 1 mm. across were observed. Limonite pseudomorphs after these pyrite cubes were not seen, but all other gradations between the pyrite- and limonite-filled burrows are represented. A crudely concentric wall layering is found in some of the burrows, although this structure seems to be a chemical diffusion phenomenon related chiefly to the postdiagenetic conversion of pyrite to limonite. The burrow core may also consist of these minerals, or the tubes may be infilled with chalky sediment or mixtures of calcite and chalk. The walls of some burrows contain appreciable quantities of calcite.

The pyrite- and limonite-filled burrows are found throughout the Fort Hays and range locally as high as Unit 63 (which is the highest range recorded for burrow forms among the rocks studied). They are abundant in numerous beds and are absent from very few units. A density of 37 burrows per meter (horizontal transect) was found locally in Unit 13, Loc. 1, but the burrows are ordinarily considerably less numerous.

These burrows very probably do not represent a single ethological group. Most of the smaller pyrite- and limonite-filled burrows resemble *Montfortia* Lebsconte (1886, pl. 34, fig. 1-9) to some extent. All are substantially larger than *Trichichnus.* Some of the larger burrows are similar in configuration to the calcite-filled burrows described above and should perhaps be interpreted similarly. A few resemble *Phytopsis* HALL (HÄNTZSCHEL, 1962, p. *W*210), while others are more irregular and nondescript. The burrows having concentrically layered walls resemble *Asterosoma* form *"Cylindrichnus concentricus,"* yet this layering is in most instances produced by physiochemical changes in burrow composition.

FEEDING BURROWS PENETRATING OTHER TRACE FOSSILS

The burrows of this group (Pl. 8, fig. 8, 12; Pl. 9, fig. 7; Fig. 4,*I*) consist largely of pyrite, limonite, or mixtures of these minerals, and they vary considerably in length and orientation. The chief trait unifying the group is the obvious preference of the burrowing organisms for feeding within previously constructed (primary) burrows. Specimens were found almost exclusively within the burrows of sediment-ingesting organisms, particularly in spreiten structures, and the secondary burrows are generally in structural continuity with the primary burrows (Pl. 8, fig. 12). None of the secondary burrows were found in permanent dwelling burrows such as *Thalassinoides.* The secondary burrows range in diameter from 0.1 to 0.4 cm., most being between 0.2 and 0.3 cm. in diameter. The length and orientation of the burrow is generally related intimately to the length and orientation of the primary burrow; rare specimens exceed a length of 24 cm. The burrows have distinct outer walls, and most are solidly infilled with pyrite or limonite; the burrow cores in such structures are typically indistinguishable from the burrow walls. A few burrows are largely chalk-filled but contain various amounts of finely disseminated pyrite or limonite; the walls of some burrows are distinct but very thin, and the core is conspicuous. Bulbous to irregular enlargements are seen on some specimens (Pl. 8, fig. 8).

Organisms which choose to feed in or along the burrows of other organisms generally do so because 1) the primary burrower produces zones of weakness in the sediment, which facilitate locomotion and feeding among the secondary burrowers, or 2) the primary burrower secretes or defecates nutrient-rich materials, upon which the secondary burrower feeds. Although the Fort Hays organisms possibly benefitted from structural weaknesses in the substrate produced by primary burrowers, the substrate probably was not sufficiently rigid that feeding movements in other directions would have been deterred. This, in addition to the typical association of secondary burrows with the primary ones of sediment-ingesting, rather than suspension-feeding organisms, suggests that the secondary organisms were coprophagous.

The organisms either lined their burrows with large quantities of mucus that later helped concentrate diagenetic sulfides, or extruded organic-rich sediment castings which reacted similarly. The local burrow enlargements perhaps represent places where the organisms turned around within the burrows or attempted to branch off from it.

These burrows are scattered throughout the Fort Hays but are seldom abundant; they seem to be most common in the middle part of the member. In places where the primary burrows are not well preserved, the secondary ones are easily mistaken for the pyrite- and limonite-filled burrows described above.

BURROWS AND TUBES ASSOCIATED WITH PELECYPOD VALVES

Chalk- and mineral-filled tubular structures which lie in contact with the inner surfaces of inoceramid valves are seen commonly in the Fort Hays (Pl. 8, fig. 13-14). Most of the chalk-filled structures seem to be associated with *Inoceramus* only because the pelecypod shell blocked the path of the burrowing organism and it followed the shell surface until it found the edge and escaped (Pl. 8, fig. 13). This may also be true of some of the mineral-filled structures. Most of the latter, however, seem to be restricted to the valve surface and do not reflect obvious attempts by the organisms to leave the shell. The burrow structures consist typically of pyrite or limonite. They may be either simple cylindrical tubes or irregularly branching structures, and may be straight over a considerable part of their length or markedly sinuous throughout. They rarely exceed 0.4 cm. in diameter, and most are less than 0.2 cm. They may be solidly infilled with pyrite or limonite, or the core may consist of chalky sediment. Calcite is not generally present. Although a few of these structures are recessed into the pelecypod valves (Pl. 9, fig. 1), most such specimens reflect obvious replacement of the valve by diagenetic pyrite, not the activity of boring organisms.

Pelecypod valves apparently served as a rigid substrate to which the vermiform organisms could attach their dwelling tubes. The tubes are rarely found on the exterior of the valves, possibly because the organisms could not compete with the profusion of oysters which encrusted the living pelecypods. Once the pelecypod died and the valves were turned concave upward, the smooth interior surface became available for occupation by the wormlike organisms. The pelecypod valves must have been quickly filled in by shifting sediments, else this fresh surface would also have been exploited by the oysters or other epizoans. The tube occupant was thus probably tolerant of burial by sediment and was not strictly a suspension-feeding organism. Such an organism has a relatively close analog in the Recent detritus-feeding polychaete *Clymenella mucosa,* which ordinarily constructs a vertical sandy tube in detrital substrates but which may also attach its tube to the interior of a disarticulated pelecypod valve (Pl. 9, fig. 2).

Except for Units 1 through 4, these tubular structures are abundant locally through the Fort Hays and the lower few beds of the Smoky Hill. Their absence or extreme rarity in the basal and upper-middle parts of the Fort Hays is explained by the dearth of inoceramid valves in these beds.

OTHER BURROWS

Certain burrows that are abundant in Unit 9 (Pl. 6, fig. 8) resemble ?*Spongeliomorpha annulata* KENNEDY (1967, pl. 2, fig. 1) from the Lower Chalk of England, and rare ovoid structures in the lower-middle part of the Fort Hays (Pl. 9, fig. 7) resemble *Rosselia* DAHMER (HÄNTZSCHEL, 1962, fig. 131,*2a*). Adequate documentation is lacking in both instances, however, and the resemblances may be superficial. Other distinctive-looking trace fossils apparently defy any sort of identification (e. g., Pl. 10, fig. 5).

Although HATTIN (1965, p. 20) reported several large burrows bearing arthropod-like claw marks, reinvestigation of these structures by HATTIN and me revealed that they are actually the remains of rodent runways. Such structures are easily mistaken for *Thalassinoides.*

HATTIN (1965, p. 20) also reported numerous burrow structures that are completely backfilled with cuplike increments of chalky sediment. In most such instances, however, the structures are actually cross-sectional views of *Teichichnus* or *Zoophycos* spreiten; in transverse view the individual burrows comprising the spreiten resemble nested chevrons.

ENVIRONMENTAL IMPLICATIONS AND PALEOECOLOGY

REGIONAL-TEMPORAL SETTING

The Niobrara transgressive hemicycle represents one of the most widespread of Cretaceous marine transgressions (COBBAN & REESIDE, 1952, p. 1025; REESIDE, 1957, p. 525-528). Waters of this epiric sea covered practically all of the Western Interior Region of Canada and the United States and were probably connected with the Arctic Ocean as well as with the Gulf of Mexico. The influence of both of these faunal realms is reflected in mollusk assemblages of the Western Interior. Macroinvertebrate fossils are generally more abundant and diverse in the southern and western parts of this area, suggesting that environmental conditions were more favorable there.

KAUFFMAN (1967, p. 82-90, fig. 1-3) defined 12 lithotypes in the central part of the Western Interior of the United States, representing as many phases of deposition in each hemicycle. Siliceous sands of Phase 1 mark the beginning and end of a cycle, and carbonate muds of Phase 12 generally indicate maximum transgression. The rocks that I studied in Kansas apparently reflect KAUFFMAN's transgressive phases 10 through 12. The "sandy massive limestone" of Phase 10 is represented by the basal bed of the Fort Hays, which contains detritus reworked from the underlying Carlile Shale, and the "massive, relatively pure limestone" of Phase 11 and the "chalk and highly chalky limestone" of Phase 12 are represented by most of the Fort Hays and parts of the Smoky Hill. Fort Hays sediments were thus deposited during the latter part of the transgression and at a considerable distance from shore (REESIDE, 1957, fig. 14), although not necessarily at great depth.

Advent of the Niobrara cyclothem in Kansas is obscured by the unconformity at the base of the Fort Hays (Table 1). According to HATTIN (1962, 1964, 1965), the sea floor in Kansas probably lay above wave base during the early and middle parts of the Niobrara transgressive hemicycle. Then the sea floor was returned below wave base and began to receive Fort Hays sediments. The shore line was far removed by this time so that very little terrigenous detritus reached Kansas.

DIVERSITY AND ABUNDANCE OF TRACE FOSSILS

A minimum of approximately 13 different kinds of burrowing organisms were evidently present during Fort Hays deposition: those which produced forms of *Asterosoma, Chondrites, Laevicyclus, Planolites, Teichichnus, Thalassinoides, Trichichnus, Zoophycos,* cylindrical shafts, mechanically filled burrows, various mineral-filled or mineral-replaced burrows (including both feeding and dwelling structures), and the *Arthrophycus*-like burrows. If the several species and varieties recorded represent true taxonomic and not merely ethologic and preservational differences, then about 19 kinds of organisms reworked the carbonate muds.[1] The actual number is probably intermediate between these two extremes. Most of the organisms belonged to the same general endobenthonic community, although the community structure changed gradually during Fort Hays deposition (Fig. 5).

Of these organisms, at least six actively ingested sediment and produced feeding burrows (Table 3). *Teichichnus* sp. probably also belongs to this group, although SEILACHER (1957, p. 203-204) concluded that certain teichichnians are the result of burrow-maintenance activities, not feeding. At least nine, and possibly 12, organisms constructed more or less permanent dwelling burrows (Table 3). The origin of *Laevicyclus* sp. remains somewhat unclear, and *Trichichnus linearis* possibly represents a combined feeding-dwelling burrow such as that of the tiny polychaete *Heteromastus filiformis* (SCHÄFER, 1962, fig. 159). The scaphopod-shaped tubes perhaps represent an agglutinated detrital test.

The abundance of individual species and ethologic variants has been discussed above, under "systematic descriptions." Line transects were also used to obtain data on total burrow densities within given strata. Paradoxically, the total abundance of individuals is difficult to estimate because of both the characteristically poor preservation of most burrows and the extreme profusion

[1] Certain poorly documented burrows have been omitted from this discussion.

