Stratigraphy, Trace Fossil Associations, and Depositional Environments In the Borden Formation (Mississippian), Northeastern Kentucky

James R. Chaplin
Morehead State University

Annual Field Conference of the Geological Society of Kentucky
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Kentucky Geological Survey
Donald C. Haney, Director and State Geologist
University of Kentucky, Lexington

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COVER

Photographs of the trace fossils *Zoophycos*, *Lophoctenium*, *Scalarituba*, and *Helminthoida*. Past workers in the Borden Formation commonly referred to *Zoophycos* and *Lophoctenium* as "rooster tail" marks and to *Scalarituba* and *Helminthoida* as "curly worm" marks.

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DEDICATION

The Geological Society of Kentucky is pleased and proud to dedicate this guidebook to Dr. Vincent E. Nelson, Professor Emeritus, of the University of Kentucky. Vin, as he is known to his friends, was born and reared in Rock Island, Illinois, earning a Bachelor of Arts degree there in 1935 from Augustana College. Thereafter, he pursued graduate study in geology at the University of Chicago, and was awarded the Kirkham Fellowship in the academic year of 1937-38. He earned the degree of Doctor of Philosophy in geology from the University of Chicago in 1942. His dissertation was a study of structural relationships in the Teton Mountains of western Wyoming.

Vin began his association with the University of Kentucky in the fall semester of 1938. Since that time he has been a faithful and enthusiastic member of the Geological Society of Kentucky, serving as president of the Society twice. Rarely has he missed a field trip or meeting. Among other accomplishments, Vin has contributed significantly to an understanding of structural features in the Pine Mountain area of southeastern Kentucky. During his long tenure as a member of the professorial staff of the University of Kentucky, Vin has been a wholly effective teacher, whose many students recall with pleasure and gratitude countless associations with him both in and out of the classroom. He also served for several years as director of the geology field camp at Crested Butte, Colorado, and he has been particularly helpful to the Department of Geology by maintaining contact with alumni. From 1942 to 1945 Vin was employed by the United States Geological Survey investigating mineral deposits in New Mexico, Idaho, Tennessee, and Washington. From 1961 to 1964 he served as Professor, Chief of Party, with distinction, for a University of Kentucky contract team at Bandung Technological Institute in Indonesia.

Vin retired January 31, 1978. We wish him many more years of pleasurable retirement, and look forward to his continuing participation in activities of the Society.

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I sincerely thank Paul Basan for his perceptive comments and stimulating conversations in which he shared with me some of the results of his several years of trace fossil work and for the opportunity to work with him in the field.

I am especially indebted to Mrs. W. R. Falls for typing the final form of this guidebook.

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ABSTRACT

Environments of deposition of the Borden Formation (Lower to Middle Mississippian) will be examined. Lithostratigraphy, sedimentary structures, and trace fossil associations will be particularly emphasized. Samples of several diverse trace fossil associations can be collected.

INTRODUCTION

The Borden Formation of northeastern Kentucky records the marine part of an ancient deltaic complex that prograded across northeastern Kentucky during Early Mississippian time. Although this delta has been studied in broad outline, the relationships between rocks from different deltaic environments and the trace fossils that lived in these environments have not been examined in detail. The purpose of this field trip is to elucidate these environment-trace fossil relationships and to examine the marked differences in lithologic character, thickness, and depositional pattern of the lithic units in the Borden Formation throughout northeastern Kentucky (Fig. 1).

During Devonian and Mississippian time a series of deltas gradually filled in large, shallow marine basins in the eastern interior of the United States. The first delta was the Devonian Catskill delta in the northeast, followed by the Devonian-Mississippian Bedford-Berea delta in Ohio, and the Lower-Middle Mississippian Borden delta in Indiana, Illinois, and Kentucky.

Depositional environments recognized in the Borden Formation of northeastern Kentucky include basin-floor mudstones and shales; turbiditic sandstones, siltstones, and hemipelagic mudstones; prodelta shales; delta front siltstones and shales; delta platform mudstones, siltstones, and minor carbonates; and high intertidal dolomites.

PHYSICAL FRAMEWORK OF THE BORDEN DELTA

In northeastern Kentucky the rocks that comprise the delta and associated basinal deposits are collectively termed the Borden Formation. These rocks, in upward sequence, are the Henley Bed, the Farmers Member, the Nancy Member, the Cowbell Member, the Nada Member, and the Renfro Member. The Borden Formation is underlain by the Sunbury Shale (which is composed of basin-floor deposits) and overlain by the Newman Limestone (which was deposited in a nearshore open marine to restricted marine environment) or the Breathitt Formation (which is composed of deltaic deposits) (Fig. 2). The average stratigraphic thickness of the Borden Formation is 670 feet (204 m) and the maximum thickness is approximately 900 feet (274 m). The lowest members of the Borden Formation are primarily basinal (Henley Bed) and prodeltaic deposits (Nancy Member) with episodic intrusions of turbiditic sandstones and siltstones (Farmers Member). The middle part of the formation, the Cowbell Member, represents the delta front (interdeltaic bay and distal bar), and the Nada Member represents the delta platform and the beginning of delta destruction (marine transgression). As the delta prograded from the north-northeast, it eventually filled a "sediment-starved basin" to the south-southwest and covered the deeper-water sedi-

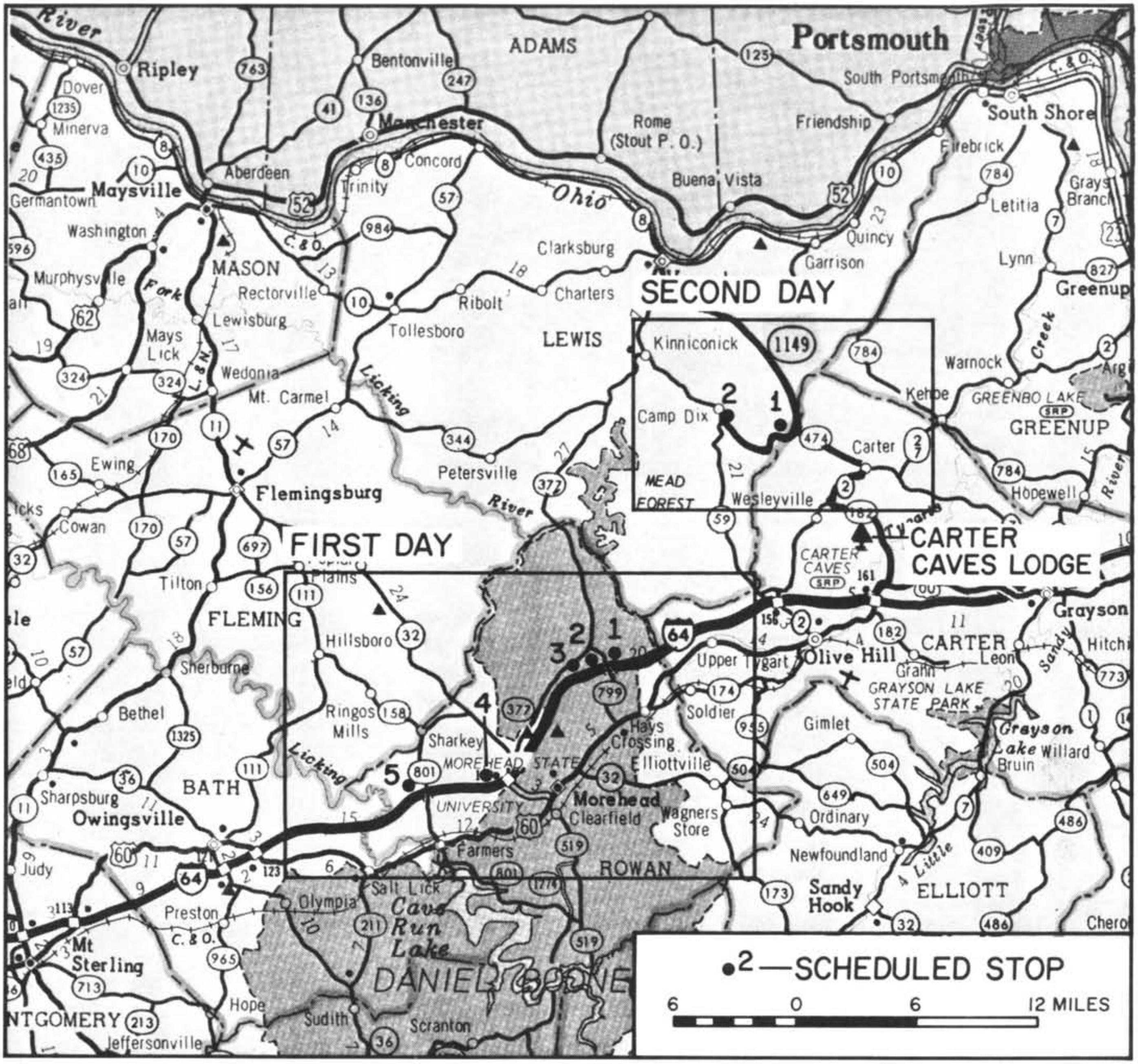

Figure 1. Map showing route of field trip and location of stops.

ments derived from it. The deltaic sediments are succeeded by high intertidal dolomites of the Renfro Member and shallow-water carbonates of the overlying Newman Limestone. Figure 2 is a generalized stratigraphic column showing the vertical succession of units, thicknesses, depositional environments, and lithologies in the Borden Formation and the underlying and overlying units in northeastern Kentucky.

It must be recognized that the strict equating of each member in the Borden Formation with a specific deltaic environment is only approximate and further studies will probably lead to revision. For example, the Nancy Member may represent basin-floor deposits at some localities, at least in its lower part. Nevertheless, in a general way, these members seem to correspond to specific parts of the delta geometry, at least insofar as that geometry can be deducted from studying lithologic character, thickness variations, sedimentary structures, and trace fossil associations.

The terms "delta platform," "delta front," and "prodelta" refer to the geometric configuration of the delta. The delta platform is the part of the subaqueous delta that is proximal to the sediment source. It includes an interdeltaic bay and skeletal carbonate bank facies.

SYSTEM	SERIES	UNIT		THICK-NESS IN FEET (m)	PROBABLE ENVIRON-MENTS	GENERAL CHARACTERISTICS
MISSISSIPPIAN	CHESTERIAN	NEWMAN LIMESTONE	Upper Member	0-126 (0-38)	Near-shore, open marine to restricted marine	Limestone, finely to moderately crystalline, cherty, oolitic, alternating with shale; abundant megafossils.
MISSISSIPPIAN	CHESTERIAN	NEWMAN LIMESTONE	Ste. Genevieve Ls. Mbr.	0-100 (0-30)	Carbonate shoal	Limestone, gray to white, moderately to coarsely crystalline, sandy, oolitic, often crossbedded; magafossils rare.
MISSISSIPPIAN	MERAMECIAN	NEWMAN LIMESTONE	St. Louis Limestone Mbr.	0-23 (0-7)	Shallow sub-tidal to sub-aerial	Limestone, micritic, cherty; laminated micritic "crusts" at top; silicified megafossils common; excellent conodont fauna.
MISSISSIPPIAN	MERAMECIAN	BORDEN FORMATION	Renfro Mbr.	0-20, (0-6)	High intertidal	Dolomite and dolomitic limestone, yellowish-tan, silty, locally burrowed; megafossils rare to common.
MISSISSIPPIAN	? OSAGIAN	BORDEN FORMATION	Nada Mbr.	0-85 (0-26)	Delta platform	Shale, red and green, with intercalated layers of glauconite-streaked siltstone and crinoidal, glauconite-streaked limestone; trace fossils and megafossils common to abundant; contains conodonts.
MISSISSIPPIAN	OSAGIAN	BORDEN FORMATION	Cowbell Mbr.	85-380 (26-116)	Delta front	Siltstone, massive, locally containing shale intervals; sedimentary structures and trace fossils common to abundant; contains calcareous lenses with abundant whole and fragmented megafossils.
MISSISSIPPIAN	OSAGIAN	BORDEN FORMATION	Nancy Mbr.	60-410 (18-125)	Prodelta	Shale, bluish-gray, silty, bioturbated; abundant sideritic nodules and beds; stringers and beds of siltstone and very fine-grained sandstones; abundant cephalopod fauna.
MISSISSIPPIAN	OSAGIAN	BORDEN FORMATION	Farmers Mbr.	1-270 (.3-82)	Turbidites	Sandstones, very fine-grained to fine-grained, tabular bedded, alternating with greenish-gray mudstones; abundant sedimentary structures, sole markings, and trace fossils; cephalopods common at top.
MISSISSIPPIAN	? KINDERHOOKIAN	BORDEN FORMATION	Henley Bed	3-30 (.9-9)	Basin floor	Mudstone, greenish-gray, pyritic, structureless; contains a diverse and abundant conodont fauna.
MISSISSIPPIAN	KINDERHOOKIAN	Sunbury Shale		5-25 (1.5-8)	Basin floor	Shale, brownish-black, fissile, pyritic; abundant spores, conodonts, fish plates, and inarticulate brachiopods; fossil lag deposit at base.
MISSISSIPPIAN	KINDERHOOKIAN	Berea Sandstone		0-100 (0-30)	Delta front	Sandstone, light-gray, fine-grained; flow rolls, convoluted beds, ripple marks, cross laminations present.
? DEVONIAN	?	Bedford Sh		0-90 (0-27)	Prodelta	Shale, light-olive-gray, pyritic, with sandy, ripple-marked siltstone stringers; fossils rare.
DEVONIAN		Ohio Shale		135 250 (41-76)	Basin floor	Shale, black, fissile, pyritic; scattered discontinuous limestone cone-in-cone layers; contains packages and intercalations of greenish-gray, pyritic, bioturbated shales; spores, conodonts, fish plates, and inarticulate brachiopods present.

Figure 2. Generalized stratigraphic column showing vertical succession of units, thicknesses, depositional environments, and lithologies in the Borden Formation and underlying and overlying units in northeastern Kentucky.

The delta front is a complex of associated sub-environments contained in the advancing locus of active deposition of a prograding delta. Interdeltaic bay and distal bar sub-environments are recognized in this zone; each sub-environment, because of differing processes, is characterized by a distinctive suite of sedimentary structures and trace fossil associations. The prodelta environment is an area in which clay-sized sediments are deposited in front of the delta front; the prodelta environment is associated with a specific prograding delta system. Basin-floor deposits are hemipelagic clays that were deposited basinward from the prodelta. There was little deltaic deposition on the basin floor with the exception of periodic intrusions of turbidite sands and silts.

Regional studies on lithologic character, stratigraphic thickness, sedimentary structures, and paleocurrent data (Wilson, 1950; Clarke, 1969; Moore and Clarke, 1970), and studies on body fossils and trace fossil associations indicate that the Borden Formation in northeastern Kentucky is mainly an upward-coarsening (shallow-upward) sequence of terrigenous clastic rocks associated with a prograding delta (marine regression). The source was from the north-northeast and the delta migrated toward a relatively deeper part of a "starved basin" to the south-southwest. The exception in the Borden Formation is the Farmers Member. The presence of turbidites in the Farmers Member suggests that the delta prograded into relatively deep water. The more proximal turbidites (Lewis and Greenup Counties), the more distal turbidites (Rowan and Bath Counties), and the deltaic siltstones (Cowbell Member) are compositionally submature to mature. This indicates that the deltaic sands, which were probably Cowbell and were redeposited as turbidites in the Henley and Nancy environments, had been reworked in a littoral zone.