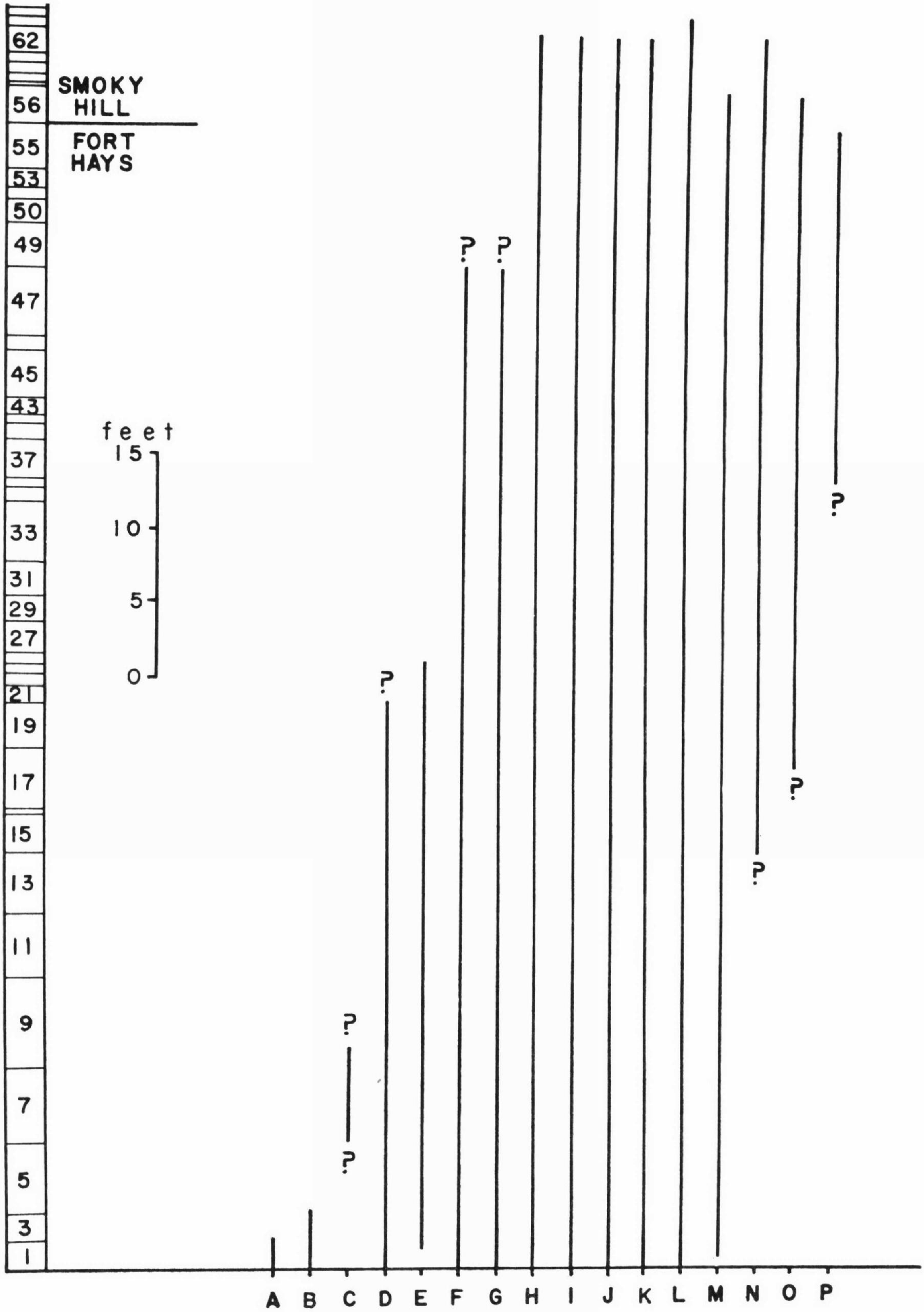

FIG. 5. (*See* explanation on facing page.)

TABLE 3.—*Functional Classification of Trace Fossils from the Fort Hays Member in West-Central Kansas.*

BURROW FORM	ETHOLOGICAL FUNCTION* FEEDING BURROWS (FODINICHNIA)	DWELLING STRUCTURES (DOMICHNIA)
Asterosoma form "*Cylindrichnus concentricus*"		X
Asterosoma form "helicoid funnel"	X	
Chondrites sp.	X	
Laevicyclus sp.		?X
Planolites sp.	X	
Teichichnus sp.	?X	
Thalassinoides sp. cf. *T. paradoxicus*		X
Thalassinoides sp.		X
Trichichnus linearis		?X
Zoophycos sp. A	X	
Zoophycos sp. B	X	
Cylindrical shafts		X
Mechanically filled burrows		X
Calcite-filled burrows independent of other trace fossils		X
Pyrite- and limonite-filled burrows independent of other trace fossils		X
Mineral-filled burrows penetrating other trace fossils	X	
Burrows and tubes associated with pelecypod valves		X
Arthrophycus-like burrows		X
Scaphopod-shaped tubes		?X

* Resting traces (cubichnia), crawling traces (repichnia), and grazing traces (pascichnia) are not preserved in the Fort Hays of west-central Kansas. (The ethological functions are those defined by SEILACHER, 1953b, p. 432-434, fig. 6.)

of burrows found on the better exposures. On most surfaces of chalk or chalky limestone that exhibit distinct structures, the burrows appear to be more or less isolated (e.g., Pl. 5, fig. 3). Closer examination usually shows that these burrows are set in a matrix of older burrows. Very fresh rock exposures that have reacted slightly with the chemicals of running water reveal complex bioturbate textures in which the activities of at least three, and possibly four, generations of burrowers are represented (Pl. 10, fig. 1). The various generations are detected through color differences and cross-cutting relationships. Successively older burrows are successively less obvious, and the oldest set is represented only by an obscure, bioturbated background. This oldest set is not ordinarily seen even in moderately well-preserved specimens (Pl. 9, fig. 4), and the younger sets thus appear to be more distinct. Only the last-formed set is seen consistently in moderately weathered exposures (Pl. 5, fig. 1).

Chalk-filled burrows in shaly chalk (Pl. 10, fig. 2), or chalky shale (Pl. 9, fig. 9), unlike those in chalk or chalky limestone, are rarely more abundant than they appear to be upon first examination. Two generations of burrowers are evident in a few places, but most specimens show only a single set of burrows.

Another difficulty is that the preponderance of burrows in the Fort Hays and Smoky Hill have been altered to some degree by the compaction of beds. Vertical mineral-filled burrows ordinarily remain more or less straight and cylindrical but horizontal ones may be slightly to strongly flattened. Individual burrows of spreiten structures are preserved locally as tabular bodies only 2 or 3 mm. thick, whereas they were apparently as much as 10 mm. in diameter originally. In shaly chalks and chalky shales many of the horizontal chalk-filled burrows have been flattened to form small lenslike bodies (Pl. 9, fig. 6), and the inclined burrows have become shorter and irregularly zigzagged (Pl. 10, fig. 3).

Line transect methods for showing burrow dimensions and intensity of burrowing must therefore be used with caution in the Fort Hays. Although 94 transects were run in this member and the lower few feet of the Smoky Hill, most of the data remains subjective rather than quantitative.

Nevertheless, certain broad trends in burrow abundance and distribution were documented qualitatively. The lower one-half to two-thirds of the Fort Hays is generally more intensely burrowed than the upper part, and burrow densities within individual bedding units (Appendix 2) are more nearly uniform from one locality to another. Fewer generations of burrowers are generally detectable in the upper part of the Fort Hays and lower few feet of the Smoky Hill, and the total intensity of burrowing has a much wider range in beds of this interval. These trends are probably related to the gradual change in community structure noted previously.

In addition, the data from a few of the line transects (Table 4) are judged to be essentially accurate. These transects were made mostly on beds of shaly chalk and chalky shale, where bioturbation is ordinarily less intense than in beds of chalk or chalky limestone. Data used in comparing different strata or localities were recorded in places where the rocks were weathered to practically the same stage at each locality.

The greatest density of measurable burrows observed in the four major lithotypes (Table 2) is tabulated below (p. 30). These data probably reflect more or less maximum burrowing intensity in beds of chalky shale and shaly chalk because only one or two generations of burrows are generally involved. Burrows in most beds of chalk and chalky limestone, however, are decidedly more abundant than indicated above (cf. Pl. 10, fig. 1). Representative burrow densities among other beds of chalky shale and shaly chalk are indicated in Table 4D-E.

FIG. 5. Stratigraphic ranges of trace fossils from the Fort Hays and basal Smoky Hill Members in Trego County, Kansas. Bedding thicknesses based upon measurements at Loc. 1. Note the abrupt termination of burrows at the top of Unit 62.——*A. Arthrophycus*-like burrows.——*B.* Scaphopod-shaped tubes.——*C.* Mechanically filled burrows.——*D. Thalassinoides* sp. cf. *T. paradoxicus*.——*E. Laevicyclus* sp.——*F. Asterosoma* form "*Cylindrichnus concentricus*."——*G.* Cylindrical shafts.——*H. Asterosoma* form "helicoid funnel" Type A. ——*I. Chondrites* sp. ——*J. Planolites* sp.——*K. Trichichnus linearis*.——*L.* Mineral-filled burrows.——*M. Teichichnus* sp.——*N. Zoophycos* sp. A.——*O. Thalassinoides* sp.——*P. Asterosoma* form "helicoid fuunel" Type B.

Greatest Density of Measurable Burrows in Major Lithotypes

UNIT	LOC.	LITHOLOGY	BURROWS PER METER	PERCENT OF TRANSECT OCCUPIED BY BURROWS	MEAN SIZE (mm.)	MEDIAN SIZE (mm.)	STANDARD DEVIATION
62	3	chalk	115.5	35.7	3.0	2.0	3.0
7	6	chalky limestone	111.4*	40.8	3.5	3.0	2.5
36	3	shaly chalk	68.5	26.1	4.0	3.0	4.0
48	3	chalky shale	78.1	22.7	3.0	1.5	4.0

* This figure is exceeded by data from Unit 3, Loc. 1 (Table 4B) and from Unit 9, Loc. 3 and 1A (Table 4C), but in these places the bed of chalky limestone contains zones of laminated chalk and is therefore not exactly typical of chalky limestone.

Burrow densities within particular stratigraphic intervals are ordinarily very similar from place to place in Trego County (Table 4A), apparently reflecting widespread similarity of environmental parameters during each phase of deposition. The slight differences in burrow density from one locality to another are probably not especially significant. Two separate transects were run in each of several different strata at Loc. 1, for example (the second transect was designated "1A"), and these data suggest that burrow size and density vary almost as much locally as they do between localities (e.g., Table 4C).

Variations in burrow configuration are much more pronounced vertically in the section than laterally along given stratigraphic horizons. In addition to the gradual decline in overall burrow density toward the top of the Fort Hays mentioned previously, two periodic types of vertical variation were observed. One is the difference between burrow density in beds of chalk or chalky limestone and the intervening bed of shaly chalk or chalky shale (Table 4B). The other is a typical succession from comparatively sparse burrows in the middle part of a bed of chalk or chalky limestone (Pl. 3, fig. 4) to more abundant burrows in the upper part of the same bed (Table 4C). The significance of these two variations is discussed below.

Size data presented in Table 4 are generally less meaningful than density data because of stratigraphic variations in degree of bedding compaction. The standard deviation is nevertheless a good indicator of local size diversity, and the difference in burrow size observed between middle and upper parts of the same stratum (e.g., Table 4C) remains significant.

One can only speculate as to why distinct "generations" of burrowers are discernible in the Fort Hays. Ordinarily one might expect a continuum in which a given population of burrowers would grade almost imperceptibly into the next. A possible explanation is that the various generations represent the seasonal settling of larvae; there is good evidence for seasonal spatfall of oysters in the Fort Hays (Frey, in preparation).

COMPARISON BETWEEN TRACE FOSSILS AND BODY FOSSILS

The abundance and diversity of trace fossils in the Fort Hays are in striking contrast with abundance and diversity of contemporaneous body fossils, practically all of which are epibenthic or planktonic. In the basal bed of the member, for example, I found at least 12 kinds of trace fossils (Fig. 5) and a maximum density of 97.5 burrows per meter (Table 4B), whereas the same bed contained only 3 macroinvertebrate species, all pelecypods: the gryphioid *Pycnodonte aucella,* having a maximum density of 4.5 specimens per square meter (vertical quadrat), and rare fragments of the oysterid *P. congesta* and the pterioid *Inoceramus* sp. cf. *I. erectus.* In the interval between the lower part of Unit 5 and Unit 35 trace fossils are equally abundant and diverse; macroinvertebrates consist almost entirely of *I. deformis,* having densities of 0 to 4 valves per square meter (vertical quadrat); *P. congesta,* abundantly to profusely encrusting the valves of *I. deformis;* and rare specimens of the worm *Serpula,* also encrusting *I. deformis.* Between Units 35 and 54 trace fossils are generally less abundant but are by no means rare, yet macroinvertebrates of any kind are difficult to find. In Unit 55 through the lower few feet of the Smoky Hill Member *I. (Volviceramus) grandis, I. platinus,* and *P. congesta* are moderately common but are still subordinate to the ichnofauna. These distributions suggest that the sea floor was less hostile to benthos than is implied by macroinvertebrate fossils but that mobile or hemisessile endobenthos were favored over sessile epibenthos.

Paradoxically, the situation is reversed in most of the Smoky Hill. *Inoceramus (Volviceramus) grandis, I. platinus,* and *Pycnodonte congesta* range well above the strata that I measured (Appendix 2), yet the upward range of most trace fossils terminates abruptly at Unit 62; a few extend into Unit 63. During this part of Niobrara deposition sessile epibenthos were favored over the endobenthos. As suggested below, this probably reflects poor oxygenation of sediments relative to the overlying water.

SEDIMENTATION

The chalks and chalky limestones of the Fort Hays are literally riddled with interpenetrating burrows, but the shaly chalks and chalky shales contain more distinct, relatively sparse burrows. As noted by Middlemiss (1960), burrows of the first type indicate slow deposition, whereas the latter indicate rapid deposition. These conclusions must be tempered by a consideration of initial population density, but they undoubtedly hold in general.