Preliminary results of nautiloid and goniatite studies on the Borden Formation by Charles Mason (George Washington University) and conodont studies by the author suggest that the sedimentary sequence is probably time-transgressive; older rocks are to the north-northeast and younger rocks are to the south-southwest. These studies tentatively confirm the north-northeast to south-southwest prograding nature of the Borden delta in northeastern Kentucky.

STRUCTURE

The area of the field trip (Fig. 1) is on the western edge of the Appalachian Basin and about 80 miles (128 km) east of the axis of the Cincinnati Arch. The outcrop pattern of the Borden Formation is controlled locally by the regional dip of 30 to 50 feet per mile eastward from the Cincinnati Arch. Principal structural features of the region are shown in Figure 3.

A structural feature in northeastern Kentucky of recent interest is the Waverly Arch. Woodward (1961) proposed a broad, low, subsurface arch (the Waverly Arch) that extended from north-central Ohio southward into eastern Kentucky (Fig. 3). This arch was an axis of low and persistent relief or minor subsidence from the late Middle Cambrian through the Early Ordovician. Woodward did not study the activity of the arch after Middle Ordovician Black River time.

Dohm (1963), working in Elliott County, Kentucky, found strong evidence for a late Osagean uplift along the Northern Paint Creek Uplift. Figure 3 shows the position of the Northern Paint Creek Uplift in relation to the Waverly Arch. He reported a pronounced thinning of Lower Mississippian sediments (a maximum loss of section of approximately 400 feet) and a relatively shallow (5,000 ± feet) basement complex. Dohm concluded that recurrent movements along the Waverly Arch, one of which occurred in late Osagean time, were a predominant factor in the development of the Northern Paint Creek Uplift.

Kearby (1971) concluded that the Cowbell Member of the Borden Formation is a lower delta front deposit derived from a northeastern source. He found that the Cowbell is succeeded by shallow marine to supratidal deposits (Nada and Renfro Members) instead of the expected upper delta front and lower delta plain deposits. He concluded that the most likely explanation for the absence of upper delta front and delta plain deposits is renewed uplift along the Waverly Arch or sedimentary infilling of a broad shallow marine platform which could have caused cessation of sediment influx by diversion of a distributary system. However, other explanations for the absence of the non-marine part of the delta need examining. First, since only a diagonal cross section of the Borden Formation is exposed in the study area, the non-marine equivalents may be exposed to the north-northeast in coeval formations that are yet unrecognized. Second, the non-marine part of the delta may not be exposed or may have been subsequently eroded to the north-northeast, the presumed source directions.

Dever (1973) first suggested that the Waverly Arch influenced deposition of parts of the Newman Limestone in northeastern Kentucky. He based his conclusion on thinning and subaerial diagenesis of lower Newman members. Dever initially accepted Woodward's Cambrian-Ordovician axis of the Waverly Arch as the axis of thinning during the Mississippian. However, later studies by Ettensohn (1975b) showed that the axis of maximum thinning of Mississippian units was approxi-

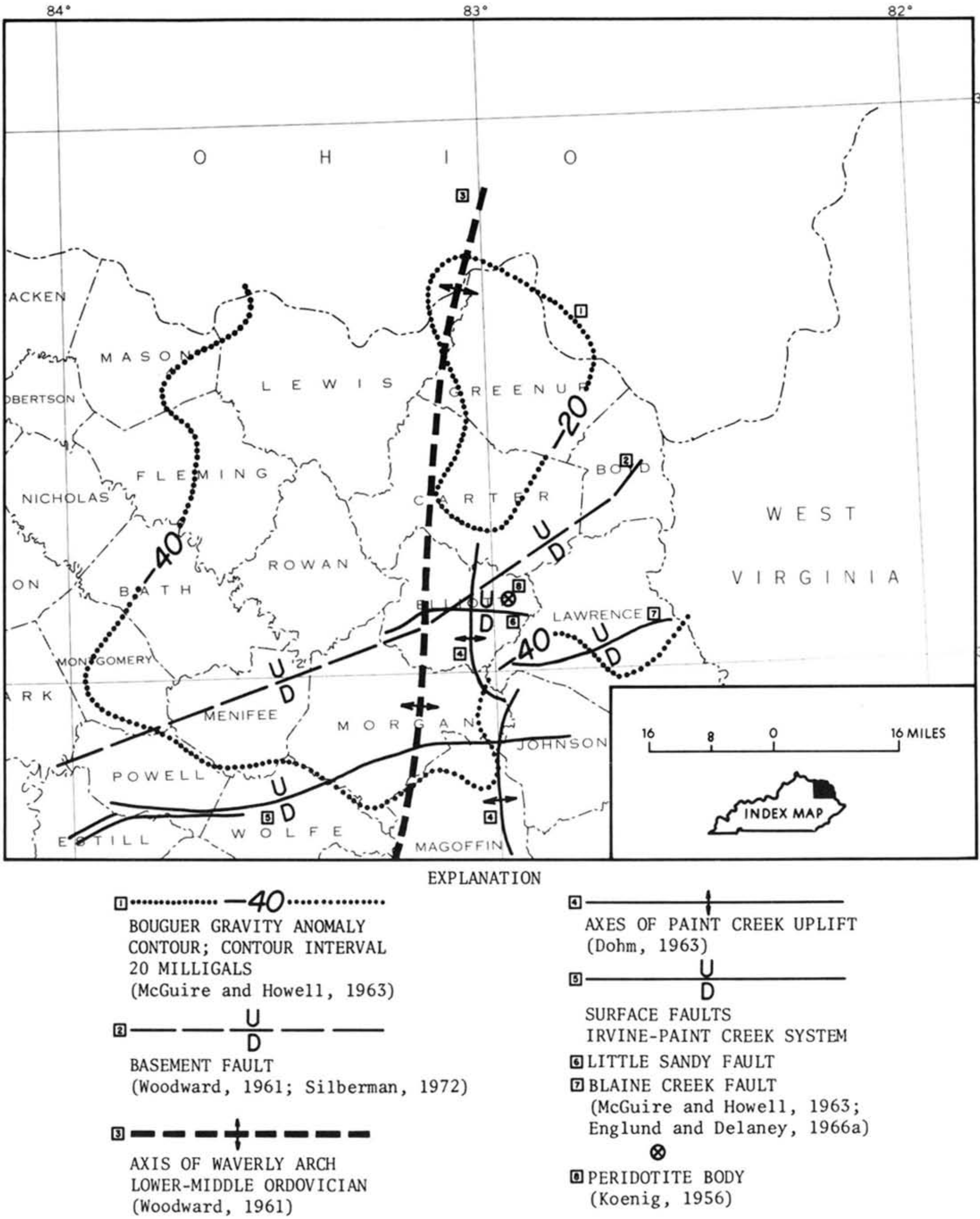

Figure 3. Map of northeastern Kentucky showing major structural features of field trip area. After Dever (1980).

mately 7 to 8 miles west of the Cambrian-Ordovician axis of Woodward. This more westerly axis has since been adopted by Dever (1977).

Calvert (1974) dismissed the Waverly Arch of Woodward (1961) as a myth. He reported that isopachous maps, structural maps, and stratigraphic cross sections of Cambrian and Ordovician formations in Ohio, the same formations studied by Woodward, show no evidence for such a feature. Calvert cites alternate explanations for stratigraphic thinning or the absence of strata in lieu of certain paleoarches described in geologic literature.

Additional discussions of the Waverly Arch and the presumed effects of synsedimentary tectonic activity on Carboniferous sedimentation in northeastern Kentucky can be found in Dever and others (1977), Ettensohn (1975a, 1975b, 1980), Ettensohn and Dever (1975), Ettensohn and Peppers (1979), and Horne and Ferm (1976, 1978).

It is interesting that when examining the regional total stratigraphic thickness of the Borden Formation in northeastern Kentucky no appreciable thinning of the Borden sequence is apparent along the proposed axis. More significantly, some of the maximum thicknesses plotted for the Borden Formation are found to nearly coincide with the proposed axis of Woodward (1961) and the axis shown by Ettensohn (1980) if the axis is projected northward (Fig. 4). Evidence for uplift on the Waverly Arch in late Osagean time (erosion of upper parts of the Cowbell (Dohm, 1963) and thinning of the Borden sequence over the uplift (Kearby, 1971)) that Ettensohn (1980, p. 1010) refers to as "scant but suggestive" is not only scant but absent in the Borden Formation, at least from Greenup and Lewis Counties in the north to Bath and Rowan Counties to the south, a distance of approximately 65 miles (104 km). Evidence for erosion of the upper parts of the Cowbell is at best tenuous. The Cowbell Member is one of the least variable units with regard to stratigraphic thickness in the Borden sequence. Thicknesses for the Cowbell Member in the field trip area are consistantly around 300 feet (94 m). It should be noted that stratigraphic thicknesses for members of the Borden Formation taken from published geologic quadrangle maps must be used with caution, as all of the members of the Borden Formation have highly gradational lower and upper contacts and different field mappers have not consistently placed these lithic boundaries in the same stratigraphic position. Regional studies of stratigraphic thickness variations involving the Borden Formation must be restricted to the variation in overall formation thickness and not individual member thickness unless that thickness is first carefully field checked.

STRATIGRAPHY

Borden Formation

Henley Bed

The Henley Bed, the basal unit of the Borden Formation as proposed by Peck (1969) in his redefinition of the Farmers Siltstone, consists mainly of grayish-green to greenish-gray, structureless mudstones with thin interbeds of turbidite-like siltstones and very fine-grained sandstones. This is particularly true near the top. To the northeast, siltstone and sandstone interbeds and reddish-brown shales become more common throughout the Henley. Compositionally, the Henley commonly consists of quartz (59 percent), feldspar (1 percent), dolomite (4 percent), kaolinite (4 percent), illite (28 percent), and chlorite (4 percent). In the wet sieving process for microfossil recovery, 85 to 95 percent of the residue from Henley mudstones typically passes through the 53-micron sieve, demonstrating the predominant clay-sized nature of the Henley deposits. Iron sulfide nodules often occur near the top of the unit. The average thickness of the Henley in northeastern Kentucky is 10 to 15 feet (3 to 4.5 m); it reaches a maximum thickness of approximately 40 feet (12 m) to the north in the Garrison quadrangle (Chaplin and Mason, 1978).

Body fossils and traces fossils are rare to absent in the Henley, but microfossils, particularly conodonts and foraminifera, are extremely abundant and diverse near the base and at the top of the unit. Autochthonous conodont faunas recovered from the Henley are many and highly diverse; several zonal indices for the Kinderhookian are present. Important commonly occurring conodont form-genera in the Henley include *Siphonodella, Polygnathus, Protognathodus, Bispathodus, Psedopolygnathus, Apatognathus*, and *Spathognathodus*. A proposed conodont zonation of the Lower Mississippian (Kinderhookian) for northeastern Kentucky and a comparison of Great Basin, Rocky Mountain, and European conodont faunas is forthcoming (Chaplin, in press). The need for detailed biostratigraphic studies of the Borden Formation, and for that matter of the entire Carboniferous in northeastern Kentucky, cannot be overemphasized. Age assignments have been based mainly on stratigraphic position of lithic units, with little or no regard to biostratigraphy. This has resulted in numerous tenuous correlations and depositional models for Carboniferous sedimentation that lack credibility. The problem has often troubled others working in and near the field trip area, but apparently it has seldom inhibited their zealous support of "mythical" time-rock boundaries.

The Henley Bed represents deposition in the deepest part of a marine "starved basin" (basin-floor environ-

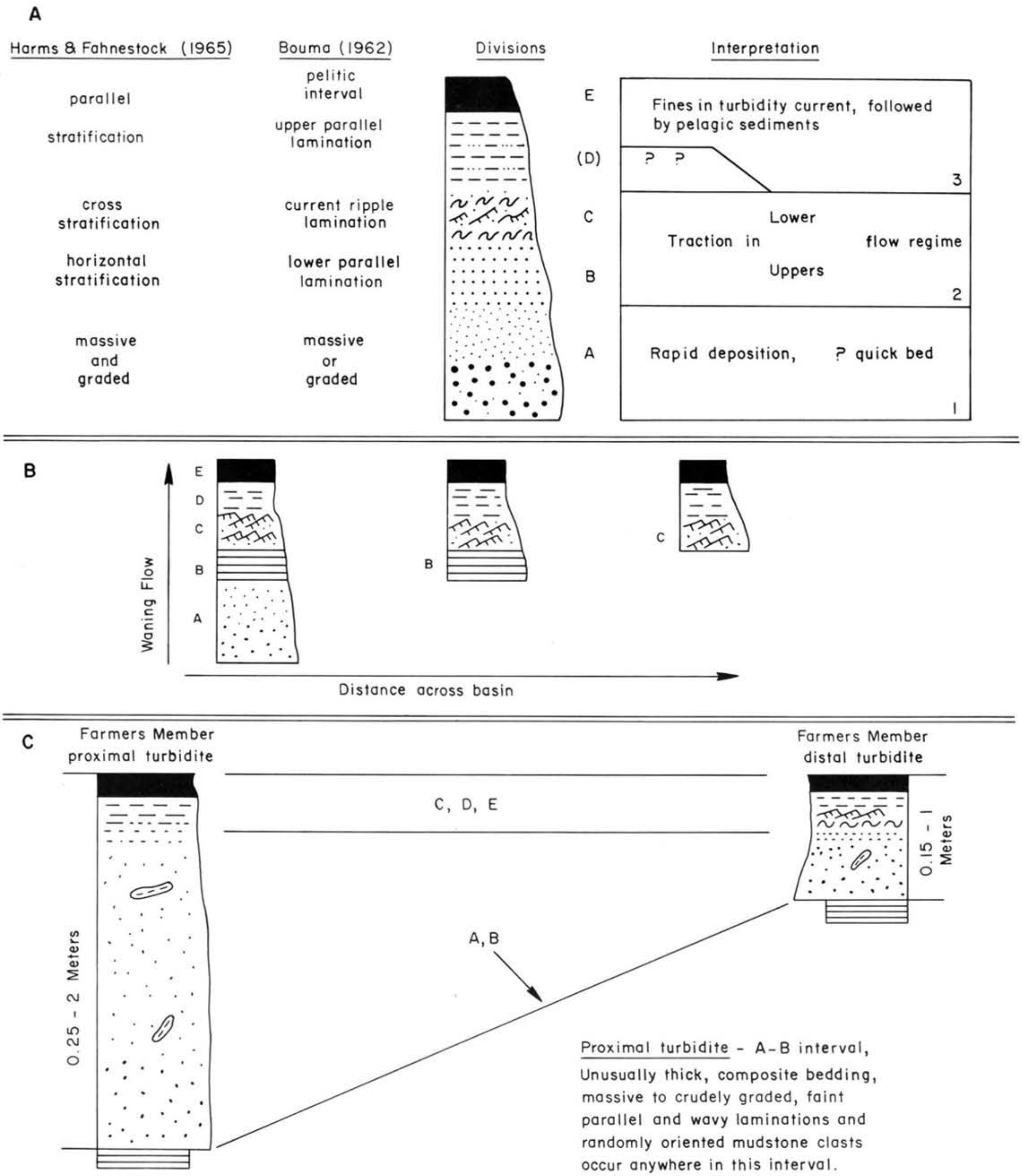

Figure 4. (A) Bouma's (1962) model for classic turbidites. After Link (1975) and Walker (1978). (B) Waning flow interpretation of Bouma sequence. Groups of turbidites that begin with divisions Tb and Tc were deposited by progressively slower flows that presumably were from a distant source. After Walker (1978). (C) Comparison of distal and proximal turbidite sedimentary features of the Farmers Member. All Bouma (1962) and Harms and Fahnestock (1965) intervals have been recognized in both types of turbidites; however, the Tc-Te intervals are commonly missing. The Tc interval is better developed in the distal turbidites.

ment) in which fine detritus accumulated very slowly. The environment was commonly dominated by hemipelagic and pelagic-like accumulations of muds, and was frequently interrupted by the influx of turbidity currents that carried very fine- to fine-grained sands and silts. Autochthonous mudstones and shales of the Henley occur as partings and thin interbeds in the overlying Farmers Member and separate the allochthonous sandstones and siltstones of turbidity current origin that comprise the Farmers Member. Therefore, the Henley Bed and the autochthonous mudstone and shale partings and thin interbeds (Henley) in the Farmers Member represent relatively long periods of slow sediment accumulation. In contrast, the allochthonous sandstones and siltstones of the Farmers Member represent very brief intervals of sediment accumulation from the intrusion of turbidity currents into a relatively deep "starved basin."