The nearly pure carbonate muds of the Fort Hays evidently accumulated very slowly and were thoroughly reworked by different generations of burrowers (Pl. 10, fig. 1). This sediment was diluted periodically by influx

TABLE 4.—*Line-Transect Data for Size and Density of Chalk-Filled Burrows.*

[Burrows were measured to the nearest 0.5 mm. The localities—Loc.—are arranged from west to east ((see Fig. 1). Units are described in Appendix 2.]

A.—*Similarity of Burrows Along Given Stratigraphic Horizons*

UNIT	LOC.	BURROWS PER METER	N	RANGE	MEAN	MEDIAN	MODE	STANDARD DEVIATION
17 (upper 0.6 ft.)	3	32.8	14	7.0	5.0	5.0	5.5	2.0
	1	34.4	21	10.0	4.0	4.0	4.5	3.0
9 (middle part)	3	41.0	35	30.5	6.0	3.0	2.0	8.0
	6	54.3	24	8.0	4.5	4.0	4.0	2.0
	1	47.9	19	10.0	4.5	4.0	3.0	3.0
	2	54.6	35	9.5	4.5	4.5	-	2.5
8 (middle part)	3	26.2	16	21.0	5.0	3.0	2.5	5.0
	1	32.8	20	10.5	4.5	4.0	2.5	2.5
	2	34.9	16	8.0	4.5	4.0	-	3.0
7 (lower 0.6 ft.)	3	28.3	38	7.0	3.5	4.0	4.0	2.0
	6	35.9	23	7.5	6.0	5.0	4.5	2.0
	1	24.6	18	15.0	6.0	5.0	7.0	4.0
	2	38.5	17	8.0	5.0	5.0	-	2.5
2 (middle part)	3	12.7	12	8.0	6.0	6.5	-	3.0
	1	12.6	10	10.5	5.5	4.5	-	1.0

B.—*Variation in Burrows Among Different Stratigraphic Horizons: Different Lithotypes*

UNIT*	LOC.	BURROWS PER METER	N	RANGE	MEAN	MEDIAN	MODE	STANDARD DEVIATION
31 (lower 0.7 ft.)	3	61.5	30	21.0	4.5	3.0	2.5	4.0
30 (middle part)	3	23.0	14	4.0	2.0	1.5	1.5	1.0
29 (upper 0.4 ft.)	3	72.7	20	8.0	3.5	3.0	2.0	2.0
9 (lower 0.2 ft.)	3	34.2	17	13.5	7.0	6.5	6.5	3.5
8 (middle part)	3	26.2	16	21.0	5.0	3.0	2.5	5.0
7 (upper 0.3 ft.)	3	34.4	21	8.0	4.5	4.0	5.0	2.5
3 (lower 0.2 ft.)	1	131.1	32	10.0	1.5	1.5	1.5	2.0
2 (middle part)	1	12.6	10	10.5	5.5	4.5	-	1.0
1 (upper 0.6 ft.)	1	97.5	58	20.0	2.5	1.5	1.5	3.5

* Transition from upper part of a bed of chalky limestone, through a thin bed of chalky shale, to lower part of the overlying bed of chalky limestone.

C.—*Variation in Burrows Among Different Stratigraphic Horizons: Single Lithotype*

UNIT	LOC.	BURROWS PER METER	N	RANGE	MEAN	MEDIAN	MODE	STANDARD DEVIATION
62 (upper part)	3	115.5	44	16.0	3.0	2.0	1.5	3.0
62 (middle part)	3	82.0	35	15.0	5.0	2.5	2.0	4.0
45 (upper part)	3	72.1	33	15.0	5.0	4.5	1.5	3.5
45 (middle part)	3	44.9	24	11.5	5.0	4.0	3.0	3.0
9 (upper part)*	3	150.0	48	10.0	2.5	1.5	1.5	2.0
9 (lower part)**	3	41.0	35	30.5	6.0	3.0	2.0	8.0
9 (upper part)*	1	109.1	30	7.5	2.0	1.5	1.5	1.5
9 (lower part)**	1	47.9	19	10.0	4.5	4.0	3.0	3.0
9 (upper part)*	1A	131.1	32	10.0	2.0	1.5	1.5	2.0
9 (lower part)**	1A	43.7	24	7.0	4.5	4.5	5.5	2.0

* Refers to upper part of a slightly shaly zone 0.25 to 0.35 foot thick, 3.05 to 3.1 feet above the base of Unit 9.

** Refers to lower part of the shaly zone described in the preceding footnote (e.g., Pl. 2, fig. 6).

D.—*Burrows in Shaly Chalk*

UNIT*	LOC.	BURROWS PER METER	N	RANGE	MEAN	MEDIAN	MODE	STANDARD DEVIATION
61	1	59.0	18	4.5	2.5	2.0	0.5	1.5
46	3	24.6	15	9.5	4.0	3.0	3.0	3.0
36	3	68.5	23	18.5	4.0	3.0	2.5	4.0

* Transects were run near the middle part of each unit.

E.—*Burrows in Chalky Shale*

UNIT*	LOC.	BURROWS PER METER	N	RANGE	MEAN	MEDIAN	MODE	STANDARD DEVIATION
48	3	78.1	31	23.5	3.0	1.5	1.5	4.0
42	1	39.3	18	15.0	3.0	1.5	0.5	4.0
30	3	23.0	14	4.0	2.0	1.5	1.5	1.0
26	3	20.5	10	7.5	6.0	5.5	6.5	2.5
12	3	1.8	2	0.5	5.5	-	-	-
10	3	6.6	2	2.0	3.5	-	-	-
8	3	26.2	16	21.0	5.0	3.0	2.5	5.0
8	1	32.8	20	10.5	4.5	4.0	2.5	2.5
8	2	34.9	16	8.0	4.5	4.0	-	3.0
2	3	12.7	12	8.0	6.0	6.5	-	3.0
2	1	12.6	10	10.5	5.5	4.5	-	1.0

* Transects were run near the middle part of each unit.

of terrigenous constituents which increased the rate of sedimentation and decreased the amount of time available for reworking of sediment by a given population of burrowers (Pl. 9, fig. 9; Pl. 10, fig. 2, 3). In consequence, bedding features and sedimentary structures were largely obliterated in the chalky sediments but were partially preserved in sediments containing large quantities of terrigenous detritus.

Changes from slow to rapid deposition were typically gradational (Pl. 5, fig. 3), but they were evidently abrupt in some instances. Occasionally the rate of sedimentation was also variable within a given sedimentologic regimen; in the middle part of Unit 9, for example, a thick interval of heavily bioturbated, nearly pure chalky limestone is interrupted gradationally by a thin layer of somewhat less intensely bioturbated, slightly impure chalk (Pl. 2, fig. 6). The deposition of chalky sediment on rare occasions was sufficiently rapid that vestigial bedding features were preserved (Pl. 5, fig. 3), and the terrigenous clays sometimes accumulated so rapidly that burrowers had very little time to rework the sediment (Pl. 9, fig. 5).

Terrigenous constituents are generally more abundant in the Smoky Hill, and burrow densities are correspondingly decreased. The upward range of chalk-filled burrows terminates abruptly at Unit 62, however, and the rarity or absence of burrows through most of the member must be explained by ecologic parameters other than the rate of deposition. As suggested by HATTIN (1965, p. 21), this is probably a reflection of poor oxygenation.

SEILACHER (1964b, p. 303) has noted that abundant trace fossils are good evidence against highly euxinic conditions in the depositional environment. Burrowing organisms in themselves do not necessarily preclude black, organic-rich sediments; but most animals in such sediments are hemisessile, building shallow burrows which communicate with the sediment-water interface, and they derive oxygen largely from the overlying water rather than from the substrate (FREY, 1970b). The key to trace fossils as indicators of sediment aeration is thus the proportion of traces made by highly vagile organisms, especially those which obtain nutrients through the ingestion of sediments. Such organisms actively rework and thus help oxygenate the enclosing sediments. Organisms of this kind were abundant to profuse locally in Fort Hays sediments (producing such structures as *Asterosoma, Planolites,* and *Zoophycos*), and indicate that these sediments were well aerated. (The abundance of filter-feeders or surficial deposit-feeders in the Fort Hays indicates that the waters were also well oxygenated, although this argument is hardly necessary; the sediments obviously could not have become oxygenated if the overlying water had not first been well aerated.) The dearth of such burrows above the lower few feet of the Smoky Hill in west-central Kansas suggests, on the other hand, that these deposits were poorly oxygenated.

Although the Fort Hays presently contains less organic matter than the Smoky Hill (MILLER, 1968, Appendix A), the water and the carbonate muds of the Fort Hays must have been high in organic content initially, else the dense populations of sediment-ingesting and suspension- or detrital-feeding organisms would not have been sustained. (In addition to trace-making organisms, epibenthos such as oysters and inoceramid clams were abundant locally.) The present ratio of organic matter in the Fort Hays and Smoky Hill is probably related to the relative abundance of benthonic organisms in the two members; fewer organisms were present in equivalent thicknesses of Smoky Hill sediment, thus smaller quantities of organic detritus were removed by feeding. Organic residues capable of concentrating diagenetic sulfides are therefore represented in the Fort Hays mostly by pyrite- and limonite-replaced organic burrow linings and in the Smoky Hill by abundant pyrite and limonite nodules.

As evidenced by the compaction of beds and the deformation of burrows (e.g., Pl. 9, fig. 6; Pl. 10, fig. 3) and other sedimentary structures, the carbonate sediments of the Fort Hays originally contained substantial quantities of interstitial water. The initial water content of the sediments undoubtedly affected the activities of the burrowing organisms, particularly with regard to ease of feeding and burrowing, and it possibly also influenced the animals' population structures. According to HARRISON & WASS (1965), the abundance and distribution of benthonic organisms in an otherwise homogeneous environment may be governed by substrate water. On the other hand, RHOADS & YOUNG (1970) judge that the abundance of endobenthic organisms may govern the distribution of substrate water. The activities of abundant endobionts in the Fort Hays may thus have increased the porosity and incoherence of sediments.

This watery, incoherent sediment was apparently responsible for the nonpreservation of tracks and trails in the rocks studied. For example, the trackway *Crossopodia* M'COY has been found in every formation of the Colorado Group other than the Niobrara Chalk (HATTIN & FREY, 1969), and there is no reason to believe that the *Crossopodia* organism was not also present in the Niobrara depositional environment. The sediment was evidently too soupy to support definite imprints, with the rare exception of *Laevicyclus* circlets—and these are common only in the basal two beds of the Fort Hays.

No evidence is found in the Fort Hays for chalk hardgrounds such as those reported in Europe (BROMLEY, 1967; VOIGT, 1959). In addition to the features discussed above, the profusion of irregularly interpenetrating burrows (Pl. 10, fig. 1), deep feeding burrows (e.g., Pl. 2, fig. 7), and burrows which skirt obstructions in the substrate (Pl. 9, fig. 3), indicate that the sediment remained incoherent for long periods of time and that the organisms burrowed to considerable depth. In contrast with hardground burrows, none of the Fort Hays or Smoky Hill habitation burrows seem to have been reoccupied by subsequent organisms; where two burrowing organisms are definitely associated (in space, if not in time), the relationship is almost invariably represented by the more ephemeral burrows of sediment-ingesting organisms (e.g., Fig. 4,*1*), not by permanent dwelling burrows. Furthermore, unlike hardground dwelling burrows (BROMLEY, 1967, pl. 7a), none of the Fort Hays dwelling burrows are preserved as true cavities in the rock.

DEPTH OF BURROWING

In consequence of the slow rate of deposition in the Fort Hays, particular burrow types are commonly concentrated along certain stratigraphic levels. Where well exposed in thick beds of chalky limestone, the irregular biodeformational structures reflect only a crude zonation of burrow types (Pl. 10, fig. 1), but if the last-formed set of burrows is distinct, the zones are seen to grade upward from an area containing larger, comparatively sparse burrows to an area having smaller, more abundant burrows (Pl. 3, fig. 4; Pl. 5, fig. 3). This apparently reflects preferred depths of burrowing by particular organisms; the larger burrowers moved and fed farther below the sediment-water interface than did the smaller ones. Because the substrate surface remained at nearly the same stratigraphic level for long periods of time, the respective depth zones became thoroughly mottled with burrows. Preferred depths of burrowing below this datum are also apparent in numerous specimens of *Teichichnus* sp. (Pl. 4, fig. 1), *Asterosoma* form "helicoid funnel" (Pl. 2, fig. 6; Pl. 3, fig. 3), and other burrows (Pl. 9, fig. 8).

Deep vertical burrows are abundant locally in the Fort Hays (e.g., Pl. 3, fig. 1, 2; Pl. 4, fig. 1; Pl. 5, fig. 6-7; Pl. 7, fig. 4-6; Pl. 8, fig. 4, 7). Such burrows are generally most common in intertidal and nearshore environments (Seilacher, 1964b, p. 313; Rhoads, 1967, p. 475), yet the chalky sediments of the Fort Hays were deposited near the height of the Niobrara marine transgression in an area that was far removed from the nearest shoreline (Reeside, 1957, fig. 14). Burrows that are fundamentally short may be preserved as long, vertical burrows when sedimentation is rapid; the organisms extend their burrows upward in order to maintain a standard position relative to the sediment-water interface (Goldring, 1964, fig. 1). Fort Hays sediments accumulated too slowly for this, however, and except in the vicinity of scour-and-fill structures, none of the burrows reflect the organisms' attempts to maintain position with respect to shifting substrate levels. In littoral and shallow sublittoral environments, deep vertical burrows generally reflect adaptations by organisms to exploit currents (Seilacher, 1967) and to cope with environmental extremes (Rhoads, 1966, p. 21). Neither explanation fully accounts for the presence of such burrows in the Fort Hays, although currents were present and the waters were relatively shallow during parts of Fort Hays deposition (as discussed below). More likely, the deep vertical burrows of the Fort Hays were constructed as a means of combatting unstable substrates (e.g., Frey, 1970a). Animals which construct such burrows may be viewed in a sense as the pioneer species of a community; they are able to exploit soft, yielding sediments—whether in shallow or deep waters—and their durable lebensspuren help stabilize the substrate so that other kinds of animals may then move in.

CURRENTS

Inorganic sedimentary structures are probably the best indicators of currents in the Fort Hays depositional environment (e.g., Pl. 1, fig. 2-3), but biogenic sedimentary structures also reflect their occurrence. Mechanically filled burrows (Pl. 8, fig. 2-3) show that currents capable of transporting coarse shell debris were present at least during earlier episodes of Fort Hays deposition. These burrows are apparently rare, yet, as suggested previously, many such structures may have been filled largely with chalky sediment where shell debris was not available and are thus indistinguishable now from the adjacent rock.

The most widespread ichnological evidence for currents is found along very thin shale partings in chalky limestones, where burrows have obviously been truncated by substrate scour (Pl. 10, fig. 4). On very fresh exposures of rock the shale partings are seen to consist of thin laminae and cross laminae. The partings are present at numerous stratigraphic levels in the Fort Hays, and burrow populations above and below most of the thin scour zones are practically identical; the currents thus are inferred to have been periodic and brief, not significantly disrupting the activities of burrowing organisms. Most such scour zones may be traced laterally throughout Trego County (Frey, in preparation), attesting to the remarkably widespread occurrence of given currents.

The presence of currents is also suggested by the proportion of dwelling burrows to feeding burrows, which imply occupancy by suspension-feeding and deposit-feeding organisms, respectively. As noted by Purdy (1964) and Seilacher (1967), suspension-feeding organisms depend upon suspended organic matter for food, which requires at least a certain amount of turbulence, whereas deposit-feeding organisms depend upon deposited organic matter, which reflects relatively quiet waters. The dominance of dwelling structures in the Fort Hays (Table 3) indicates that the waters were somewhat turbulent, but the presence of numerous feeding burrows shows that the agitation was not ordinarily very strong. The currents were probably intermittent.

Seilacher (1953a, fig. 6) has shown that in the face of persistent currents certain organisms orient themselves in order to enhance the efficiency of their feeding mechanisms. Such explanation possibly accounts for the parallel alignment of certain *Teichichnus* spreiten in the Fort Hays (Pl. 4, fig. 1), although this explanation implies that the teichichnian organism was probably a suspension-feeder, not a sediment-ingestor.

Currents capable of cutting local channels and scour-and-fill structures, transporting coarse shell debris, scouring the substrate over broad areas, and keeping organic matter in suspension were probably also capable of circulating the sea water so that it became well oxygenated. Current indicators, both inorganic and biogenic, are most abundant in the lower one-half to two-thirds of the Fort Hays (Frey, in preparation); their prominence declines in the upper part of the member, and they are rare or absent in the lower part of the Smoky Hill. This distribution suggests that current strength and persistence decreased with successive intervals of time during Niobrara deposition, and it implies that successively later sediments were successively less aerated.

BATHYMETRY

Sediments reworked from the Carlile Shale into the basal bed of the Fort Hays suggest the influence of a fluctuating wave base and, consequently, that initial Niobrara sediments were deposited in very shallow water. The water evidently deepened then so that wave base remained well above the sediment-water interface [the thin but widespread scour zones in the Fort Hays (Pl. 10, fig. 4) are probably the result of minor turbidity flows (Frey, in preparation) rather than periodic lowerings of effective wave base]. Nevertheless, although strong currents have been observed at great depths in Recent oceans (Shepard, 1963, p. 97-100), small, well-defined channels and scour structures such as those in the Fort Hays (Pl. 1, fig. 2-3) suggest moderately shallow waters. These structures become progressively less abundant stratigraphically upward in the member, perhaps correlative with gradual deepening of the waters during Fort Hays deposition; this is suggested also by the trace fossils.

Seilacher (1963, fig. 2; 1964b, fig. 7-8, table 1; 1967, fig. 2) established a relative scale for the bathymetric zonation of characteristic trace fossils, called "facies." He concluded that these "facies" are related chiefly to gradients in food supply, which, in turn, partly reflects the intensity of wave and current activity in the depositional environment. Seilacher's facies (1967, fig. 2) correspond in a very general way with the marine benthonic environments reiterated by Ager (1963, fig. 2.3), as tabulated below; with continued refinement of this relative scale, depth estimates should eventually become more quantitative, although the paleobathymetric significance of a given trace fossil is rarely inequivocal.

Paleobathymetric Estimation

Ichnological "Facies"	Benthonic Environment
Scoyenia facies	(non-marine)
Skolithos facies *Glossifungites* facies	littoral
Cruziana facies	infralittoral and circalittoral
Zoophycos facies	circalittoral and bathyal
Nereites facies	bathyal and abyssal

Most of the trace fossils of the Fort Hays may be referred to the *Cruziana* facies. The more diagnostic forms include *Thalassinoides, Teichichnus,* and the *Arthrophycus*-like burrows (Seilacher, 1964b, fig. 7, table 1). *Laevicyclus* is probably also indicative of moderately shallow water (Farrow, 1966, p. 123, 125; Henbest, 1960; Kemper, 1968), and *"Cylindrichnus concentricus"* and "helicoid funnels" from the Cretaceous of Utah (Howard, 1966) were found in shallow-water deposits. Flat, nonspiraled varieties of *Zoophycos* are generally indicative of greater water depth (i.e., the *Zoophycos* facies), although such forms are also found in the *Cruziana* facies (Bandel, 1967, p. 9). *Chondrites* and *Planolites* are facies-crossing types that may be found in numerous environments; the latter are found even in the *Scoyenia* facies (Seilacher, 1963, fig. 1).

In spite of numerous long-ranging forms (Fig. 5), certain trace fossils are characteristic of particular parts of the Fort Hays. Especially noteworthy is the apparent restriction of the *Arthrophycus*-like burrows to the base of the member and *Laevicyclus* and *Thalassinoides* sp. cf. *T. paradoxicus* to the lower part of the member, whereas *Zoophycos* sp. A was observed only in approximately the upper one-half of the member. Furthermore, in the upper few feet of the member the abundance of *Teichichnus* decreases as that of *Zoophycos* sp. A increases. These distributions suggest that at the onset of Fort Hays deposition the water was relatively shallow (below wave base but within the inner or middle part of the *Cruziana* facies) and that by the inception of Smoky Hill deposition the water had deepened perceptibly (to the outer part of the *Cruziana* facies or the inner part of the *Zoophycos* facies). This increase in depth was apparently regular and gradual because distinct bathymetric zonation, such as that found by Farrow (1966, fig. 11) in the Jurassic of Great Britain, is not conspicuous in the Fort Hays (Fig. 5).

Evidence from body fossils (Frey, in preparation) generally substantiates the paleobathymetric implications of the ichnofauna.

SUMMARY

Trace fossils are abundant and diverse in the Fort Hays Limestone Member of the Niobrara Chalk (Upper Cretaceous) in west-central Kansas, although most specimens are poorly preserved, and tedious study is required for classification and interpretation of them. Distinctive, named trace fossils include *Asterosoma* form *"Cylindrichnus concentricus," Asterosoma* form "helicoid funnel" (two types), *Chondrites* sp., *Laevicyclus* sp., *Planolites* sp., *Teichichnus* sp., *Thalassinoides* sp. cf. *T. paradoxicus, Thalassinoides* sp., *Trichichnus linearis* (Frey, n. gen., n. sp.), *Zoophycos* sp. A, and *Zoophycos* sp. B. Trace fossils that could not be identified with certainty or which do not require formal names include *Arthrophycus*-like burrows, scaphopod-shaped tubes, mechanically filled burrows, cylindrical shafts, calcite-, limonite-, and pyrite-filled tubular burrows, feeding burrows that course along other burrows, and burrows and tubes associated with pelecypod valves. Tracks, trails, and resting traces were not observed.

Most of these trace fossils are restricted to, or are much more abundant in, thick beds of chalk or chalky limestone. Burrows are much less common in beds of shaly chalk, and only *Planolites* sp. and certain pyrite- and limonite-filled burrows are found consistently in beds of

chalky shale. *Laevicyclus* sp., *Thalassinoides* sp., and mechanically filled burrows are found typically at lithologic interfaces between chalky limestone and chalky shale.

Fresh exposures of chalky limestone commonly reveal complex bioturbate textures in which different episodes of burrowing are conspicuous; linear density of burrows is difficult or impossible to establish among such strata. Bioturbation is considerably less intense in beds of shaly chalk and chalky shale, where burrow densities of 20 to 40 specimens per meter (horizontal transect) are typical.

Burrow densities along discrete stratigraphic levels are uniform from place to place in Trego County, Kansas, especially in the lower two-thirds of the Fort Hays; burrows are generally less abundant in the upper part of the Member,[1] and here the density of burrows is more variable laterally. In addition, certain ichnogenera are characteristic of particular parts of the Fort Hays; for example, *Laevicyclus* sp., *Thalassinoides* sp. cf. *T. paradoxicus,* and the *Arthrophycus*-like burrows were observed only in the lower part of the member and *Zoophycos* sp. A only in the upper part.

On a smaller scale, crude stratigraphic zonation of burrow types is found commonly within thick beds of chalk or chalky limestone; the zones grade upward from an area containing large, relatively sparse burrows (e.g., *Planolites* sp., *Asterosoma* form "helicoid funnel") to an area having smaller, more abundant burrows (e.g., *Chondrites* sp.).

At numerous stratigraphic levels, thin scour zones that truncate burrow structures may be traced laterally for tens of miles.

Several kinds of chalk- and mineral-filled burrows found in the Fort Hays range into the lower part of the overlying Smoky Hill Chalk Member of the Niobrara. Burrows within this stratigraphic interval are ordinarily less abundant and diverse than those in the Fort Hays, and in west-central Kansas their upward range terminates abruptly at a bed of chalk about 6 feet above the Fort Hays-Smoky Hill contact. Higher in the section biogenic sedimentary structures and current influenced inorganic sedimentary structures are rare.

[1] This generality applies less to beds of chalky shale than to the other lithotypes because abundance of *Planolites*, the dominant trace fossil in chalky shales, does not change markedly through the section.

CONCLUSIONS

1) Of the 19 or 20 taxonomic and ethologic varieties of trace fossils documented in the Fort Hays and lower Smoky Hill, 6 or 7 evidently represent feeding activity and 9 to 12 represent excavation of habitation structures. The total assemblage reflects a diverse community of burrowing organisms, most members of which were generally equally important. Diversity and abundance within this community far exceeds that within contemporaneous epibenthic communities (composed chiefly of pycnodontid oysters and inoceramid clams), suggesting that:

- a) conditions in the depositional environment were more favorable to mobile organisms than to sessile epibenthos, and
- b) the overall environment was less hostile than is indicated by the low diversity of preserved tests and shells.

2) Complex bioturbate textures and profuse interpenetrating burrows in chalky limestones indicate that sediments of this type were deposited very slowly and were thoroughly reworked by successive generations of burrowing organisms. Burrows are less common in beds of chalk and are much less common in beds of shaly chalk and chalky shale (which contain proportionately larger quantities of terrigenous silt and clay), suggesting increased rates of deposition and reduction in the amount of time available for sediment reworking by a given population of burrowing organisms.