Farmers Member

The Farmers Member of the Borden Formation of northeastern Kentucky represents a regressive sequence of more proximal (north-northeast) to more distal (south-southwest) turbidite facies. The sequence consists of a monotonous succession of alternating tabular-bedded allochthonous sandstone-siltstones and autochthonous mudstone-shales (Fig. 5). Outcrops have been examined throughout the field trip area and 12 stratigraphic sections have been measured bed-by-bed and described using a vertical profile analysis (Visher, 1965) and bed-by-bed sequence analysis (Walker, 1967). Studies of lithologic character, bed thickness, internal sedimentary structures, sole mark types and directions of sole marks, and trace fossils have been completed on approximately 600 individual beds. Outcrop localities along Interstate 64 (Stops 4 and 5, Day 1) offer an unusual opportunity to literally walk the length of the beds in an attempt to trace individual beds and to note any slight lateral changes in lithologic character, bed thickness, internal sedimentary structures, sole marks, and trace fossil associations. When a single bed can be traced in large exposures, a typical property is the uniformity in thickness. Occasionally a bed pinches out or thickens, but parallelism of bedding planes is maintained to a remarkable degree (Fig. 5). Regionally, individual beds tend to thin and thicken and even pinch out more frequently to the north-northeast (more proximal facies) than to the south-southwest (more distal facies).

Individual thicknesses of sandstone beds in the more distal turbidite facies of the Farmers range from 9 to 95 centimeters; most beds have thicknesses of 20 to 30 centimeters. Thicknesses of the interbedded shale-mudstones range from 3 to 23 centimeters; most beds have a thickness of 10 to 20 centimeters in the distal turbidite facies. To the north-northeast (more proximal facies) the individual thicknesses of sandstone beds range from 5 centimeters to 2 meters; most beds have thicknesses of 10 to 25 centimeters. The shale-mudstone interbeds in the more proximal facies range in thickness from 1 to 65 centimeters; the overwhelming majority of beds have a thickness of only 1 to 5 centimeters. In the more proximal facies of the Farmers (Stone Hill section), 218 beds were measured over a stratigraphic thickness of approximately 31 meters, and 94 of the 109 mudstone-shale interbeds in the Farmers sequence had thicknesses of only 1 to 10 centimeters. The author's turbidite studies of the Farmers agree with Walker's (1967, p. 34) in that no consistent relationship between sandstone and mudstone thickness has been found. However, Nederlof (1959) has been able to demonstrate a prominent association between sandstone and mudstone thickness; he finds that the thick sandstones are associatied with the thicker mudstones.

The allochthonous sandstones of the Farmers commonly are composed of quartz (67 to 78 percent), illite (8 to 16 percent), kaolinite (5 to 9 percent), chlorite (2 to 6 percent), feldspar (2 to 4 percent), and siderite (0 to 2 percent). The autochthonous mudstone and shale interbeds (Henley) are commonly composed of quartz (45 to 56 percent), illite (25 to 38 percent), kaolinite (6 to 8 percent), chlorite (6 to 9 percent), feldspar (2 to 3 percent), and siderite (2 to 3 percent). Sandstones in the Farmers are very fine grained to fine grained, moderately to well sorted, and texturally submature to immature. Siltstones in the Farmers consist of medium- to coarse-grained silt, are poorly to moderately sorted, and are texturally immature.

The average thickness of the Farmers Member in the field trip area is 60 to 140 feet (18 to 43 m), and it reaches a maximum thickness of approximately 270 feet (82 m) to the north-northeast in the Garrison quadrangle (Chaplin and Mason, 1978). There is a marked thinning to the south-southwest to a thickness of 1 to 35 feet (3 to 11 m) in the Olympia quadrangle (McDowell and Weir, 1977). Thicknesses are misleading, as the lower and upper contacts, especially the upper contact of the Farmers, are highly gradational and placement of the lithic boundary in the field is highly subjective.

Internal sedimentary structures of the Farmers include parallel laminations (Fig. 6), ripple-drift laminations, cross laminations, convolute laminations, and associated flame structures (Fig. 6). At several localities along Interstate 64 fallen broken blocks provide an opportunity for study of these internal sedimentary structures in the third dimension. Sole marks make it possible to determine which way was originally up. The internal sequence of structures in sandstone beds of the

Figure 5. Thick-bedded turbidites of the Farmers Member (F) at Ramey section (Day 1, Stop 5) are overlain by Farmers-Nancy transitional beds (F-N); thick mudstone interbeds separate thin-bedded sandstone turbidites.

Farmers is similar to that attributed to turbidites by Bouma (1962). One of the most significant observations about turbidites was Bouma's recognition of an ideal sequence of internal sedimentary structures within many beds. The beds were divided into Division Ta (lowest), massive or graded; Division Tb, parallel laminations; Division Tc, current ripple lamination or convolute bedding; Division Td, parallel laminations; Division Te (highest), pelitic (Fig. 4A). This sequence was interpreted by Harms and Fahnestock (1965) and by Walker (1978) as a progressively decreasing flow regime with groups of turbidites beginning with Divisions Tb and Tc, and represents deposition from progressively slower flows that presumably were from a distant source (Fig. 4B). It seems that the rate of deposition of sediment determines whether a massive bed or laminated bed will form in the upper flow regime (and probably also in the lower flow regime) (Walton, 1967; Parkash and Middleton, 1970). This interpretation contrasts with the usually accepted idea that massive beds form in the upper part of the upper flow regime (Walker, 1965, p. 22; Harms and Fahnestock, 1965, p. 107). Walker (1967, p. 26) combined Bouma's Divisions Td and Te together and termed it interturbidite. This is because Division Td is normally impossible to recognize in weathered exposures. Individual divisions can be formed by other types of currents, and none in isolation can be considered uniquely diagnostic of turbidity current deposition. However, the repetition of complete or incomplete Ta-Te sequences through many meters of beds can at present best be explained by deposition from turbidity currents. In many turbidites, not all of Bouma's divisions are present, as noted by Walker (1967) and by other workers. Furthermore, the sequence of structures described by Bouma (1962) cannot be applied to all turbidite-type deposits, particularly those deposited in "proximal" situations (Walker, 1970; Corbett, 1972; Walker and Mutti, 1973). Well-established changes in turbidites with increasing distal conditions were summarized by Walker (1967, p. 32). In addition, Walker compared features of proximal turbidites with those of distal turbidites and noted that as the environment becomes more distal, bed thickness decreases exponentially, erosion becomes less common, and parallel laminations and cross laminations become more abundant. In the field trip area, similar features will be pointed out in the more proximal and distal facies of the Farmers Member. The terms "proximal" and "distal" do not necessarily apply to geographic position within a basin, but rather to the positions of upstream commencement and downstream termination of deposition from turbidity currents.

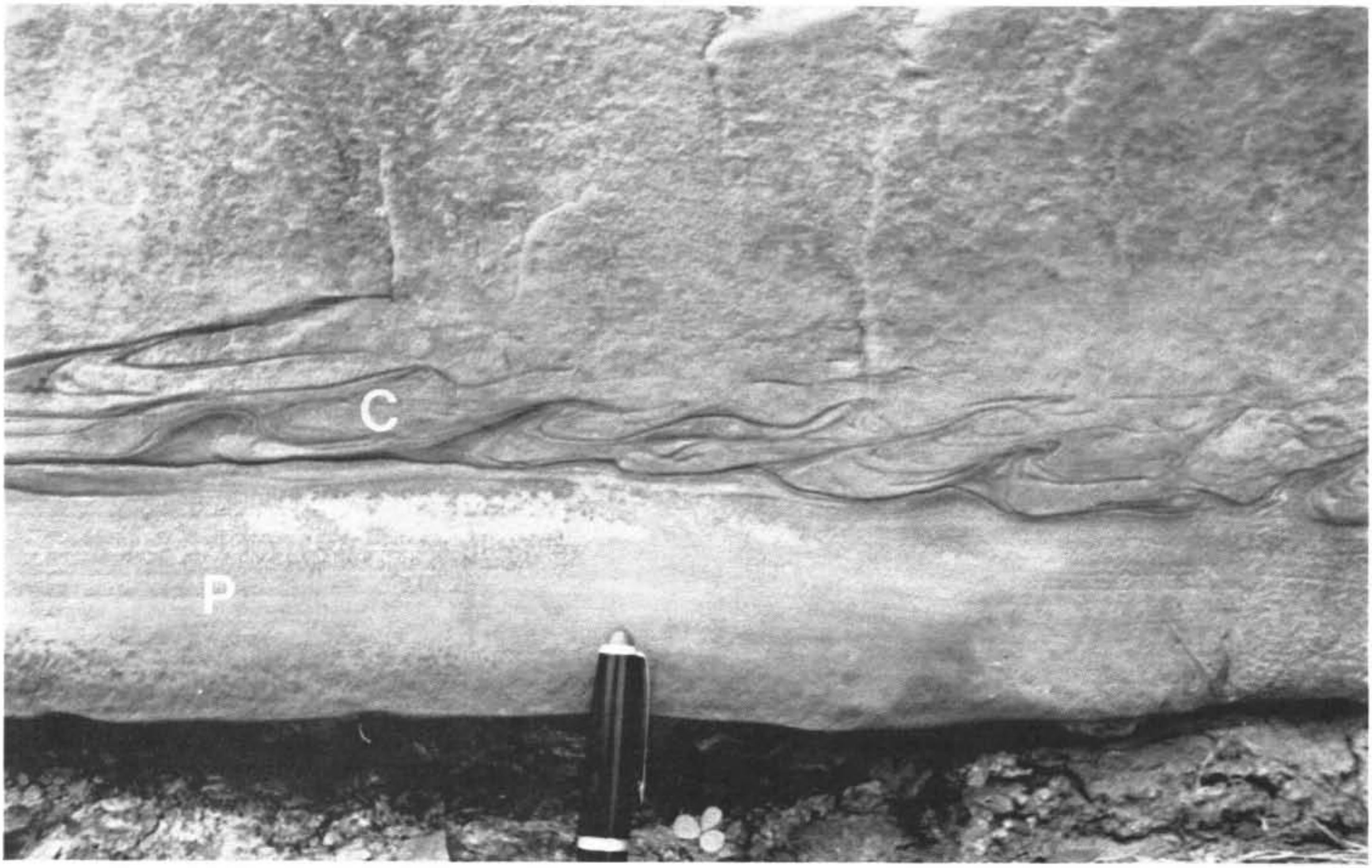

Figure 6. Turbidite bed 24 in Farmers Member along Interstate 64, at milepost 138.4, shows parallel laminations (P) and convolute laminations (C) and associated flame structures.

In the field trip area the most common Bouma divisions recognized are the Tb-Te (Fig. 7) and Tc-Te in the more distal turbidite facies and the Ta-Tb and Tc-Te in the more proximal turbidite facies. The massive or graded division (Ta) is thicker and better developed in the more proximal facies to the northeast. However, this division is usually represented by a massive or structureless interval and not by graded bedding. One explanation for the scarcity of grading may be the narrow range of grain size available at the site of deposition. The turbiditic sandstones were derived from well-sorted, very fine-grained sands so that during deposition, even from turbidity flow, no typical graded beds could be formed. Normark (1978) suggests that submarine fans fed directly from deltaic systems on continental shelves might display a restriction of grain-size distribution. Grading within individual sandstone beds in the Farmers is subtle. There is an upward decrease in the relative proportions of the largest size grades as the tops of most sandstones are extensively bioturbated. This suggests an increase in silt and clay-sized material upward. The very fine pelagic pelitic division (Te) of Bouma represents in principle a period of quiescence between periods of turbidity current activity, and some of these intervals in the Farmers bear an autochthonous conodont fauna. These pelitic horizons are generally found at the top or above individual turbiditic sandstone beds. Therefore, the intervening clay-mudstone layers in the Farmers and the uppermost, unlaminated, structureless clay-mudstones represent normal pelagic sedimentation. The most likely reason for the frequent absence of the pelitic division, as will be noted in the more proximal facies of the Farmers, is that it was never formed; the mud was swept away before deposition, either by an ocean current or by the succeeding turbidity current. Alternatively, the pelitic division might have been eroded after deposition by the scouring of a succeeding turbidity current. It is also possible that the current contained no excess mud after deposition of the lower four divisions (Ta-Td), and that a fine floor of non-turbiditic pelagic sediment could not be distinguished from the upper laminated division (Td).

Characteristics of turbidites in ancient and modern environments compared with features of the Farmers Member are shown in Table 1. A comparison of proximal and distal turbidite facies of the Farmers Member is

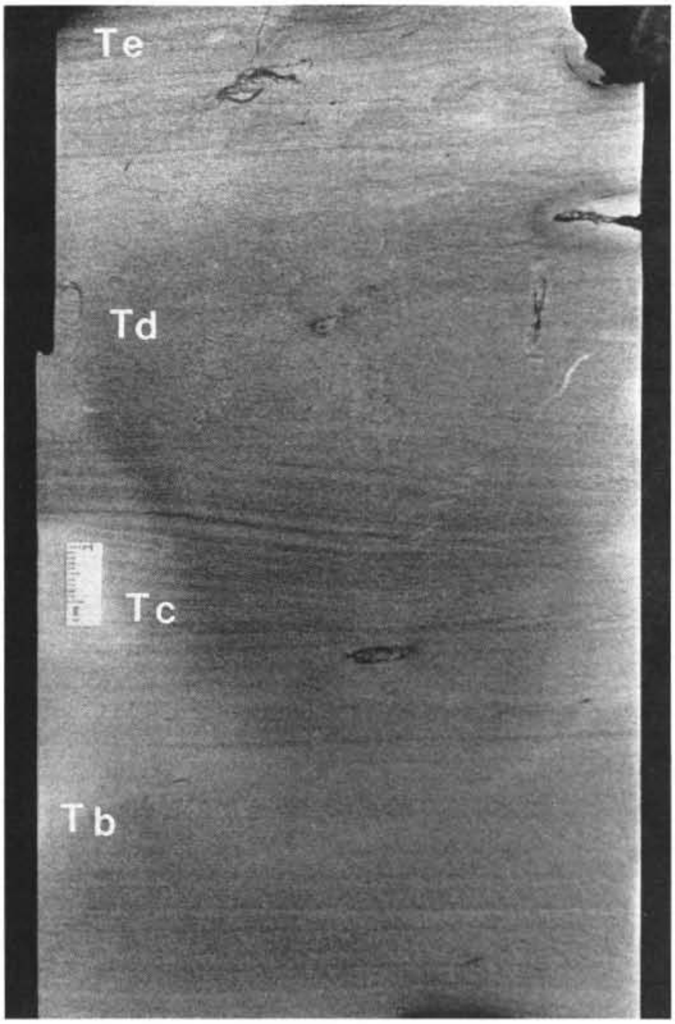

Figure 7. A polished slab from turbidite bed 17 in Farmers Member at Ramey section (Day 1, Stop 5) that was cut perpendicular to bedding shows Bouma divisions Tb-Te. Note burrowed zones.

shown in Figure 4C and in Table 2.