3) Compactional deformation of burrows and dearth of surficial biogenic sedimentary structures suggest that most Fort Hays sediments were soft and watery. The abundance of irregularly penetrating burrows, deep feeding burrows, and burrows which avoid obstacles in the substrate indicate that the sediment remained soft until late in diagenesis (the slowly accumulating sediment being reworked to considerable depth by different generations of burrowers).

4) The abundance of burrows made by sediment-ingesting organisms indicates that the sediments contained considerable quantities of organic detritus but that the feeding activities of the organisms helped keep the sediments well oxygenated.

5) Currents of low to intermediate strength were present during Fort Hays deposition, as evidenced by channel structures, mechanically filled burrows, very thin scour zones which truncate burrows, and abundance of habitation burrows. Such currents probably kept the waters well circulated, thus enhancing the oxygenation of sediments.

6) The absence of trace fossils diagnostic of the *Skolithos* or *Glossifungites* facies indicate that the Fort Hays depositional environment was decidedly subtidal, although terrigenous detritus reworked from the Carlile Shale suggests that, initially, sediments of the Niobrara were influenced by wave base. Most members of the ichnofauna may be referred to the *Cruziana* facies, suggesting offshore waters of shallow to intermediate depth. The vertical succession of characteristic trace fossils implies that the waters deepened gradually during Fort Hays deposition, possibly to depths reflected by the *Zoophycos* facies.

7) Each phase of Fort Hays deposition was remarkably uniform over broad geographic areas, as evidenced by laterally persistent strata and by similarities in burrow configuration and density within strata traced from one locality to another. Environmental parameters associated with these phases changed gradually with time, however, as shown by the vertical succession of burrows and by the decline in a) total burrow density, b) diversity of burrow types, and c) abundance of current-type inorganic sedimentary structures, in the upper part of the Fort Hays. These trends persisted until early in Smoky Hill deposition.

8) Phases of deposition represented by the lower 50 feet of the Smoky Hill in west-central Kansas were also uniform over widespread areas. Paucity of trace fossils and scour-and-fill structures in this stratigraphic interval nevertheless indicates a major change in the overall depositional environment. Part of this change is evidently explained by poor circulation of waters and poor aeration of sediments, possibly correlative with increasing depth of water.

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APPENDIX 1.—LOCALITIES EXAMINED

1. Numerous discontinuous, stratigraphically incomplete exposures of Fort Hays Member along small intermittent stream, E½ E½ sec. 8, W edge sec. 9, and mutual corner secs. 9, 8, 16, and 17, T 15 S, R 23 W, Trego Co., Kansas. Offsets yield complete section.
2. Vertical, nearly complete exposure of Fort Hays Member on south shore Cedar Bluff Reservoir, S½ NE¼ sec. 6, T 15 S, R 22 W, Trego Co., Kansas. Upper few feet of section missing.
3. Continuous, stratigraphically incomplete exposures of Fort Hays Member along north side Smoky Hill River and west side Hackberry Creek, SW¼ sec. 24 and NW¼ sec. 25, T 14 S, R 25 W, Trego Co., Kansas. Offsets yield complete section.
4. Roadcut directly north of Smoky Hill River, NW¼ NW¼ sec. 29, T 14 S, R 24 W, Trego Co., Kansas. Lower few feet of Fort Hays Member.
5. Roadcut at south end of dam, Cedar Bluff Reservoir, SE¼ NW¼ sec. 1, T 15 S, R 22 W, Trego Co., Kansas. Lower few feet of Fort Hays Member.
6. Continuous, stratigraphically incomplete exposures of Fort Hays Member along east side Sand Creek, E½ sec. 13 and NE ¼ sec. 24, T 15 S, R 24 W, Trego Co., Kansas. Thick but incomplete section.
7. Bluffs along Smoky Hill River, NW¼ NW¼ sec. 32, T 14 S, R 25 W, and SW¼ sec. 6, T 15 S, R 25 W, Trego Co. and east border Gove Co., Kansas. Upper part of Fort Hays Member.
8. Roadcut along U.S. Highway 183, approximately one mile north of Saline River, secs. 10 and 3, T 11 S, R 18 W, Ellis Co., Kansas. Complete section of Fort Hays Member.
9. Bluffs along intermittent stream(s), NW¼ sec. 3, E½ sec. 4, and NE¼ sec. 9, T 11 S, R 20 W, Ellis Co. and south border Rooks Co., Kansas. Offsets yield complete section of Fort Hays Member.

APPENDIX 2.—MEASURED SECTIONS

The following tabulations show the bedding units established for the Fort Hays and lowermost Smoky Hill in Trego County, Kansas (Fig. 1-2). Beds less than 1.0 foot thick were measured to the nearest 0.01 foot; thicker beds were measured to the nearest 0.05 foot. (The thickness of several very thin beds remains virtually constant through distances exceeding 20 miles.) Detailed descriptions of these beds are being published in another report (Frey, in preparation).

The upper part of the exposure at Loc. 2 was not accessible at the time of measurement and was measured indirectly.

Units 64 and 66 are the twin bentonites at the base of the "Group A" beds of the Smoky Hill established by Bass (1926, p. 19-23); they have been used by certain workers as the contact between the Fort Hays and the Smoky Hill (Runnels & Dubins, 1949, p. 6-7). In Trego County the lithologic transition from chalky limestones of the Fort Hays to chalks and shaly chalks of the Smoky Hill is abrupt and conspicuous, and I have drawn the contact at this point (between Units 55 and 56).

		Thickness (ft.)		
		Locality	Locality	Locality
Unit	Lithotypes	3	1	2
	SMOKY HILL CHALK MEMBER, NIOBRARA CHALK			
*	chalk and shaly chalk	47.7	17.2	—
66	bentonite	0.02	0.02	—
65	shaly chalk	0.42	0.41	—
64	bentonite	0.05	0.05	—
63	shaly chalk	0.64	0.59	—
62	chalk	1.35	1.35	—
61	shaly chalk	0.32	0.24	—
60	chalk	0.72	0.67	—
59	shaly chalk	0.67	0.55	—
58	chalk and shaly chalk	0.72	0.64	—
57	chalky shale and shaly chalk	0.40	0.52	—
56	chalk	*1.95*	*2.20*	—
	Thickness of exposed part of Smoky Hill Chalk Member:	55.0	24.45	—
	FORT HAYS LIMESTONE MEMBER, NIOBRARA CHALK			
55	chalky limestone	2.60	2.95	—
54	chalky shale	0.10	0.08	—
53	chalk and chalky limestone	1.00	1.35	....
52	chalk and shaly chalk	0.74	0.70	↑
51	bentonite and bentonitic shale	0.05	0.06	|
50	chalky limestone	1.45	1.60	10.8
49	chalky limestone	2.95	2.85	|
48	chalky shale	0.07	0.07	↓
47	chalky limestone	4.60	5.05	....
46	chalk and shaly chalk	0.43	0.42	0.43
45	chalky limestone	2.90	3.00	2.90
44	chalky shale	0.15	0.11	0.12
43	chalky limestone	1.10	1.15	1.35
42	shaly chalk and chalky shale	0.05	0.09	0.09
41	chalk and shaly chalk	0.40	0.34	0.34
40	chalky shale	0.08	0.09	0.09
39	chalky limestone	1.10	1.10	1.10
38	chalky shale	0.10	0.11	0.12
37	chalky limestone	2.65	2.75	2.80
36	chalk and shaly chalk	0.32	0.52	0.50
35	chalky limestone	0.68	0.72	0.64
34	chalky shale	0.18	0.28	0.21
33	chalky limestone	3.85	3.75	3.65
32	chalky shale	0.08	0.12	0.11
31	chalky limestone	2.05	2.20	1.95
30	chalky shale	0.09	0.12	0.12
29	chalky limestone	1.75	1.60	1.60
28	chalky shale	0.09	0.11	0.09
27	chalky limestone	2.25	2.25	2.35
26	chalky shale and shaly chalk	0.58	0.61	0.32
25	chalk and shaly chalk	0.32	0.45	0.51
24	shaly chalk and chalky shale	0.14	0.18	0.12
23	chalky limestone	0.70	0.88	0.74
22	shaly chalk and chalky shale	0.07	0.05	0.07
21	chalky limestone	0.95	1.05	0.89
20	shaly chalk and chalky shale	0.11	0.09	0.07
19	chalky limestone	2.75	3.00	2.80
18	chalky shale	0.10	0.11	0.11
17	chalky limestone and shaly chalk	4.45	4.15	3.90
16	chalk and shaly chalk	0.32	0.30	0.25
15	chalky limestone	2.35	2.50	2.05
14	chalky shale	0.09	0.08	0.08
13	chalky limestone	3.75	4.00	3.90
12	chalky shale	0.09	0.12	0.09
11	chalky limestone	4.35	4.35	4.15
10	chalky shale	0.23	0.17	0.26

9	chalky limestone	5.30	6.00	5.25
8	chalky shale and shaly chalk	0.06	0.10	0.10
7	chalky limestone	4.35	4.90	4.70
6	shaly chalk and chalky shale	0.06	0.05	0.05
5	chalky limestone	4.35	4.85	4.55
4	chalky shale	0.11	0.19	0.16
3	chalky limestone	1.60	1.80	1.50
2	chalky shale	0.07	0.06	0.03
1	chalky limestone	*1.85*	*2.15*	*1.70*
Thickness of Fort Hays Limestone Member:		72.95	77.75	>69.7
Thickness of exposed part of Niobrara Chalk:		128.0	102.2	>69.7

CODELL SANDSTONE MEMBER, CARLILE SHALE

*	sandy shale and shaly sand	0.0	0.85	0.90

BLUE HILL SHALE MEMBER, CARLILE SHALE

*	shale and sandy shale	*0.95*	*9.50*	*28.10*
Thickness of exposed part of Carlile Shale:		0.95	10.35	29.0
Total thickness of measured section:		129.0	112.6	98.7

* Numerous undesignated beds.

EXPLANATION OF PLATES

PLATE 1

Exposures of Fort Hays Member in Trego County, Kansas.

FIGURE

1. South-facing exposure of Fort Hays at Loc. 7. Unit 27 at base of exposure.
2. Cross-laminated to very thinly cross-bedded scour zone 0.95 foot thick in upper part of Unit 7 (arrow), Loc. 1. Small cavities in Unit 9 (at *A*) resemble "cavity preservation of burrows" (see Bromley, 1967, pl. 7a).
3. Broad, shallow channel in Unit 7 (at arrow), Loc. 1; the overall structure is nearly 40 feet wide.
4. Differentially resistant chalky limestone, held up mainly by large chalk-filled burrow systems. Middle part of Unit 7, Loc. 1 (knife for scale, at arrow).
5. Differentially resistant chalky limestone, held up by combination of chalk-filled burrows, shell fragments, and inoceramite lenses (at arrow). Lower part of Unit 9, Loc. 1 (hammer head is 15 cm. in length).

PLATE 2

Trace Fossils from the Fort Hays Member.

FIGURE

1. External molds of chalk-filled burrows on upper bedding surface, Unit 55, Loc. 3. Many of the burrows may be attributed to *Thalassinoides* sp., although these are largely obscured by burrows of other kinds. (The knife used for scale in this and subsequent illustrations is 6.6 cm. in length, closed.)
2. Vertical spreiten of *Teichichnus* sp., illustrating use of black felt-tipped pen to show burrow configuration. Vertical water stains (at arrow) superficially resemble burrows. Spreiten are interpenetrating; lower structure burrowed subsequently by other organisms. Middle part of Unit 31, Loc. 1.
3. Cross-sectional view of *Asterosoma* form "helicoid funnel" Type B. Vertical exposure, upper part of Unit 47, Loc. 1. Quarter-dollar coin for scale.
4. Vertical, incompletely preserved spreite of *Teichichnus* sp. Individual burrows etched in relief by weathering. Lower part of Unit 45, Loc. 3.
5. Transverse view of *Asterosoma* form *"Cylindrichnus concentricus,"* showing wall layering. Hand specimen, upper part of Unit 7, Loc. 5. Burrow about 1.3 cm. in diameter.
6. *Asterosoma* form "helicoid funnel" Type A (at and near *B*), *Chondrites* sp. (horizon at *A*), and other burrows, illustrating use of line transect. Vertical exposure, middle part of Unit 9, Loc. 3.
7. *Asterosoma* form "helicoid funnel" Type A. Vertical exposure, lower part of Unit 1, Loc. 1. Shafts between funnels about 0.8 cm. in diameter.

PLATE 3

Trace Fossils from the Fort Hays and Smoky Hill Members.

FIGURE

1. *Asterosoma* form *"Cylindrichnus concentricus,"* partly replaced by limonite. Vertical exposure, middle part of Unit 17, Loc. 3.
2. *Asterosoma* form *"Cylindrichnus concentricus,"* incompletely replaced by pyrite. Vertical exposure, middle part of Unit 17, Loc. 1. Arrow is 2.5 cm. in length.
3. Cross-sectional views of *Asterosoma* form "helicoid funnel" Type B. Vertical exposure, middle part of Unit 47, Loc. 1.
4. *Planolites* sp. (horizon at *B*) and *Chondrites* sp. (horizon at *A*) in chalk of Smoky Hill Member. Vertical exposure, Unit 62, Loc. 3.
5. *Asterosoma* form "helicoid funnel" Type B. Note differences in size and orientation of upper and lower shafts. Inclined pyrite-filled burrow at upper left of funnel. Vertical exposure, Unit 47, Loc. 1.
6. *Asterosoma* form "helicoid funnel" Type A; upper shaft is dark because it contains considerable limonite. Vertical exposure, middle part of Unit 47, Loc. 1. Quarter-dollar coin for scale.
7. Incompletely preserved spreite of *Teichichnus* sp. Compare the horizontal trunk stem with that in Plate 5, figure 4. Vertical exposure, middle part of Unit 47, Loc. 1.

PLATE 4

Trace Fossils from the Fort Hays Member.

FIGURE

1. Spreiten of *Teichichnus* sp. concentrated within distinct zone. Burrows such as the long, vertical structures at right are commonly associated with *Teichichnus* sp. Middle part of Unit 47, Loc. 1.

2-3. Horizontal circlets of *Laevicyclus* sp. in chalk and chalky shale. Bedding surface, lower part of Unit 2, Loc. 4. Pennies for scale.

4. Specimens of *Planolites* sp., exhibiting preferred horizontal orientation. Vertical exposure, lower part of Unit 11, Loc. 1.
5. Incompletely preserved spreite of *Zoophycos* sp. A (center of photo) and *Planolites* sp. (lower half of photo) in nearly horizontal exposure. Lower part of Unit 55, Loc. 3.
6. *Teichichnus* sp., in typical form. Vertical exposure, middle part of Unit 47, Loc. 1.

PLATE 5

Trace Fossils from the Fort Hays Member.

FIGURE

1. *Planolites* sp. in vertical exposure. Lower part of Unit 7, Loc. 1.
2. Incompletely preserved spreite of *Teichichnus* sp., exhibiting thickened trunk stem. Vertical exposure, middle part of Unit 19, Loc. 1.
3. Chalk-filled burrows in chalky shale (dark zone near base of photo = Unit 54) and in chalky limestone (Unit 55), Loc. 7. Most large burrows *(B)* may be attributed to *Planolites* sp. and most small ones *(A)* to *Chondrites* sp.; the former are generally about 0.8 cm. in diameter. Vestigial bedding features are apparent in middle part of chalky limestone bed. Vertical exposure.
4. *Teichichnus* sp., in vertical exposure. Lower part of Unit 19, Loc. 3. Penny for scale.
5. *Thalassinoides* sp. cf. *T. paradoxicus*, weathered to relief in chalky limestone. Note closely spaced horizontal components (at arrow). Burrows partly obscured by patches of resistant chalk. Oblique surface; top inclined toward viewer. Middle part of Unit 7, Loc. 1.
6. Long, vertical burrow such as those commonly associated with *Teichichnus* sp. Compare upper part of this burrow with base of spreite in figure 2, above. Unit 19, Loc. 3. Quarter-dollar coin for scale.
7. Long, vertical burrow in juxtaposition with teichichnian spreiten. Middle part of Unit 17, Loc. 1. Nickel for scale, at arrow.

PLATE 6

Trace Fossils from the Fort Hays Member.

FIGURE

1. Close-up view of part of *Thalassinoides* sp. cf. *T. paradoxicus* burrow systems shown in Plate 5, figure 5.
2. *Thalassinoides* sp. in chalky shale (sole of fallen block of chalky limestone), Loc. 2. Note superposed horizontal burrow at top-center. Penny for scale, at arrow.
3. Fragment of *Thalassinoides* sp. in shaly chalk. Vertical exposure, Unit 36, Loc. 3. Penny for scale.
4. Vertical, pyrite-filled burrow, exhibiting individual pyrite cubes. Hand specimen, Unit 9, Loc. 3. Burrow about 0.3 cm. in diameter.
5. *Trichichnus linearis*, in vertical exposure, Unit 3, Loc. 2. Burrows about 0.2 mm. in diameter. Holotype (IU 10992-1).
6. Branching specimen of *Trichichnus linearis*, about 0.2 mm. in diameter. Vertical exposure, Unit 25, Loc. 3. Paratype (IU 10993-1).
7. *Trichichnus linearis*, in vertical exposure, Unit 3, Loc. 4. Burrows about 0.2 mm. in diameter. Burrow walls of specimen at arrow contain no pyrite. Paratype (IU 10994-1).
8. Burrows resembling *?Spongeliomorpha annulata* KENNEDY. Vertical exposure, lower part of Unit 9, Loc. 3 (cf. burrows in lower part of photo, Plate 2, figure 6). Base of photo represents a distance of 14 cm.
9. Fragment of *Thalassinoides* sp., replaced by calcite. Location as in Plate 2, figure 1. Penny for scale.

PLATE 7

Trace Fossils from the Fort Hays Member.

FIGURE

1. Spreite of *Zoophycos* sp. A. Oblique surface; fallen block of chalky limestone, Loc. 2.
2. Cross-sectional view of the spreiten of *Zoophycos* sp. B. Vertical exposure, lower part of Unit 7, Loc. 3.
3. Incompletely preserved spreite of *Zoophycos* sp. A. Vertical exposure, upper part of Unit 19, Loc. 1. Nickel for scale, at arrow.
4. Cylindrical shaft (long, vertical burrow to left of knife) and incompletely preserved spreite of *Teichichnus* sp. (above knife). Vertical exposure, Unit 1, Loc. 4.
5. Cylindrical shaft, exhibiting pyritic core. Vertical exposure, lower part of Unit 29, Loc. 3. Penny for scale.
6. Cylindrical shaft. Vertical exposure, middle part of Unit 39, Loc. 3. Burrow about 1.2 cm. in diameter.
7. *Arthrophycus*- and *?Paleophycus*-like burrows at the Carlile-Niobrara contact (Table 1), Loc. 2. Burrows situated in a thin zone of shale which intervenes between typical sand of Codell Member and chalky limestone of Fort Hays Member. Vertical exposure.
8. Annulated, *Arthrophycus*-like burrow. Hand specimen, middle part of Unit 1, Loc. 2. Burrow about 1.1 cm. in diameter.

PLATE 8

Trace Fossils from the Fort Hays Member and Polychaete Dwelling Tubes from the Recent of North Carolina.

FIGURE

1. Scaphopod-shaped tube, 1.6 cm. in length. Vertical exposure, middle part of Unit 1, Loc. 1.
2. Mechanically filled burrow containing *Inoceramus* shell fragments. Base of burrow in Unit 8 (chalky shale) and remainder in Unit 9 (chalky limestone), Loc. 3. Top of burrow inclined toward viewer.
3. Mechanically filled burrow containing *Inoceramus* shell fragments. Base of burrow in Unit 6 (chalky shale, which is inconspicuous) and remainder in Unit 7 (chalky limestone); top of burrow obscured by lichen-covered exfoliation slab. Vertical exposure, Loc. 5. Penny for scale.
4. J-shaped calcite-filled burrow weathered out of chalky limestone. Vertical exposure, lower part of Unit 45, Loc. 1. Burrow about 0.4 cm. in diameter.
5. Calcite-filled burrow partly weathered out of chalky limestone. Vertical exposure, upper part of Unit 45, Loc. 3. Burrow about 1.4 mm. in diameter.
6. Incomplete, vertical dwelling tubes of the polychaete *Clymenella*, excavated from a tidal flat near Beaufort, North Carolina. Burrows about 0.3 cm. in diameter.
7. Irregular pyrite-filled burrows. Vertical exposure, middle part of Unit 17, Loc. 3. Penny for scale.
8. Secondary limonite-filled burrow associated with a spreite. Vertical exposure, middle part of Unit 19, Loc. 1. Nickel for scale, at arrow.
9. Chalk-filled burrows at the Carlile-Niobrara contact, Loc. 2. Burrow near knife is obscurely annulated (and inclined toward viewer), resembling *Arthrophycus*. Burrows at right have strict vertical components such as those found in *Thalassinoides* sp. cf. *T. paradoxicus*. Vertical exposure.
10. Horizontal, limonite-lined burrow preserved as a solution cavity in chalk. Bedding plane surface, Unit 52, Loc. 7. Burrow about 0.4 cm. in diameter.
11. Branching pyrite-filled burrow. Vertical exposure, middle part of Unit 17, Loc. 1.
12. Secondary pyrite-filled burrow (upper right of spreite structure) and gently curved secondary chalk-filled burrow lined with finely disseminated pyrite (center of spreite). Vertical exposure, middle part of Unit 17, Loc. 1. Spreite about 3.5 cm. across.
13. Burrows associated with pelecypod valve (internal mold of *Inoceramus deformis*). The large, white chalk-filled burrow follows the valve interior but "escapes" the valve near the hinge. *Chondrites* sp. below penny. Fallen block of chalky limestone, Loc. 2.
14. Pyrite- and limonite-filled burrows associated with pelecypod valve (internal mold of *Inoceramus*). Sole of Unit 19, Loc. 3. Penny for scale.

PLATE 9

Trace Fossils from the Fort Hays and Smoky Hill Members and Polychaete Dwelling Tubes from the Recent of North Carolina.

FIGURE

1. Limonite-filled burrows on fragment of *Inoceramus* valve (interior), Unit 56, Loc. 3 (Smoky Hill Member). Burrows about 0.2 cm. in diameter.
2. Dwelling tubes of the polychaete *Clymenella mucosa* on interior of valve of the pelecypod *Aequipecten irradians.* From *Zostera* shoal near Beaufort, North Carolina. Valve about 7.2 cm. in length.
3. Poorly preserved spreite (probably teichichnian) skirting *Inoceramus* shell fragments. Vertical exposure, lower part of Unit 19, Loc. 1. Nickel for scale.
4. Irregular chalk-filled burrows. Vertical exposure, Unit 39, Loc. 3. Pyrite nodules above and to the left of knife.
5. Bed of chalky shale lacking burrows except in its uppermost part. Chalk-filled burrows are ordinarily so widespread in the Fort Hays that their absence locally is more significant than their presence elsewhere. Vertical exposure, Unit 32, Loc. 1. Quarter-dollar coin for scale.
6. Chalk-filled burrows in chalky shale, so flattened by bedding compaction that they resemble simple lenses of chalk. Vertical exposure, Unit 48, Loc. 2.
7. Bulbous structure resembling *Rosselia.* Secondary pyrite-filled burrow along right periphery of structure, below penny. Vertical exposure, middle part of Unit 19, Loc. 1.
8. Chalk-filled burrows concentrated within particular stratigraphic zones. Vertical exposure, Units 51 and 52, Loc. 7.
9. Chalk-filled burrows in chalky shale. Vertical exposure, Unit 8, Loc. 1.

PLATE 10

Trace Fossils from the Fort Hays Member.

FIGURE

1. Bioturbate texture in moderately fresh exposure of chalky limestone, illustrating profusion of burrows and crude stratification of burrow types. Oblique surface; top of exposure inclined slightly away from viewer. Lower part of Unit 7, Loc. 6.
2. Chalk-filled burrows in shaly chalk. Oblique surface; top of exposure inclined away from viewer. Unit 26, Loc. 1. Burrows about 0.7 cm. in diameter.
3. Chalk-filled burrows in chalky shale, altered substantially by compaction of beds. Vertical exposure, Unit 30, Loc. 1.
4. Two thin shale partings (at arrows) in lower part of Unit 5, Loc. 1. Shale partings are thinly cross laminated locally, and they truncate underlying burrow structures.
5. Unidentified irregular chalk-filled burrow system, consisting of both cylindrical burrows and spreiten structures. Vertical exposure, middle part of Unit 17, Loc. 1.