External sedimentary structures of the Farmers Member include low-amplitude ripple marks and sole marks (Figs. 8-11). Sole marks are best developed in the more distal facies and consist of linear indicators (groove casts, brush casts, and bounce casts) and undirectional indicators (load casts, flute casts, and prod casts). Sole marks are present in the more proximal facies but are poorly developed or highly scoured and consist mainly of load casts and flute casts (Fig. 12). Paleocurrent studies on sole marks in the more proximal facies are very difficult.

Body fossils are rare in the Farmers Member, but when present consist of fragmented brachiopods, fenestrate bryozoans, crinoid ossicles, gastropods, pelecypods, and cephalopods. The specimens are thought to have been more or less contemporaneously transported by turbidity currents from the shelf where they lived towards a deeper part of the sedimentary basin. Shell lag concentrates, especially of whole and fragmented brachiopods, have been found at the base and on the soles of individual sandstone beds (Fig. 13). They were probably the result of bottom-current winnowing. As these fossils have been redeposited by turbidity currents, however, they have no direct value as indicators of the depth of deposition of these beds. Nautiloids and goniatites of biostratigraphic value have been collected from some beds in the Farmers.

The Farmers Member contains an abundant and diverse trace fossil association. Trace fossils in the Borden Formation will be discussed in a later section.

Clarke (1969) and Moore and Clarke (1970) first suggested that the Farmers Member of eastern Kentucky was a turbidite sequence that had many of the features of the European flysch, but was deposited on the craton and not in a geosynclinal setting. Kepferle (1977) proposed a turbidite origin for the partly coeval Kenwood Siltstone Member of the Borden Formation in north-central Kentucky and adjacent Indiana. Kepferle proposed a revised subsea fan model he called a "thin" subsea fan model to explain the depositional pattern of the Kenwood. Whatever the process of sedimentation for the Farmers Member, the interpretation must account for: (1) the interrelationship between bed thickness, lithologic character, sole marks, internal sedimentary structures, and trace fossil associations; and (2) the sequence of internal sedimentary structures. In spite of the problems with interpreting turbidite deposits, the features listed in Table 1 are best explained by turbidity currents. The Farmers depositional sequence differs significantly from existing submarine canyon-fan models in that it lacks large-scale radial dispersal patterns as well as canyon and channeled river-fan facies (Fig. 14A, B). Radial progradation, which is characteristic of a large stable submarine fan, did not occur in the Farmers Member. Rather, uniform delta progradation from multiple point sources built a clastic wedge composed of a coalescing series of small, short-lived submarine fans. This uniform progradation is indicated by regional lithofacies patterns and the vertical and lateral sequence of sedimentary structures, trace fossil associations, and paleocurrent studies (Rich and Wilson, 1950; Wilson, 1950; Clarke, 1969; Moore and Clarke, 1970). The author envisions a depositional system in which shallow-marine deltaic deposits, a submarine fan-like complex, and turbidity currents explain the sedimentation for the Borden Formation, which is relatively deep- and shallow-marine deltaic deposition. Turbidite deposition is directly related to deltaic deposition and is generated by slumping and sliding of sediment toward deeper water, forming gravity flows on the front and flanks of a prograding delta. As flows

Table 1.—Characteristics of Turbidites in Ancient and Modern Environments Compared with Features of the Farmers Member of the Borden Formation. After Cline (1970), Kuenen (1964), and Others.

	FARMERS MEMBER		
FEATURES	Similar	Partly Similar	No Basis for Comparison
1. Alternating, monotonous sequence of fine- and coarse-grained strata	√		
2. Fine-grained beds are mainly pelagic, laminated shale or structureless mudstone	√		
3. Fine-grained beds are locally uniform in composition	√		
4. Coarser-grained beds are mainly fine-grained sandstone but sediments as fine as siltstone or as coarse as conglomerate occur locally		√	
5. Sorting tends to be moderate to good at any level in a bed and improves with decrease in grain size	√		
6. Graded bedding may be observed in coarser-grained beds but may be obscure due to provenance and distance		√	
7. Lower surfaces of coarse-grained beds commonly show sole marks which protrude downward into the underlying shale	√		
8. Sole marks have directional properties in which vectoral properties are less common than linear		√	
9. Where several beds are one above the other, the directional properties tend to be uniform for all the beds		√	
10. Thick stratigraphic sequences have vertical changes in bedding style resulting from thickness variations in shale or sandstone, or both	√		
11. Strong correlation between bed thickness and grain size	√		
12. Thickness of the beds varies from a few millimeters to 6 meters		√	
13. The bases of coarser-grained beds are abrupt; the tops may be somewhat less abrupt or grade into the overlying shale	√		
14. Complete Bouma cycles (Bouma, 1962) are present locally, but truncated bases or missing parts are more common		√	

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14. Complete Bouma cycles (Bouma, 1962) are present locally, but truncated bases or missing parts are more common		√	

Table 1.—Continued

FEATURES	FARMERS MEMBER Similar	Partly Similar	No Basis for Comparison
15. The laminated divisions (Tb or Td) are common in very fine-grained, sand- and silt-sized beds	√		
16. Top-truncated Bouma divisions are more common and there are fewer fines in proximal than distal beds	√		
17. Subaerial and shallow-water environmental indicators (i.e., large-scale crossbedding, mud cracks, shallow-water fauna and flora) are absent	√		
18. Distal beds become thinner, finer grained, and better sorted	√		
19. Individual sandstone beds persist laterally	√		
20. Shallow-water faunas are absent except where they have been displaced and incorporated into the coarser-grained beds; they are highly fragmented	√		
21. A lag concentrate of shells, one or two shells thick, is found locally at the base of some beds	√		
22. Trace fossils may occur on the upper bed surfaces where gradation occurs and may be missing where beds are truncated or are immediately overlain by another turbidite that has a thin or missing shale interbed	√		
23. Nearly all deep-sea turbidites are found on slopes of less than 1°		√	
24. Mud may occur as lumps (clasts) in beds		√	
25. The sand or silt may be rich in feldspar, angular quartz, glauconite, mica, and pyrite	√		
26. Many, but perhaps not all, of the sandstone beds are intruders in the shale environment; some have attributes of turbidites	√		
27. Plant remains are present			√
28. Slump and slide features are present			√

Table 1.—Continued

FEATURES	FARMERS MEMBER Similar	Partly Similar	No Basis for Comparison
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25. The sand or silt may be rich in feldspar, angular quartz, glauconite, mica, and pyrite	√		
26. Many, but perhaps not all, of the sandstone beds are intruders in the shale environment; some have attributes of turbidites	√		
27. Plant remains are present			√
28. Slump and slide features are present			√

Table 2.—Comparison of Proximal and Distal Turbidite Facies of the Farmers Member of the Borden Formation. After Walker (1967), Link (1975), and Others.

	FEATURES		DISTAL TURBIDITES (ROWAN COUNTY, KENTUCKY)	MORE PROXIMAL TURBIDITES (LEWIS COUNTY, KENTUCKY)
1.	Bedding		laterally continuous	laterally continuous to lenticular
2.	Bedding thickness		thin sandstone beds (generally less than 30 cm, commonly 15-20 cm); mudstone interbeds usually 5-15 cm thick	thick sandstone beds (up to 2 m thick, commonly 10-25 cm thick); mudstone interbeds commonly less than 5 cm thick, often absent
3.	Mudstone/shale partings		well developed	poorly developed to absent
4.	Bedding contacts		most commonly sharp bases and gradational tops	most commonly sharp bases and tops
5.	Sand/mud ratio		commonly 3:1	commonly 4:1
6.	Grain size		mean grain size 0.06-0.08 mm (very fine sand), well sorted; maximum grain size 0.125-0.25 mm (fine sand)	mean grain size 0.06-0.08 mm (very fine sand) to 0.125-0.149 mm (fine sand), well sorted; maximum grain size 0.25-0.30 mm (medium sand)
7.	Composition		very fine-grained sandstones and siltstones	very fine-grained and fine-grained sandstones
8.	Graded bedding		rare	rare
Bouma Divisions	Massive interval	Ta	commonly occurs at the base of the bed (structureless)	extremely thick interval (makes up entire bed to lower two-thirds of an individual bed); faint laminations throughout
Bouma Divisions	Parallel lamination	Tb	common to abundant; usually marks base of bed	common, occurs at base of fine-grained sandstone beds
Bouma Divisions	Ripples and convolute laminations	Tc	common to abundant; occurs in middle or near top of bed	rare to common; best seen in upper part of bed
Bouma Divisions	Parallel lamination	Td	common to abundant; occurs near top of sandstone and siltstone beds	rare to common; best seen near upper part of sandstone beds
Bouma Divisions	Pelitic (silt/clay)	Te	common to abundant; occurs at top of bed; usually highly bioturbated (*Zoophycos*)	common at top of bed; usually bioturbated (*Zoophycos*)
9.	Complete Ta-Te Bouma divisions		rare to common	very rare, usually absent
10.	Channel-like features		rare to absent	rare to common
11.	Mudstone clasts		rare to common	common, randomly oriented

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3. Mudstone/shale partings	well developed	poorly developed to absent
4. Bedding contacts	most commonly sharp bases and gradational tops	most commonly sharp bases and tops
5. Sand/mud ratio	commonly 3:1	commonly 4:1
6. Grain size	mean grain size 0.06-0.08 mm (very fine sand), well sorted; maximum grain size 0.125-0.25 mm (fine sand)	mean grain size 0.06-0.08 mm (very fine sand) to 0.125-0.149 mm (fine sand), well sorted; maximum grain size 0.25-0.30 mm (medium sand)
7. Composition	very fine-grained sandstones and siltstones	very fine-grained and fine-grained sandstones
8. Graded bedding	rare	rare
Bouma Divisions: Massive interval (Ta)	commonly occurs at the base of the bed (structureless)	extremely thick interval (makes up entire bed to lower two-thirds of an individual bed); faint laminations throughout
Bouma Divisions: Parallel lamination (Tb)	common to abundant; usually marks base of bed	common, occurs at base of fine-grained sandstone beds
Bouma Divisions: Ripples and convolute laminations (Tc)	common to abundant; occurs in middle or near top of bed	rare to common; best seen in upper part of bed
Bouma Divisions: Parallel lamination (Td)	common to abundant; occurs near top of sandstone and siltstone beds	rare to common; best seen near upper part of sandstone beds
Bouma Divisions: Pelitic (silt/clay) (Te)	common to abundant; occurs at top of bed; usually highly bioturbated (Zoophycos)	common at top of bed; usually bioturbated (Zoophycos)
9. Complete Ta-Te Bouma divisions	rare to common	very rare, usually absent
10. Channel-like features	rare to absent	rare to common
11. Mudstone clasts	rare to common	common, randomly oriented

Table 2.—Continued

FEATURES	DISTAL TURBIDITES (ROWAN COUNTY, KENTUCKY)	MORE PROXIMAL TURBIDITES (LEWIS COUNTY, KENTUCKY)
12. Composite bedding (amalgamation)	absent	rare to common
13. Sole Marks: Scour marks	rare to common; commonly show preferred directional properties	common to very abundant; rarely show preferred directional properties due to scouring
Sole Marks: Tool marks	common to very abundant; commonly show preferred directional properties	rare to common; rarely show preferred directional properties due to scouring; very small
14. Associated fauna (displaced shelf benthic faunas and nektonic/nekto-benthic faunas)	common lag deposits of brachiopods, bryozoans, and crinoid detritus on or near sole of bed; cephalopods and conularids common; conodonts and foraminifera present in interturbidite beds	rare to common lag deposits of brachiopods, bryozoans, and crinoid detritus on or near sole of bed; cephalopods and conularids rare to common; conodonts and foraminifera rare to absent in interturbidite beds
15. Bioturbation	common to very abundant; occurs on the sole, top, and within an individual bed as horizontal and vertical traces	rare to common; commonly occurs on the sole of an individual bed or near the top as horizontal traces; vertical traces common within a bed
16. Disturbed bedding	rare to common disruption of lamination by vertical burrows	common to abundant disruption of lamination by vertical burrows
17. Trace fossils	high diversity and high abundance	low diversity and low abundance

18. Ichnogenera	Archaeichnium-like
	Belorhaphe
	Biformites
	Bifungites
	Chondrites
	Cylindrichnus
	Helminthoida
	Helminthopsis
	Lophoctenium
	Monocraterion
	Paleodictyon
	Palaeophycus
	Planolites-like
	Protopaleodictyon
	?Rhizocorallium-like
	Rind burrow
	Scalarituba
	  Scalarituba-view
	  Neonereites-view
	  Phyllodocites-view
	Spirorhaphe
	Teichichnus
	Zoophycos
	  Type-1: helicoidal (spiral)
	  Type-2: planar or flat (circular, arcuate, lobed, or antler-like)
		Bifungites
		Cylindrichnus
		Helminthoida
		Helminthopsis-like
		Scalarituba
		  Scalarituba-view
		  Neonereites-view
		Zoophycos
		  Type-1
		  Type-2
		Unidentifiable horizontal branching, non-branching, and boxwork-like burrows (highly scoured)

Table 2.—Continued

FEATURES		DISTAL TURBIDITES (ROWAN COUNTY, KENTUCKY)	MORE PROXIMAL TURBIDITES (LEWIS COUNTY, KENTUCKY)
12.	Composite bedding (amalgamation)	absent	rare to common
13. Sole Marks	Scour marks	rare to common; commonly show preferred directional properties	common to very abundant; rarely show preferred directional properties due to scouring
	Tool marks	common to very abundant; commonly show preferred directional properties	rare to common; rarely show preferred directional properties due to scouring; very small
14.	Associated fauna (displaced shelf benthic faunas and nektonic/nekto-benthic faunas)	common lag deposits of brachiopods, bryozoans, and crinoid detritus on or near sole of bed; cephalopods and conularids common; conodonts and foraminifera present in interturbidite beds	rare to common lag deposits of brachiopods, bryozoans, and crinoid detritus on or near sole of bed; cephalopods and conularids rare to common; conodonts and foraminifera rare to absent in interturbidite beds
15.	Bioturbation	common to very abundant; occurs on the sole, top, and within an individual bed as horizontal and vertical traces	rare to common; commonly occurs on the sole of an individual bed or near the top as horizontal traces; vertical traces common within a bed
16.	Disturbed bedding	rare to common disruption of lamination by vertical burrows	common to abundant disruption of lamination by vertical burrows
17.	Trace fossils	high diversity and high abundance	low diversity and low abundance

18.	Ichnogenera	*Archaeichnium*-like
		Belorhaphe
		Biformites
		Bifungites
		Chondrites
		Cylindrichnus
		Helminthoida
		Helminthopsis
		Lophoctenium
		Monocraterion
		Paleodictyon
		Palaeophycus
		Planolites-like
		Protopaleodictyon
		?Rhizocorallium-like
		Rind burrow
		Scalarituba
		  Scalarituba-view
		  Neonereites-view
		  Phyllodocites-view
		Spirorhaphe
		Teichichnus
		Zoophycos
		    Type-1: helicoidal (spiral)
		    Type-2: planar or flat (circular, arcuate, lobed, or antler-like)
			Bifungites
			Cylindrichnus
			Helminthoida
			Helminthopsis-like
			Scalarituba
			  Scalarituba-view
			  Neonereites-view
			Zoophycos
			  Type-1
			  Type-2
			Unidentifiable horizontal branching, non-branching, and boxwork-like burrows (highly scoured)

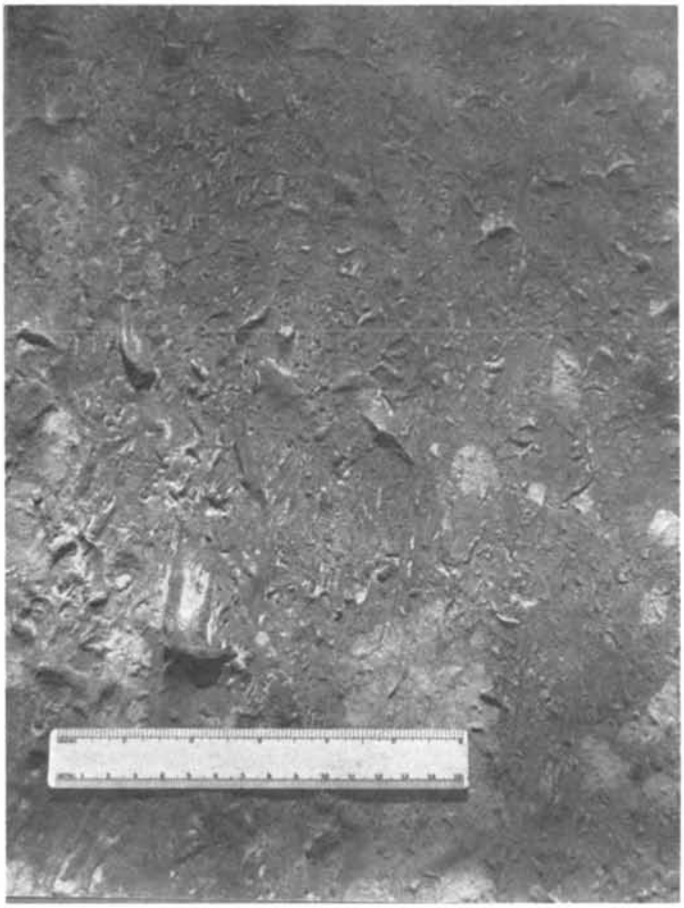

Figure 8. Sole of turbidite bed in Farmers Member at Ramey section (Day 1, Stop 5) shows tool marks.