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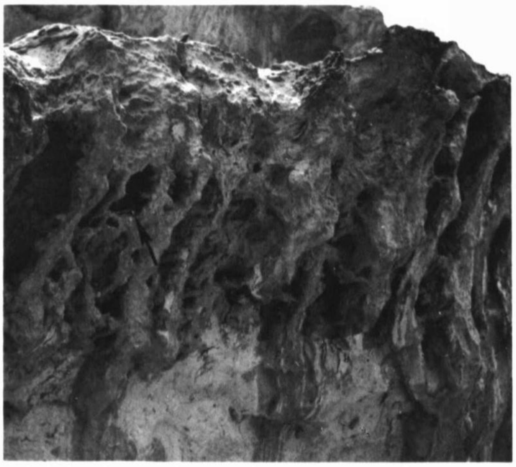

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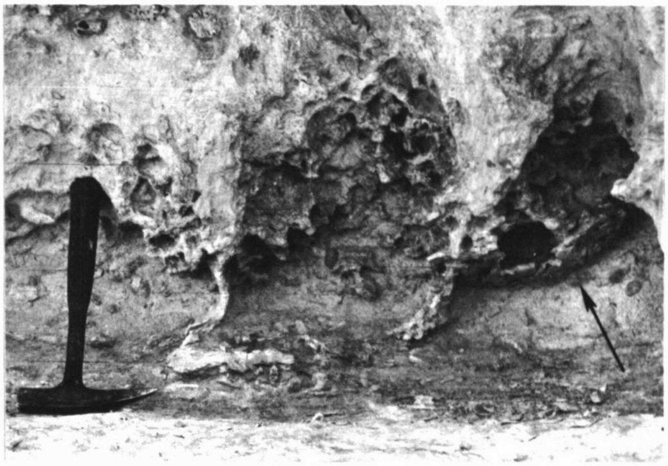

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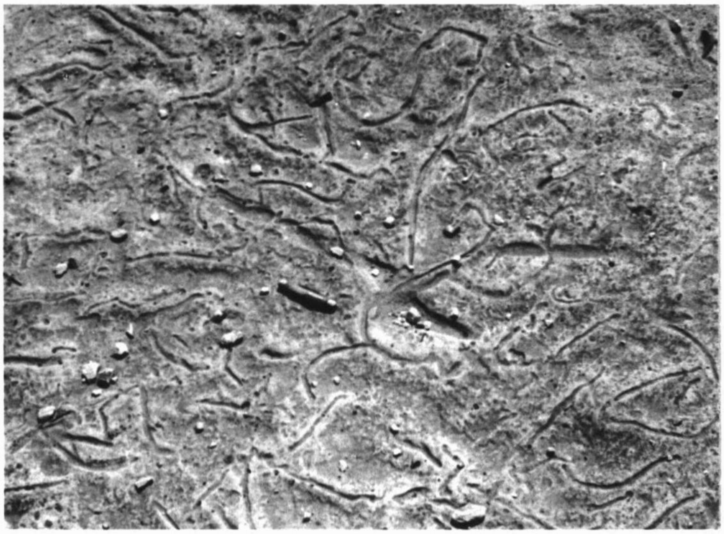

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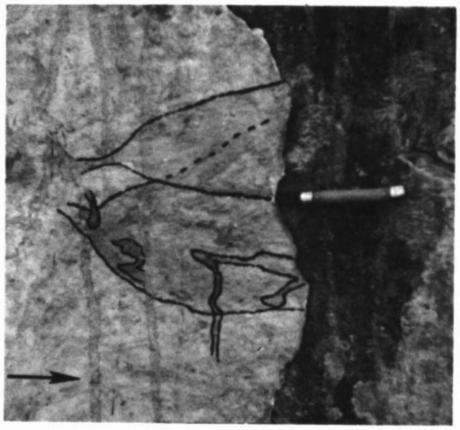

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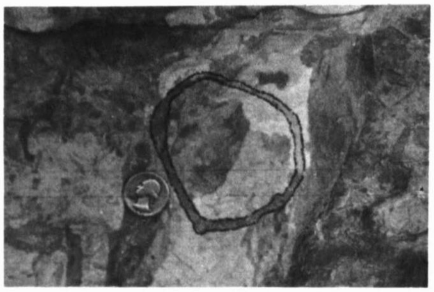

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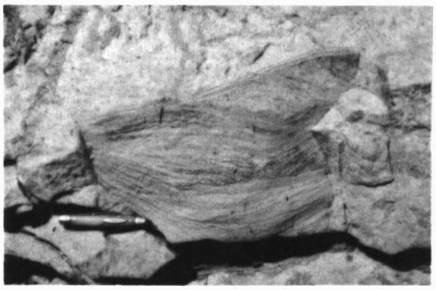

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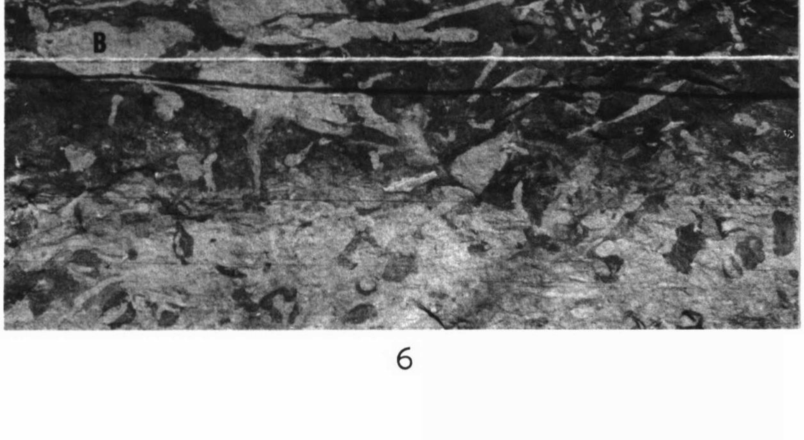

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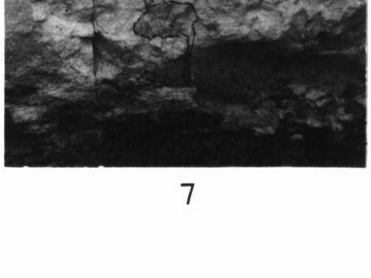

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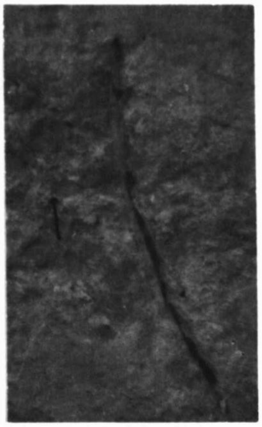

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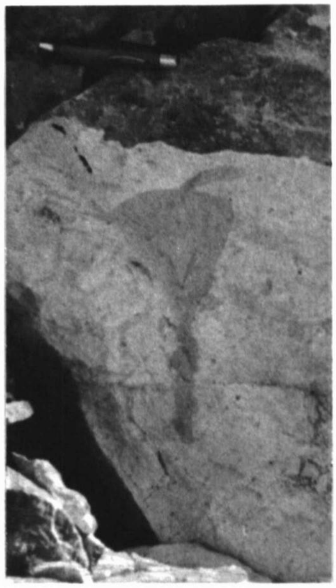

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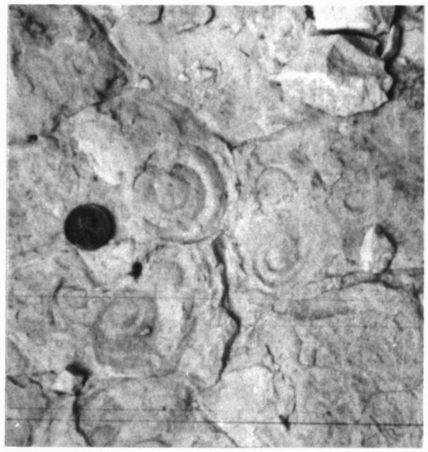

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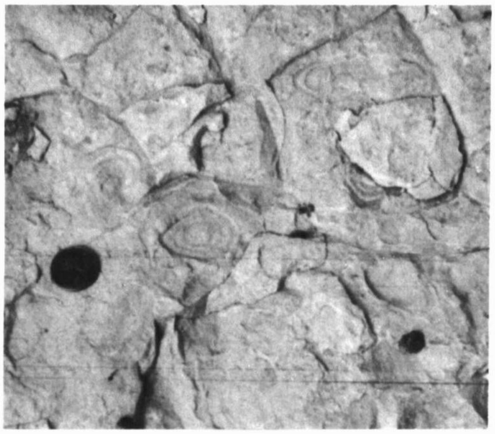

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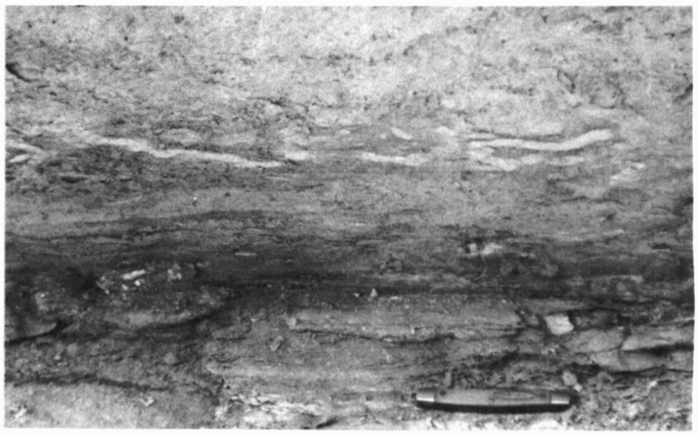

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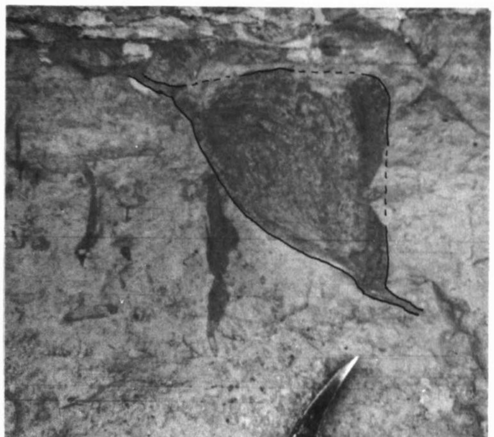

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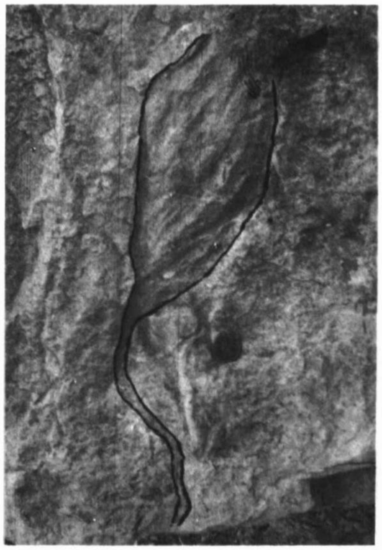

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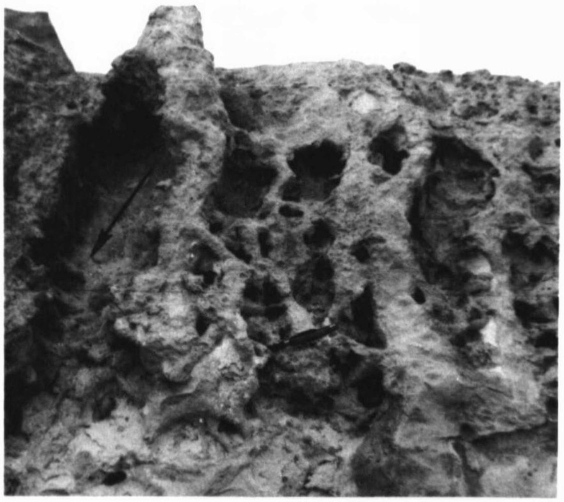

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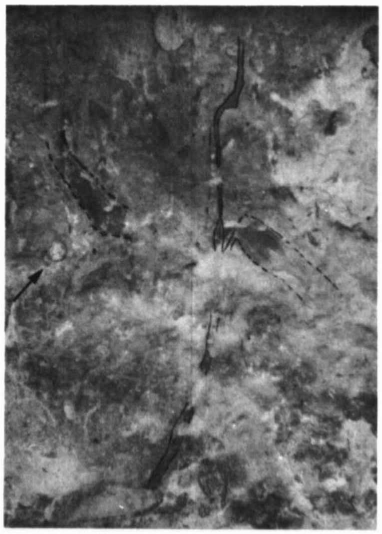

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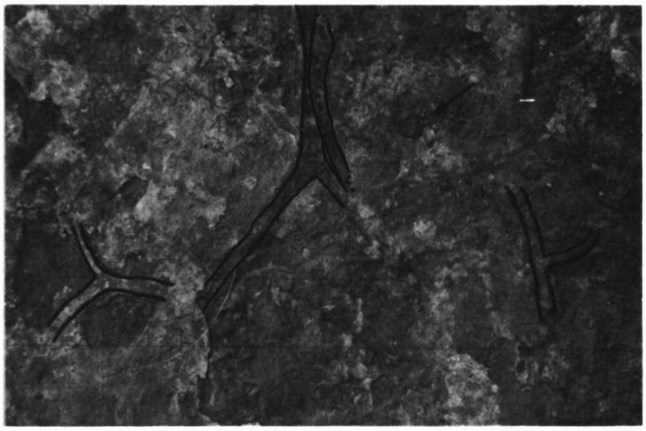