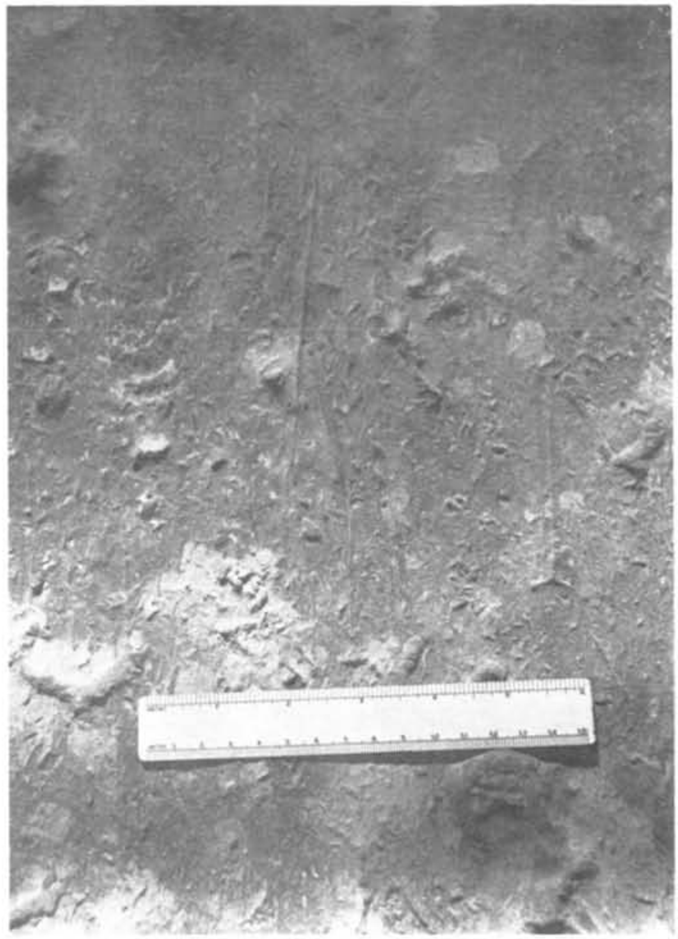

Figure 9. Sole of turbidite bed in Farmers Member along Interstate 64, at milepost 134.5, shows tool marks and groove casts.

of unconsolidated sediment deposit material and move farther from the source, they change into lower concentration sediment gravity flows which later form distal turbidites. The resulting submarine fan-like complexes form at the front and flanks of the prograding delta; this provides a likely sediment source, which under the influence of gravity slumped or slid into deeper water. As the delta progrades and fills the basin, the turbidites derived from it are covered by prodelta, delta front, delta platform, and eventually shallow-marine high intertidal and shallow subtidal carbonates. In this proposed depositional system a delta explains the deposition of the Farmers Member because (1) a delta-river system is the best and most logical source to supply the large quantity of clastic sediment needed to fill a basin and deposit the Farmers Member; (2) a delta permits a continuous point source or area of sedimentation for a progradational sequence to build out into and across a basin; (3) proximity to deltaic deposits could explain the very thick sandstone and mudstone beds in both the relatively deep- and shallow-marine facies in the Borden Formation; and (4) a growing delta would provide a likely source of unconsolidated sediment to supply a prograding submarine fan-like complex. In spite of a paucity of modern analogs for such a depositional system, the Farmers Member of the Borden Formation and other ancient examples attest to the significance of turbidite sedimentation in deltaic settings.

Farmers-Nancy Transitional Beds

In the southwestern part of the field trip area a transitional interval approximately 13 feet (4 m) thick, commonly consisting of five to six turbiditic sandstones (10 to 20 centimeters thick) and five to six mudstones (20 centimeters to 1 meter thick) overlies the massive sandstones typically mapped as Farmers (Fig. 15). This interval is appreciably thicker and contains several thicker mudstone beds which separate several thinner turbiditic sandstone beds in the northeastern part of the area. This interval is herein designated as the Farmers-Nancy transitional beds, as it separates the more massive sandstones of the Farmers below from the bluish-

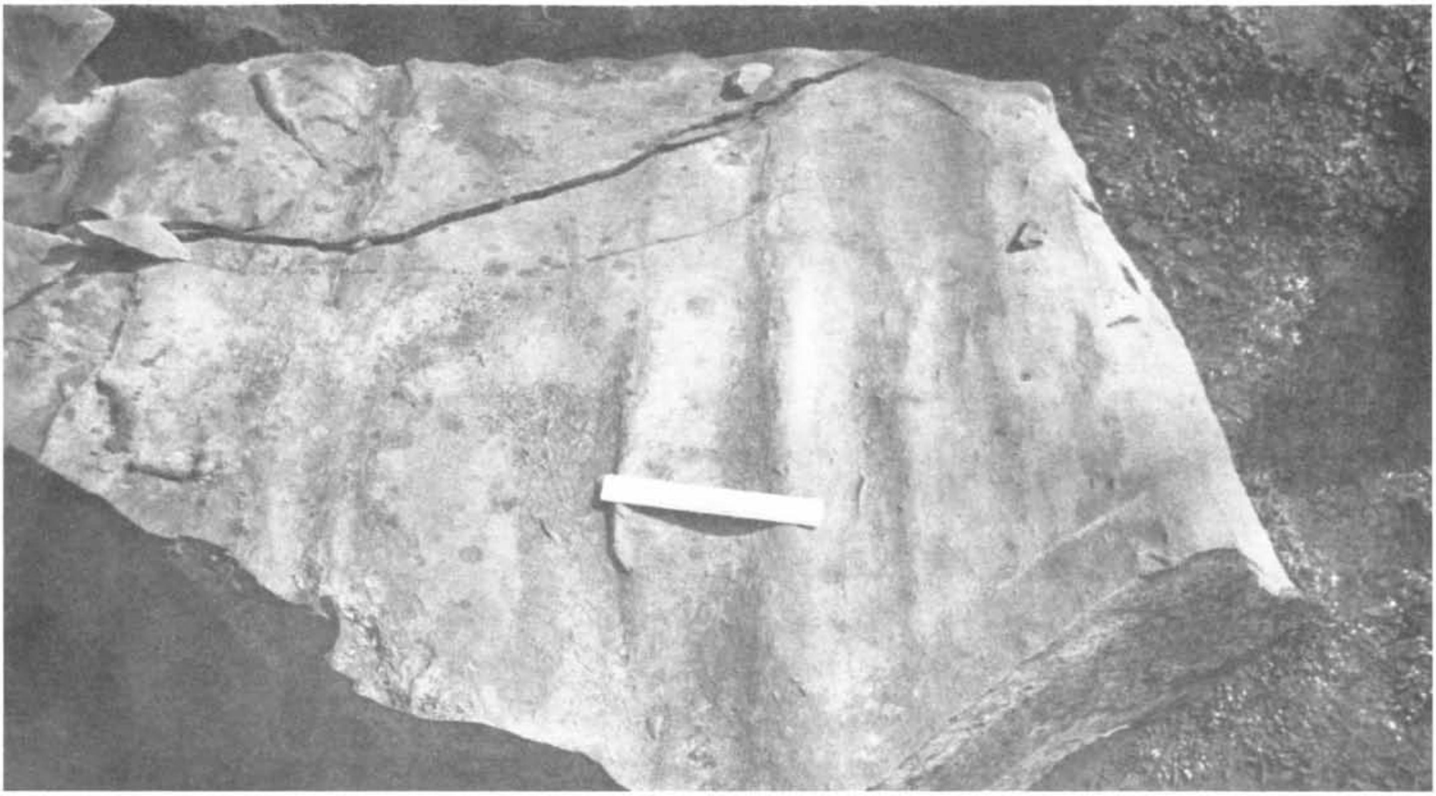

Figure 10. Sole of turbidite bed in Farmers Member along Interstate 64, at milepost 138.4, shows large load casts. Ruler is approximately 15 centimeters long.

gray, silty, sideritic shales of the Nancy Member above. The turbiditic sandstones in this interval contain excellent sole marks, consisting of well developed load casts, groove casts, and tool marks (Figs. 16 and 17). An abundant and diverse trace fossil association is found on the soles and tops of the turbiditic sandstones. *Zoophycos* type-2 traces are very abundant in the lower, glauconite-streaked sandstones. The sandstone beds tend to thin and thicken and are often difficult to trace laterally. The mudstones and shales in this interval are typically Nancy-like and contain abundant fossiliferous sideritic nodules, lenses, and beds. It is within this stratigraphic interval that a diverse and abundant cephalopod fauna (nautiloids and goniatites) has been collected and is presently under study by the writer and Charles Mason (George Washington University). Other body fossils collected from this interval include brachiopods, fenestrate bryozoans, pelecypods, trilobites, gastropods, conularids, vertebrate jaw structures, and pelmatozoan detritus (Fig. 18).

Figure 11. Sole of turbidite bed 9 in the Farmers Member along Interstate 64, at milepost 134.5, shows overlapping flutes.

Nancy Member

The Nancy Member is highly gradational with the underlying Farmers Member; there is a transitional interval of 13 to 16 feet (4-5 m) in the Morehead area. However, to the north-northeast this transitional interval is frequently 16 to 33 feet (5-10 m) thick, making the precise placement of the lithic boundary difficult. The upper contact of the Nancy with the overlying Cowbell

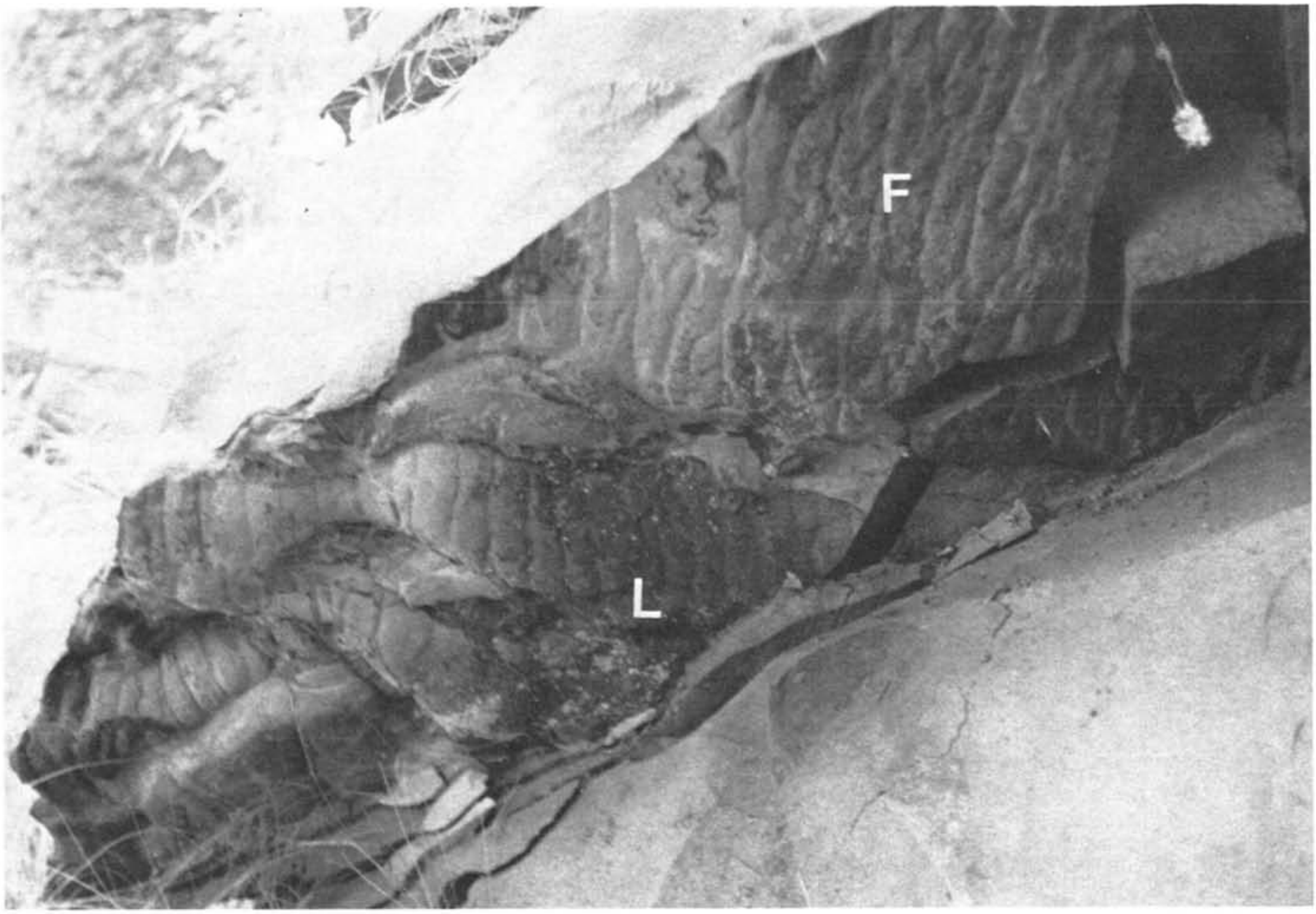

Figure 12. Sole of turbidite bed 167 in Farmers Member at Stone Hill section (Day 2, Stop 2) shows scoured load casts (L) and flutes (F).

Member is also highly gradational; there are transitional beds throughout the stratigraphic interval of 10 to 33 feet (3-10 m). The thickness of the Nancy Member in the northeastern part of the field trip area is approximately 200 feet (61 m); minimum thickness is approximately 30 feet (9 m) in the Morehead area, and maximum thickness is approximately 400 feet (122 m) southwest of the field trip area in the Olympia quadrangle. Some of the thickness variation can be attributed to placement of the lower and upper contacts of the member.

The Nancy consists of bluish- to greenish-gray, silty, highly bioturbated shales. The member increases in silt content and decreases in bioturbation upward. The Nancy contains fossiliferous, highly mineralized, sideritic nodules, lenses, and beds throughout, but they are most abundunt in the lower 20 feet (6 m). Many of the sideritic nodules in the Nancy are composite burrows; they consist of one larger tubular burrow ranging from 1 to 3 centimenters across and one or more different smaller burrow(s) within the larger one. The most common trace found within the larger burrow is the three-dimensional branching system of *Chondrites*, in which each branch diverges at approximately 45 degrees from the previous tube which is either lateral or less horizontally inclined. The systems range in width to several centimeters and often weather out on benches cut into the Nancy Member. Bioturbation has destroyed most traces of primary sedimentary structures. In the southwestern part of the field trip area (Morehead region), a 67-centimeter-thick turbiditic sandstone bed commonly occurs approximately 26 to 33 feet (8-10 m) above the base. This turbidite bed is similar in lithologic character, internal sedimentary structures, and trace fossil associations to those found in the underlying Farmers Member. The bed is highly variable in thickness and at some localities in the Morehead area it pinches out laterally (Fig. 19). The sole of this bed contains excellent traces of *Helminthopsis* and *Bifungites* and well developed load casts (Figs. 20 and 21). The top of the bed contains low-amplitude ripple marks and numerous *Zoophycos* (Fig. 22). At some localities (Stop

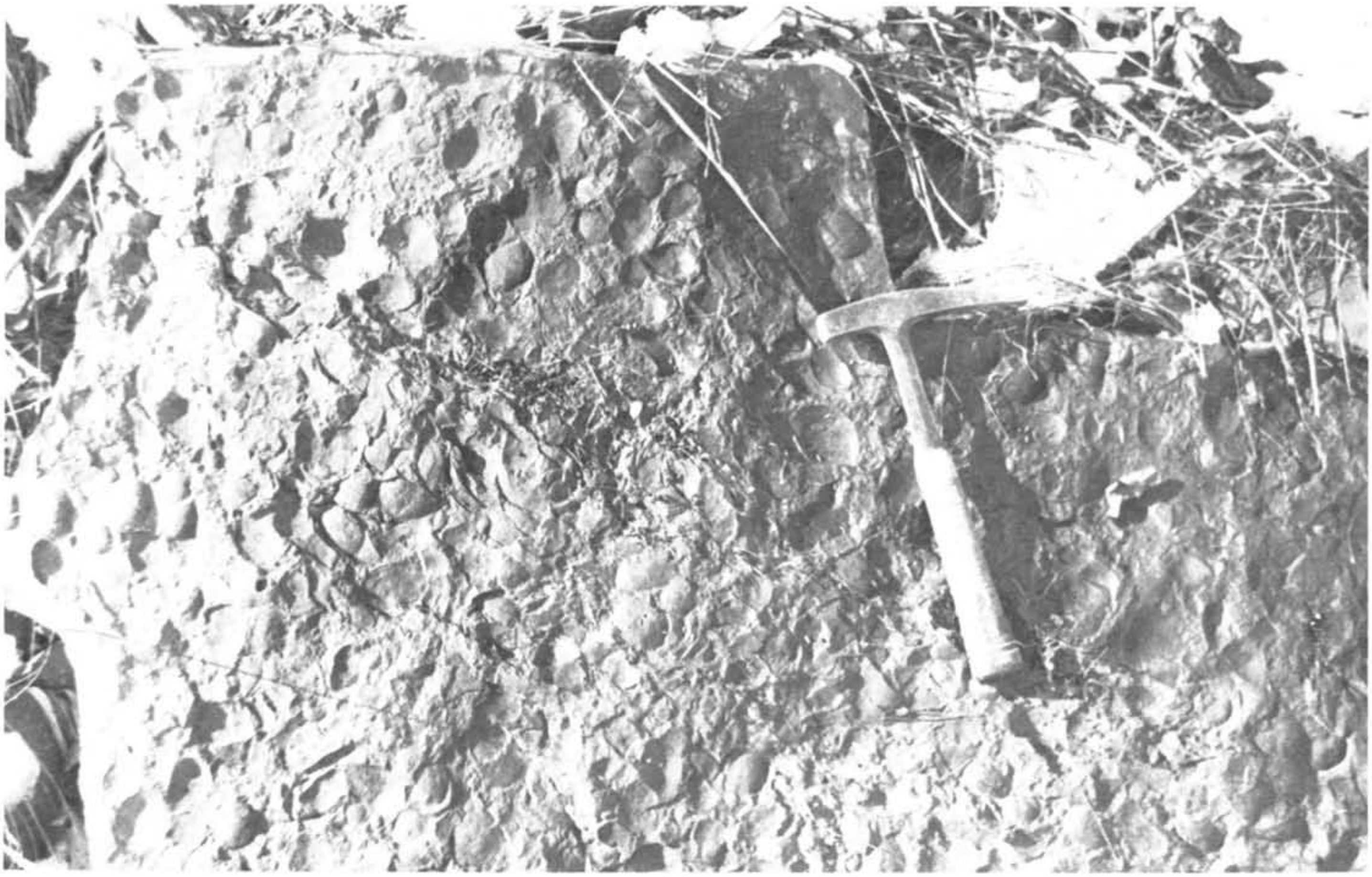

Figure 13. Sole of turbidite bed in Farmers Member along Ky. Highway 59, approximately 0.4 mile north of junction of Ky. Highways 59 and 24 contains lag deposit of brachiopods.

4, Day 1, Bull Fork section) this bed contains scattered, deeply-weathered limonitic pockets containing abundant pelecypods, gastropods, cephalopods, brachiopods, fenestrate bryozoans, trilobite fragments, and pelmatozoan detritus. This bed is well exposed at Stop 4, Day 1 (Bull Fork section) and Stop 5, Day 1 (Ramey section).

Body fossils are common in the sideritic nodules, lenses, and beds. The most common fossil forms include brachiopods, cephalopods, gastropods, and conularids. Less common forms include trilobites, fenestrate bryozoans, pelmatozoan detritus, pelecypods, hyolithids, ostracodes, corals, conodonts, foraminifera, and fish teeth, scales, and spines. Fossils in the Nancy are most commonly preserved as internal molds and casts that are infilled or replaced with barite, sphalerite, pyrite, galena, and, on occasion, marcasite, dolomite, and quartz. The cephalopod fauna in the Nancy is highly diverse and abundant. Goniatites and nautiloids commonly occur together, though one or the other dominates in particular horizons. Common goniatite genera occurring in the Nancy and the underlying Farmers-Nancy transitional beds include *Meunsteroceras* spp. (Fig. 23), *Protocanites* spp., *Imitoceras* sp., *Karagandoceras* sp., and *Kazakhstania* sp. The most common nautiloid genus is *Triboloceras* spp. The cephalopod association indicates a strong affinity to lower Osagean cephalopod faunas described from the midcontinent of the United States (Charles Mason, personal commun.; Mason and Chaplin, 1979).

The Nancy Member is a prodeltaic deposit. Characteristics of prodelta deposits in ancient and modern environments are compared with features of the Nancy Member in Table 3. A summary of bedding features, sedimentary structures, associated fauna, and trace fossils of the prodelta lithofacies of the Nancy Member are shown in Table 4.

Cowbell Member

The Cowbell Member is highly gradational with the Nancy Member below and the overlying Nada Member. Transitional beds occur throughout the stratigraphic interval of approximately 10 to 33 feet (3-10 m) at the base and at the top throughout the field trip area (Fig. 24). The Cowbell Member is approximately 300

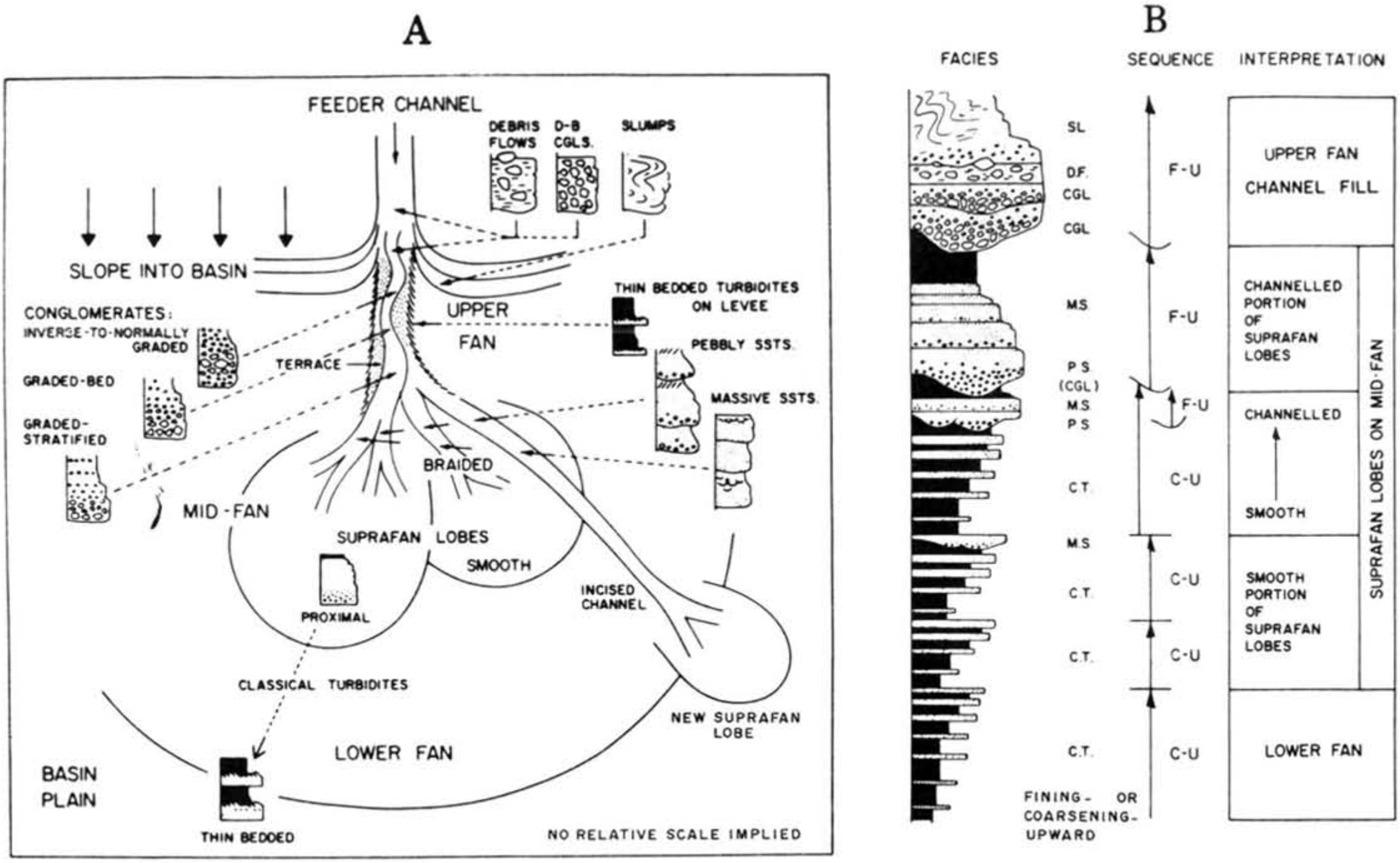

Figure 14. (A) Submarine-fan model and associated turbidite facies. From Walker (1978, p. 946). Used with permission of American Association of Petroleum Geologists. (B) Hypothetical stratigraphic sequence developed during fan progradation. C-U: Thickening- and coarsening-upward sequence. F-U: Thinning- and fining-upward sequence. C.T.: Classic turbidites. M.S.: Massive sandstones. P.S.: Pebbly sandstones. CGL: Conglomerate. D.F.: Debris flows. SL: Slumps. From Walker (1978, p. 948). Used with permission of American Association of Petroleum Geologists.

feet (91 m) thick throughout the field trip area; maximum thickness is 380 feet (116 m) in the Friendship (Erickson, 1966) and Portsmouth (Sheppard, 1964) quadrangles to the northeast. The Cowbell thins rapidly southwest of the field trip area.

The Cowbell Member consists of five relatively distinct lithologic units, which, following Kearby (1971), are designated: Unit 1—lower massive siltstone unit; Unit 2—dark shale unit; Unit 3—unit of abundant primary sedimentary structures; Unit 4—unit of alternating siltstone and shale; and Unit 5—upper massive siltstone unit. These five lithologic units are fairly traceable throughout northeastern Kentucky, but become less distinct south-southwest of the Morehead area.

The lower massive siltstone unit, Unit 1, varies in thickness from 134 feet (41 m) to 177 feet (54 m). It consists of massive, micaceous, sandy, highly bioturbated siltstones which become very shaly in particular horizons. Scattered, discontinuous, fossiliferous sideritic lenses, beds, and nodules occur throughout but are most abundant in the middle of the unit. The lower portion of the unit is highly bioturbated and outcrop surfaces are highly pitted and rough due to intensive burrowing. Sedimentary structures are poorly developed in the lower portion of the unit, but on occasion small-scale scour features and faint parallel and wavy laminations can be seen. Mud and shale clasts occur throughout the unit. Kearby (1971, p. 21) noted the absence of any bedding or primary sedimentary structures in this unit. However, in the upper 65 feet (20 m) of the unit, parallel, wavy, and cross laminations are well developed, along with climbing ripples and small-scale scour features. Scattered fossiliferous horizons occur throughout; brachiopods, bryozoans, and pelmatozoan detritus are the most common fossil types. Trace fossils are abundant but are not diverse; vertical burrows are most common in the coarser-grained beds and horizontal burrows are most common in the finer-grained, shaly siltstones. Abundant vertical and oblique, silt-filled burrows and "communal tubes" (that is, sets of sand tubes that show general "U-in-U" arrangement but touch rather than cut into each other)

Figure 15. Farmers Member (F), Farmers-Nancy transitional beds (F-N), and Nancy Member (N) at Bull Fork section (Day 1, Stop 4).

occur approximately 144 feet (44 m) above the base of the unit (Fig. 25).

The dark shale unit, Unit 2, overlies Unit 1 and varies in thickness from 26 feet (8 m) to 33 feet (10 m). It consists of olive-gray to dark-gray, parallel laminated, bioturbated silty shale and shaly siltstone which contain abundant reddish-brown, fossiliferous, sideritic nodules and lenses. These sideritic nodules are highly mineralized with galena, pyrite, sphalerite, barite, and calcite, and contain nautiloids, goniatites, pelecypods, gastropods, brachiopods, bryozoans, and pelmatozoan detritus. Reddish-brown siltstone lenses with varved-like bedding contain abundant three-dimensional branching systems of the trace fossil *Chondrites*. Horizontal grazing traces are common throughout the unit. The base of this unit is gradational with Unit 1.