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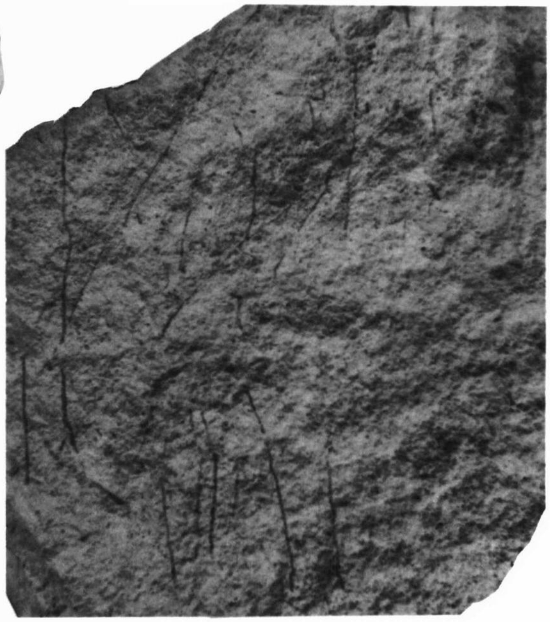

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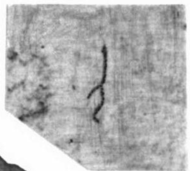

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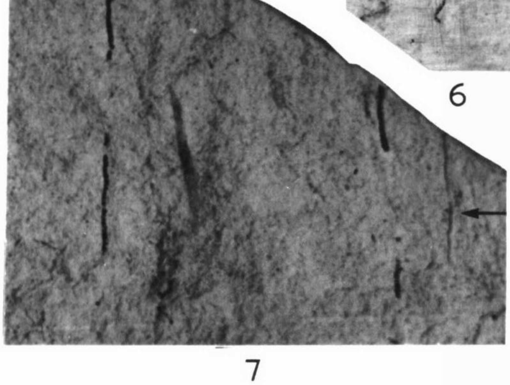

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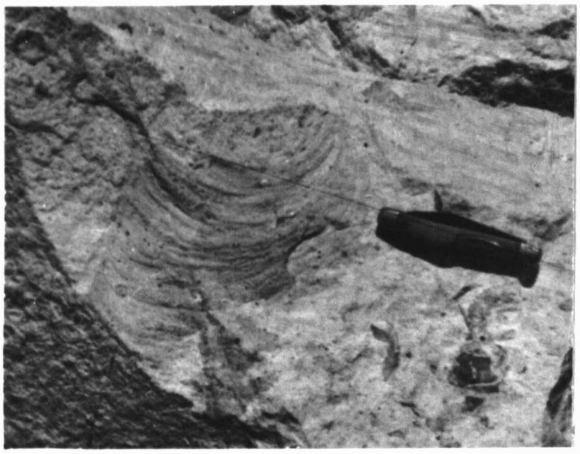

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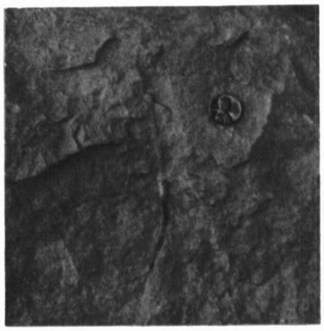

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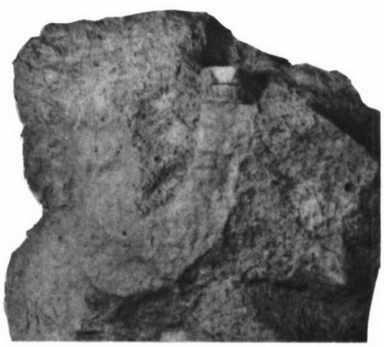

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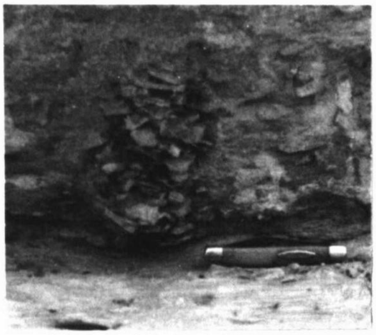

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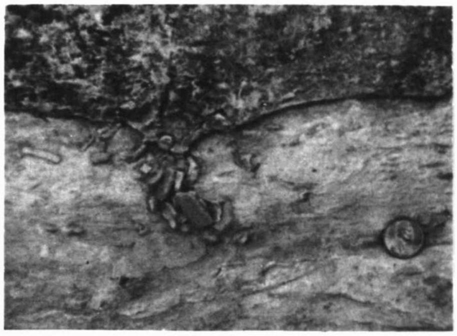

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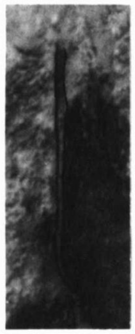

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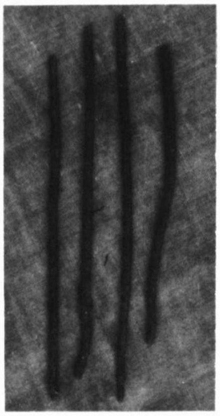

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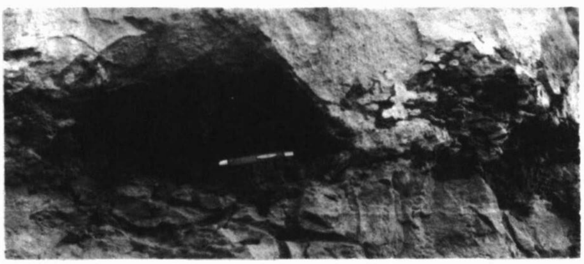

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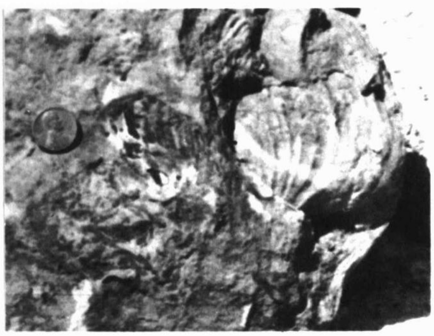

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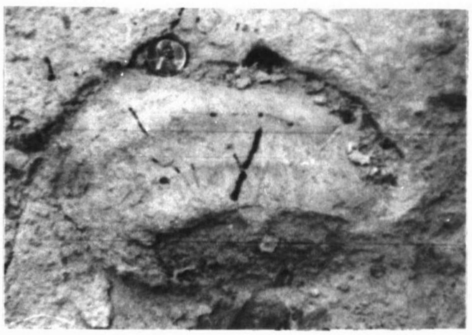

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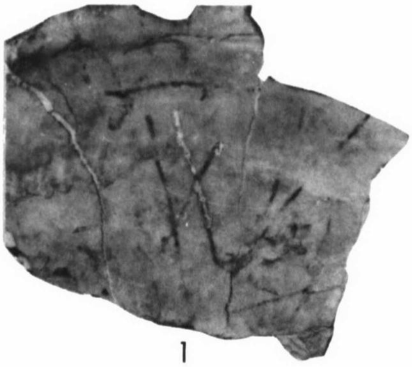
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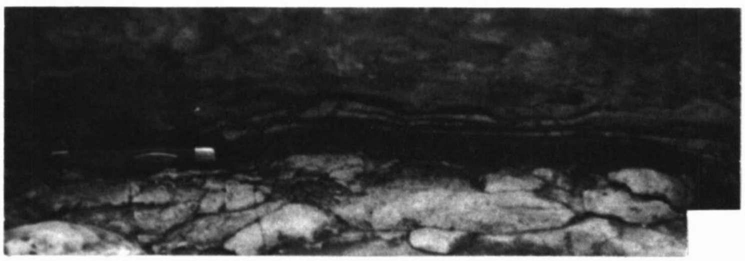
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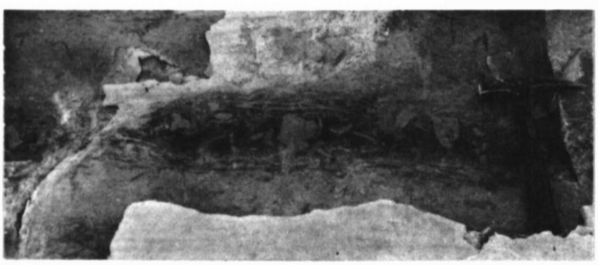
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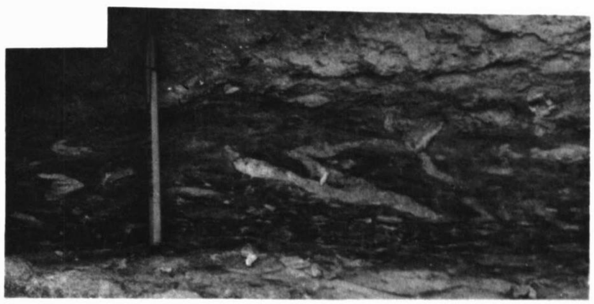
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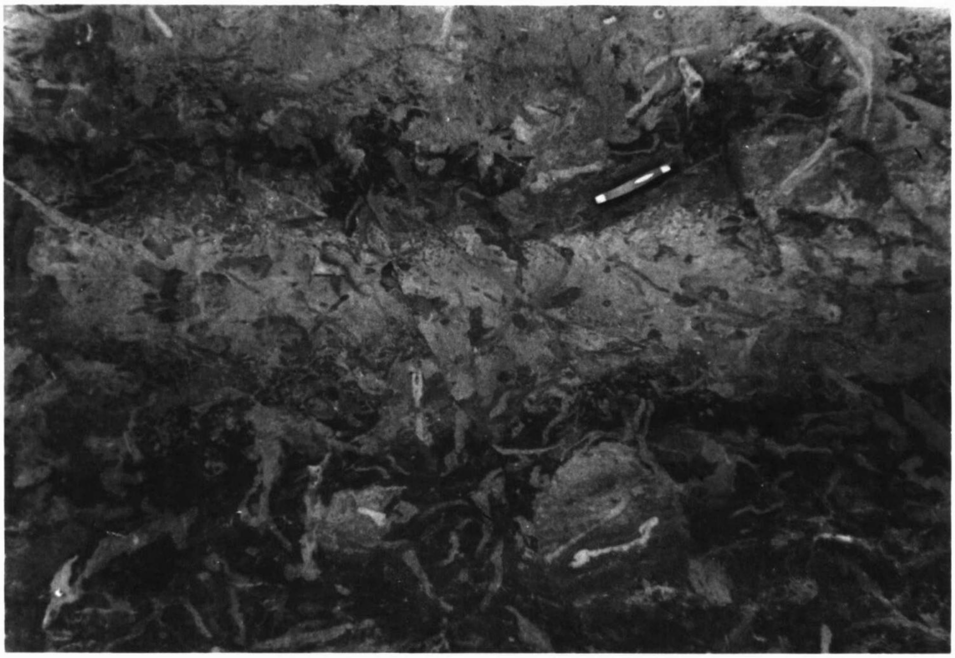

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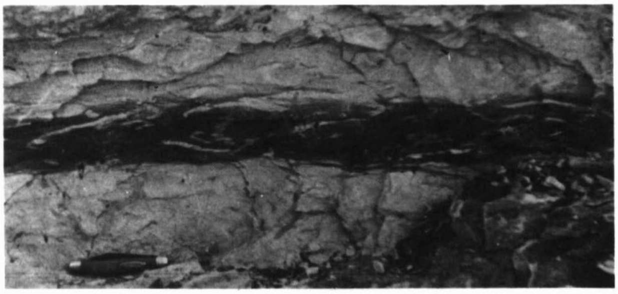

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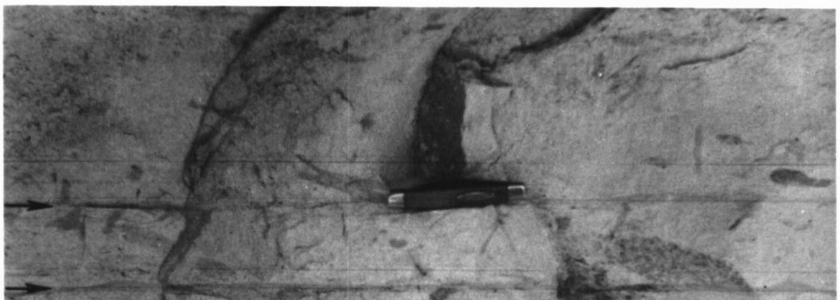

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