Unit 3, the unit of abundant primary sedimentary structures, varies in thickness from 30 feet (9 m) to 59 feet (18 m) and consists of light-bluish-gray to light-olive-gray, massive, bioturbated siltstone and silty shale. Shaly beds are most common in the lower part of the unit and near the top. The base of this unit is gradational with Unit 2. Primary sedimentary structures are well developed throughout this unit but can be best observed in the lower half. Primary sedimentary structures include small-scale, low-angle crossbedding, wavy laminations, parallel laminations, cross laminations, ripple-drift cross laminations, convolute laminations, scour-and-fill structures, sand wave structures, ripple marks, and small, soft-sediment deformation features (Figs. 26-28). Many of the scour-and-fill structures are infilled with fossil, especially pelmatozoan, detritus (Fig. 29). Scattered sideritic siltstone lenses occur throughout and often contain fragmented brachiopods, bryozoans, corals, and pelmatozoan detritus. Parallel laminations in the siltstones are often bent downward along traces of vertical burrows (Fig. 30). Traces are common to abundant; both vertical and horizontal types are well represented. Many of the vertical burrows have truncated tops due to scouring. Many outcrop faces display excellent cross-sectional views of horizontal feeding traces.

The unit of alternating siltstone and shale varies in thickness from approximately 45 feet (14 m) to 30 feet (9 m). Unit 4 consists of alternating beds of bluish-gray to light-olive-gray, glauconite-streaked, bioturbated

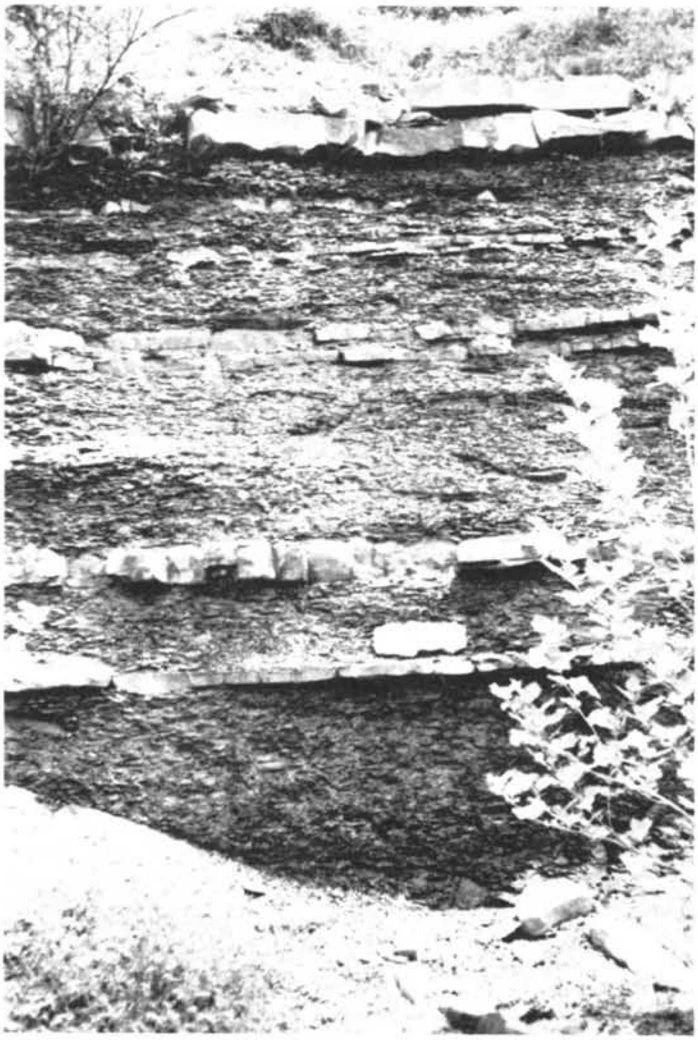

Figure 16. Farmers-Nancy transitional beds along Interstate 64, at milepost 142.0. Note load casts on sole of uppermost turbidite bed.

siltstones and highly bioturbated silty shales (Fig. 31). Primary sedimentary structures are rare, although some siltstones have parallel laminations at their base. Faint cross laminations and low-angle, small-scale crossbedding can be seen in some siltstone beds. Highly fossiliferous siltstone beds and lenses in the lower half of this unit contain body fossils of brachiopods, fenestrate bryozoans, rugose corals, and pelmatozoan detritus. Less common body fossils, occurring locally, include goniatites, nautiloids, trilobite fragments, and gastropods. Trace fossils are abundant throughout, but particularly common are vertical tapering and nontapering burrows, some of which extend throughout the entire thickness of individual siltstone beds. Numerous traces have been found on the soles of some siltstone beds, particularly near the top of the unit. This unit is slightly gradational with Unit 3 below.

Unit 5, the massive siltstone unit, is the uppermost unit. It varies in thickness from 10 to 19 feet (3-6 m) and consists of yellowish-gray to light-bluish-gray, sandy, micaceous, glauconite-streaked, massive siltstone with thin interbeds of silty shale. The unit becomes more shaly in the upper part. It contains greenish-gray shale clasts throughout. Sedimentary structures include primarily wavy and parallel laminations with alternating light and dark laminae. Locally, this unit may contain large, well-rounded, burrowed, silty concretions up to 30 centimeters in diameter. Siltstone beds near and at the top of this unit are often highly fossiliferous, containing abundant molds and body fossils of brachiopods, bryozoans, rugose corals, cephalopods, pelecypods, gastropods, and pelmatozoan detritus. Abundant vertical tapering and non-tapering burrows are common throughout the unit. The soles of some siltstone beds contain excellent traces, particularly horizontal, meandering types. The upper contact of this unit is sharp at some localities while at others, especially to the north-northeast, a gradational interval of several tens of feet can be seen.

The Cowbell Member represents a delta front depositional system. It is comprised of a complex of associated sub-environments in the advancing locus of active deposition of a prograding delta. Interdeltaic bay (Units 2 and 4) and distal bar (Units 1, 3, and possibly 5) are recognizable sub-environments of this depositional system. Characteristics of delta front (distal bar) and interdeltaic bay deposits in ancient and modern environments are compared with features of the Cowbell Member of the Borden Formation in Table 5. Table 6 is a summary of bedding features, sedimentary structures, associated fauna, and trace fossils of the interdeltaic bay and distal bar lithofacies of the Cowbell Member. Further studies of the Cowbell Member at localities where there are good vertical and lateral exposures will undoubtedly revise details of this depositional system.

Nada Member

Stratigraphically, the Nada Member is between deeper water clastics of the Borden Formation (below) and shallow water carbonates of the Newman Limestone (above). It is a highly variable member with regard to lithologic character and stratigraphic thickness. The thickness of the Nada ranges from 0 to 50 feet (0-15 m) in the field trip area and thickens to approximately 75 feet (23 m) southwest of the Morehead area. The lower contact of the Nada Member is most commonly highly gradational through several tens of feet. A prominent red shale, which some workers use to mark the base of the Nada, occurs several tens of feet below

Figure 17. Farmers-Nancy transitional beds along Interstate 64, at milepost 142.2. Load casts on sole of lower turbidite bed protrude into underlying shale. Note sharp base of overlying turbidite bed.

typical Cowbell lithologies at some localities along U.S. Highway 23 near Siloam, in Greenup County. This attests to the highly transitional nature of the Nada lithofacies. The upper contact is most often sharp. The nature of units overlying the Nada is quite variable and complex. Throughout the field trip area the Nada may be overlain by the Renfro Member or the Newman Limestone; at some localities the Nada is overlain by orthoquartzitic sandstones or bay-fill shales of the Breathitt Formation (Pennsylvanian).

The Nada consists of dark-red, greenish-gray, and grayish-purple mudstones and shales with thin, intercalated beds, lenses, and pods of sandy, glauconite-streaked, bioturbated siltstones. Locally, the Nada Member may contain discontinuous beds and lenses of glauconite-streaked, crossbedded, ripple marked, crinoidal skeletal wackestones, packstones, and grainstones. Glauconite grains and pellets occur throughout the Nada but may be especially concentrated in particular horizons. At the Perry Branch section (Day 1, Stop 1) an extremely glauconite-rich horizon occurs approximately 4 feet (1.2 m) below the top of the member. Many bryozoan zooecia and burrows are infilled with glauconite. In addition to glauconite, phosphate nodules occur in the Nada. These nodules, particularly those occurring in the upper part, often consist of phosphatized aggregates of brachiopods, pelmatozoan detritus, and gastropods that have all been highly bored.

Sedimentary structures in the Nada include ripple marks (common in siltstones) and low-angle crossbedding (common in carbonates). Body fossils in the Nada are very abundant, especially in carbonate lenses, and include, in order of decreasing abundance, brachiopods, bryozoans, pelmatozan detritus (especially crinoids), rugose corals, gastropods, pelecypods, and goniatites. The most abundant megafossils (brachiopods, bryozoans, crinoids, and rugose corals) are all suspension-feeding organisms. Microfossils recovered from the Nada include conodonts, foraminifera, glauconitized bryozoan zooecia, pyritized burrows, and fish plates and teeth. Conodonts occur throughout the Nada but relative abundances and diversities are higher in the carbonate lenses. Conodont studies do

Figure 18. Turbidite bed in Farmers-Nancy transitional beds at North Fork Triplett Creek, just north of confluence with Dry Branch, has fossil lag deposit.

not indicate a significant increase in conodont abundance within glauconite-rich zones as reported by Whitehead (1976) in his study of the partly coeval Muldraugh Formation in southern Indiana and north-central Kentucky. A biostratigraphic zonation for Osagean rocks in northeastern Kentucky utilizing conodont studies is in preparation by the writer; a biostratigraphic zonation by Charles Mason will utilize studies on cephalopod faunas.

Trace fossils are common throughout the Nada but are especially well preserved in shaly siltstone beds. The abundance and diversity of traces in the Nada will be discussed later.

The Nada Member represents a delta platform lithofacies and marks the beginning of delta destruction (marine transgression). The occurrence of glauconite-rich layers and bored phosphate nodules in the Nada indicates a depositional pause that may have been due to a marine transgression across the platform. The delta platform lithofacies can be subdivided into a skeletal carbonate bank facies (crinoidal carbonates) and an interdeltaic bay facies (shales, mudstones, and siltstones). The delta platform is subject to more variable depositional conditions than more distal parts of the delta; this may partially explain the variability of the lithologic character and stratigraphic thickness of the Nada and the quite variable and complex stratigraphic relationship of the Nada with overlying and adjacent strata. The bedding features, sedimentary structures, associated fauna, and trace fossils of the delta platform lithofacies of the Nada Member are summarized in Table 7.

Renfro Member

The Renfro Member consists of yellowish-orange, microcrystalline to finely crystalline, argillaceous dolomite and dolomitic limestone with partings, seams, and thin beds of greenish-gray shale. Relict, unfossiliferous laminations and irregular patches and vugs of calcite spar which suggest birdseye structures are locally common in the member. Parallel laminations and mat-like structures broken by vertical veinlets which resemble dessication cracks are common in the Renfro. The thickness of the Renfro varies from 0 to 20 feet (0-6 m) in the field trip area and the member thickens to the south-

Figure 19. Turbidite bed in lower part of Nancy Member along Interstate 64, at milepost 135.3, pinches out to the west.

west. The lower contact with the Nada Member is sharp to highly gradational. Body fossils are rare in the Renfro, but when present there are brachiopods, bryozoans, and pelmatozoan detritus. Microfossils are rare, but conodonts have been recovered in the more limy facies of the Renfro, especially near the top. The fauna contains zonal indices of the *Apatognathus scalenus-Cavusgnathus* Zone which characterizes the St. Louis Formation in the type Mississippi Valley region (Chaplin, 1979). Therefore, in the Morehead area at least, the uppermost part of the Renfro is lower upper Meramecian in age. The more dolomitized facies of the Renfro has not yielded, as yet, any zonally determinable conodont faunas. Trace fossils are rare in the Renfro Member, but at some localities, particularly near the top of the member, unidentifiable vertical burrows have been noted.

The Renfro Member appears to be more closely related genetically to the overlying carbonate platform facies of the Newman Limestone than to the underlying deltaic clastics of the Borden Formation. A close lithostratigraphic relationship with the overlying St. Louis Member of the Newman Limestone is suggested by the frequent intertonguing of Renfro-like lithology with St. Louis-like lithology. A close biostratigraphic relationship is indicated, at least for the upper part, by the common occurrence of similar conodont zonal indices in the St. Louis Member and the Renfro Member.

The Renfro Member represents a high intertidal depositional environment on a relatively stable carbonate platform. It marks the continued destruction of a delta complex and the commencement of shallow-water carbonate deposition of the overlying Newman Limestone.

TRACE FOSSILS

Introduction

Trace fossils have not been used to interpret depositional environments in the Borden Formation in northeastern Kentucky. Several workers in the past have alluded to "rooster tail markings" (*Taonurus* = *Zoophycos* and *Lophoctenium*) and "curly worm markings" (= *Helminthoida* and *Scalarituba*) in their studies of the Borden Formation. Kepferle (1977, 1978), in his study of the Kenwood Siltstone Member of the Borden Formation in southern Indiana and north-central Kentucky, classified and figured some trace fossils found in

Figure 20. Sole of turbidite bed 45 in Nancy Member at Ramey section (Day 1, Stop 5) shows twisted load cast.

the Kenwood. In addition, he described and diagrammed an ichnocoenose of the Borden delta front in order to infer probable water depths.

Trace fossils are of paramount significance in recognizing depositional environments in the Borden Formation of northeastern Kentucky because of their uniform composition and grain size and because, unlike most megafossils, they were not redeposited several miles or more from their initial growth sites. One of the earliest suppositions of ichnology is that marine trace fossils are depth sensitive and that characteristic suites of traces are representative of various zones or facies in ancient marine sequences. This concept was first developed in a concise manner by Seilacher (1964, 1967) and has more recently been discussed and expanded by other workers (Chamberlain, 1971a, 1971b, 1978; Rhoads, 1975). Seilacher (1967) discussed zonation in terms of feeding types as related to food resources. Rhoads (1975), however, suggested that zonation is not only due to "food partioning," and pointed out the significance of physical instability of the substrate, depletion of dissolved oxygen in deeper waters, salinity and temperature, sedimentation rates, and currents. Crimes (1975) pointed out additional pitfalls about regional facies interpretations based primarily on bathymetry. Fursich (1975) considered hydrodynamic conditions, which are in turn governed by bathymetry and geography, to be the controlling factors in trace fossil distribution.

Trace fossils are the behavioral responses of animals to their environment preserved in rock. When using trace fossils for facies interpretation it must be recognized that different organisms may make the same or very similar structures; an individual species commonly will make different tracks, trails, or markings when engaged in different activities; and the same organism is likely to leave a different trace in substrates of different texture or different consistency. Some traces are independent of facies (e.g., *Scalarituba, Phycosiphon, Chondrites*); most are influenced by facies, and occur more frequently in sediments of one facies. A few are specific to certain facies (Crimes, 1970).

Bathymetric depths should not be determined merely by the presence of a few trace fossils, but only by a

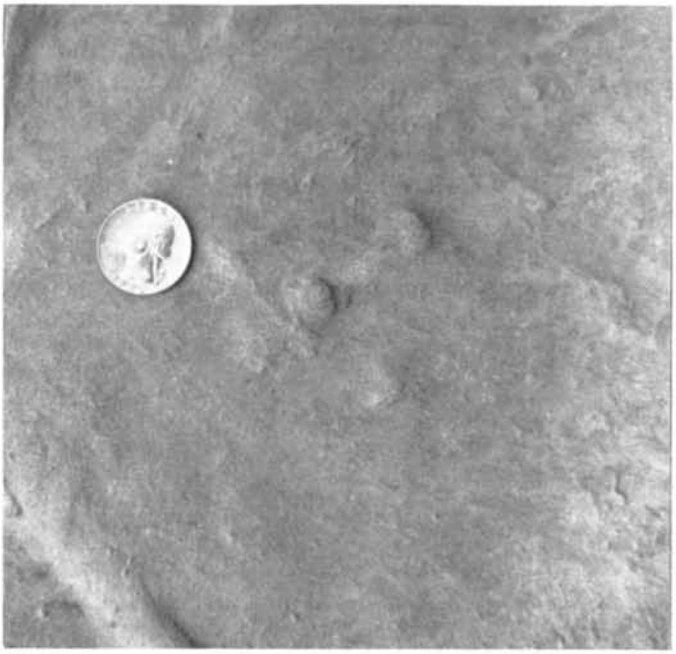

Figure 21. Trace fossil **Bifungites** is found on sole of turbidite bed 45 in Nancy Member at Ramey section (Day 1, Stop 5).

combination (trace fossil associations-assemblages), including the absence of certain others ("negative features"), the sum of which can be taken as conclusive. Seilacher (1964, 1967) established a bathymetric zonation of trace fossils, each zone being characterized by a predominant genus for which the assemblage was named. He recognized and described five marine trace fossil assemblages: the bathyal-abyssal *Nereites*; the intermediate shelf *Zoophycos*; and the shallow-water *Cruziana*, *Skolithos*, and *Glossifungites*. Chamberlain (1971b) established a *Chondrites* assemblage that is transitional between the *Zoophycos* and *Nereites* assemblages. The general gradation from vertical to horizontal and increasingly patterned burrows from shallow to deep water corresponds to a trend from suspension feeding to sediment feeding, which is in turn a response to the distribution of food (Seilacher, 1967).

The distribution of trace fossils is a function of the distribution of fauna on the ocean floor, which is controlled by environmental factors; perhaps more importantly, distribution of fauna is a function of preservation. Primary preservational hazards such as erosion cause the ichnofossil record to be biased towards burrows that extend deep into the sediment, rather than those that were formed at or near the sediment-water interface (Frey, 1971). Slow sedimentation permits thorough reworking of the substrate by infauna, thereby creating a situation where the only distinct burrows may be those that were formed last, or those that were formed by the deepest burrowers (Chamberlain, 1975; Ekdale, 1974).

The study of trace fossils in the field can be quite frustrating in that abundant specimens are present in the float below an outcrop while few may be found in place. In this study 15 ichnogenera where found in place, and the remaining 18 were found in float. Although the member from which the specimens came has never been in question, their stratigraphic value is somewhat diminished.

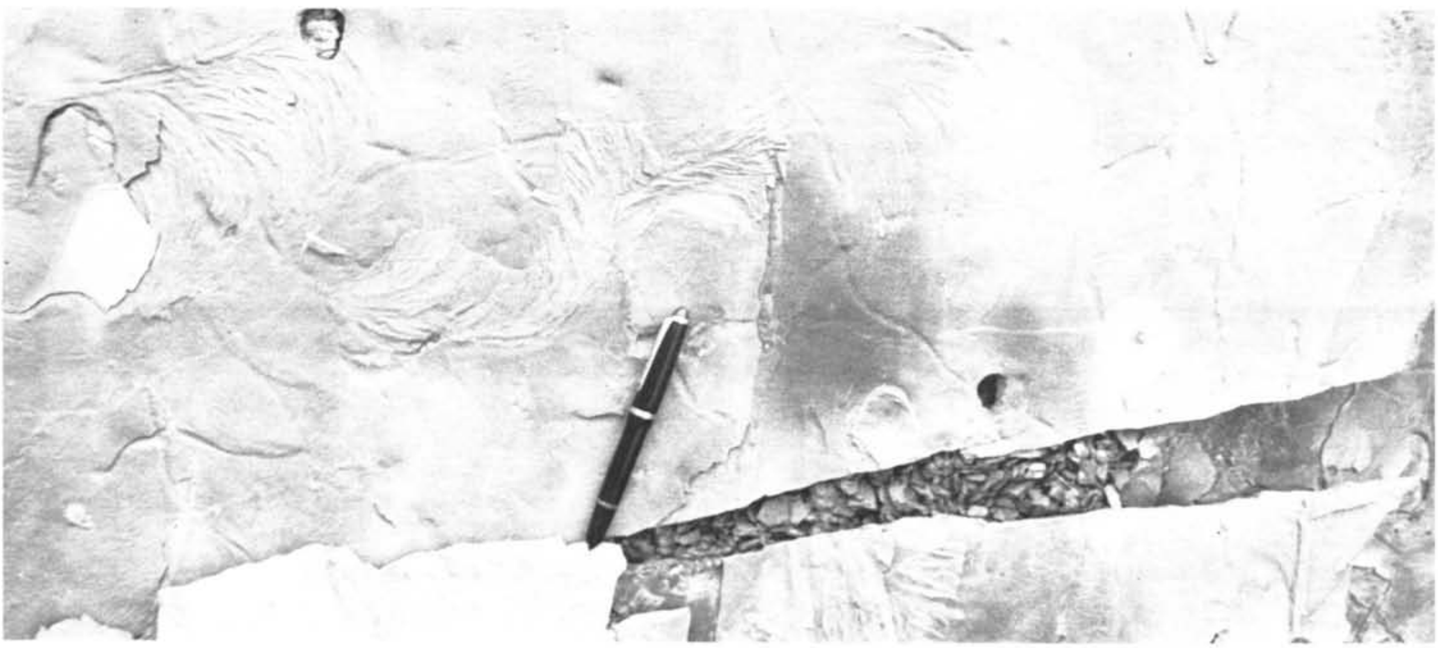

Figure 22. Low-amplitude ripple marks and **Zoophycos** occur in top of turbidite bed 45 in Nancy Member at Ramey section (Day 1, Stop 5).

Figure 23. The common goniatite genus **Muensteroceras** spp. is found in the Farmers-Nancy transitional beds and the Nancy Member in the field trip area.

In contrast to body fossils, trace fossils are improved by induration and diagenesis. Diagenesis tends to improve biogenic sedimentary structures; this is why ancient lebensspuren are better known and easier to study than modern lebensspuren. Trace fossils are almost always preserved *in situ*; cases in which they have been reworked are not common and are easy to recognize (Seilacher, 1967).

Trace Fossil Ichnofacies

Bathymetric interpretations for the Borden Formation are based primarily on a vertical and lateral succession of trace fossil assemblages, from *Nereites* to *Zoophycos* to *Cruziana*. Vertically, the bathymetry of the facies changes from relatively deep water (Henley and Farmers) to shallow water (Cowbell and Nada); laterally, the bathymetry changes from deeper water to the southwest to shallower water to the northeast in the field trip area. The interpretations are in accordance with local and regional trend analyses of lithologic character, stratigraphic thickness, and sedimentary structures.

The classification of trace fossils recovered from the Borden Formation, to date, is shown in Table 8 along with their toponomy (preservational type), ethology (behavioral type), and stratigraphic occurrence in the Borden Formation. This list represents the ichnogenera collected from 12 sections in the Bordon Formation and not all of those listed will be seen at the stops on our field trip. Many of the ichnogenera recovered from the Borden Formation are shown on Plates 1-7. Thirty-three ichnogenera have been identified; most have been preserved as endichnia (within bed) or hypichnia (lower surface of bed) trace fossils. The trace fossils show a broad range of form and behavioral habit; grazing and feeding traces are most common.

Three ichnofacies are recognized in the Borden Formation: *Nereites*, *Zoophycos*, and *Cruziana*. The *Nereites*, *Zoophycos*, and *Cruziana* facies used in this study refer to the total fauna, particular lithofacies, and sedimentary structures of the Borden Formation. Each of these facies contains distinctive behavioral types.

Nereites Ichnofacies

The *Nereites* ichnofacies is the most widely recognized and best defined ichnofacies in the field trip area. The *Nereites* assemblage contains the most diverse ichnofauna, which typically consists of complex, horizontal, deposit-feeding patterns made principally by deposit feeders that grazed more or less systematically across or horizontally through the sediment. The deposit-feeding patterns occur mainly on the soles of sandstones and, less commonly, on the tops. A clear bias is present, however, because the trace fossils from the interbedded shales are difficult to collect. Many of the traces are sand casts of burrows that originally were made in the muddy substrate, and were preserved after currents scoured and filled them with sand.

The *Nereites* ichnofacies occurs throughout the field trip area in the Farmers Member, Farmers-Nancy transitional beds, and, at some localities in the southwest, possibly in the lower part of the Nancy Member. It is best defined in the distal turbidite facies of the Farmers Member in the Morehead area.

The most abundant trace fossils in the *Nereites* assemblage are *Scalarituba* (*Scalarituba*-view, *Phyllodocites*-view, *Neonereites*-view), *Zoophycos* (type-1 and type-2), *Lophoctenium*, *Monocraterion*, *Helminthopsis*, *Teichichnus*, *Cylindrichnus*, *Helminthoida*, *Palaeophycus*, and *Chondrites*. Less common, but important, associated traces include *Belorhaphe*, *Protopaleodictyon*, *Paleodictyon*, *Biformites*, *Spirorhaphe*, *Bifungites*, and *Planolites*. *Zoophycos* (both helicoidal and planar) is by far the most abundant trace in the *Nereites* assemblage; many diverse behavioral patterns are displayed by the spreiten. Many forms transitional between *Zoophycos* and *Lophoctenium* are also common in this facies.

It is noteworthy that the *Nereites* assemblage in the Borden Formation contains eurybathic, cosmopolitan forms such as *Teichichnus*, *Chondrites*, *Zoophycos*, and *Planolites*; these forms were found in the abyssal *Nereites* assemblage from Deep Sea Drilling Project cores (Chamberlain, 1975; Ekdale, 1974, 1977, in press; Ekdale and Bergen, 1977). This does not imply abyssal depths for this assemblage in the Borden but does suggest a similarity in substrate and a similar distribution of food resources. The *Nereites* assemblage of the Borden Formation is like that of European flysch, in that both contain a high diversity of systematic, horizontal, deposit-feeding trace fossils (*Neonereites, Phyllodocites, Lophoctenium, Zoophycos, Paleodictyon, Spirorhaphe, Helminthopsis*). The *Nereites* assemblage of the Borden also contains traces similar to those occurring in a *Nerites* assemblage of the Ouachita flysch (Chamberlain, 1978) and from deep-water deposits in the Oquirrh Basin of central Utah (Chamberlain and Clark, 1973).

Zoophycos Ichnofacies

Although the *Zoophycos* ichnofacies is defined by the presence of *Zoophycos*, all occurrences of *Zoophycos* are not indicative of the ichnofacies. *Zoophycos* is the most frequently occurring trace throughout the Borden Formation; abundance and morphologic type are controlled by environmental factors related to a particular lithofacies. *Zoophycos* is common in the cores from the deep sea (Chamberlain, 1975; Ekdale, 1974) and common in some coal-bearing sequences of the Paleozoic epicontinental sea (Osgood and Szmuc, 1972; Middleman, 1976). It is also common in shallow bay sediments from the Cretaceous Western Interior (Basan and Petersen, 1978). Because *Zoophycos* is known to be eurybathyic, significant fluctuations of sea level are not necessary to account for the various occurrences of *Zoophycos* in the Borden Formation. *Zoophycos* apparently was made by a eurybathic polychaete annelid that occupied environments ranging from wave base to deep basin (Crimes, 1970). Osgood and Szmuc (1972) reported *Zoophycos* from the Cuyahoga Formation in northeastern Ohio, which they interpreted to represent deposits above wave base.

In northeastern Kentucky the *Zoophycos* ichnofacies occurs in the prodeltaic deposits of the Nancy Member. The assemblage has a low diversity and consists primarily of *Zoophycos* (type-1 and type-2), *Scalarituba* (*Scalarituba*-view), *Helminthoida, Conichnus,* and *Chondrites*. Commonly, the *Zoophycos* assemblage occurs in completely bioturbated beds, in which only *Zoophycos, Scalarituba,* and *Helminthoida* can be identified; other structures may be referred to only as *Teichichnus*-like and *Cylindrichnus*-like burrowing. It must be recognized that a high degree of bioturbation does not necessarily mean that there are a large number of organisms in such an environment; rather, it may mean that rates of deposition were so slow that organisms had adequate time to mine the sediment (i.e., the rate of infaunal reworking exceeded the rate of sedimentation). *Zoophycos* is a mining-deposit feeding pattern made endogenically (within bed) and in full relief. *Scalarituba* and *Helminthoida* are "grazing" trails made endogenically and preserved in full relief, but they are seen on interlaminar fractures. All were probably made by worms. The profuse occurrence of *Helminthoida* and *Scalarituba* (deposit feeders) burrows is interpreted to indicate an environment with slow, sometimes sporadic sedimentation, attributable to a prodelta regime.

Composite burrows are common in the *Zoophycos* assemblage, consisting of one large tubular burrow and one or more different smaller burrows within the larger one. The most common trace found within the larger burrow is the three-dimensional branching system of *Chondrites*.

The *Zoophycos* assemblage intergrades both laterally and vertically with the *Cruziana* assemblage; this is probably the result of lateral migration of each delta sub-environment. It is highly probable that continued studies of the Borden will delineate a *Zoophycos*-*Cruziana* assemblage. The *Zoophycos* assemblage of the Borden is similar to that described from the Ouachita Geosyncline of Oklahoma (Chamberlain, 1971a, 1978).

Cruziana Ichnofacies

The *Cruziana* ichnofacies is well represented in the delta front lithofacies of the Cowbell Member and the delta platform lithofacies of the Nada Member. The *Cruziana* ichnofacies is extremely well represented in the Cowbell and Nada Members in extreme northeastern Kentucky in several exposures along U.S. Highway 23 near Siloam in Greenup County.

The trace fossils show a broad range of form and behavioral habit, including crawling trails of gastropods (*Psammichnites*), resting traces of pelecypods (*Lockeia*), resting traces of asteroids (*Asteriacites*), grazing traces of worms (*Scalarituba*), feeding traces of worms (*Phycosiphon*), and dwelling burrows of anemones (*Bergaueria*). The *Cruziana* assemblage has a high diversity, consisting mainly of *Arthrophycus, Bergaueria, Chondrites, Cruziana, Cylindrichnus, Helminthoida, Phycosiphon, Planolites, Scalarituba* (*Scalarituba*-view), and *Zoophycos* (mainly type-2). Other important, but less common, associated traces include *Archaeichnium*-like, *Asteriacites, Calycraterion, Diplocraterion, Gyrochorte, Helminthopsis, Lockeia, Lophoctenium, Monocraterion, Phycodes*-like, *Psammichnites, Radionereites*-like, *Rusophycus,* and *Teichichnus*. Dwelling and resting traces are much more common in the *Cruziana* ichnofacies than in the *Nereites* or *Zoophycos* ichnofacies. Dwelling burrows become more common upwards, as the average grain size of the Cowbell increases upwards also. This grada-

Table 3.—Characteristics of Prodelta Deposits in Ancient and Modern Environments Compared with Features of the Nancy Member of the Borden Formation. After van Stratten (1959), Coleman and Gagliano (1964, 1965), Fisher and others (1969), Donaldson and others (1970), Cotter (1975), Reading (1978), and Others.

FEATURES	
1. Bedding	parallel to lenticular
2. Bedding thickness	thick mudstones interbedded with shaly siltstones, very silty shales, and thin sandstone turbidite beds
3. Color	dark-bluish-gray to light-olive-gray when fresh; weathers to reddish-brown
4. Contacts	very gradational
5. Composition	immature mudstone, silty shale, shaly siltstone; micaceous, contains organic material
6. Grain size and sorting	mean grain size 0.001-0.007 mm; poor to moderate sorting
7. Parallel laminations	faint to absent due to destruction by bioturbation; mainly in siltstones
8. Cross laminations	rare to absent; limited to shaly siltstones
9. Convolute laminations	absent
10. Ripple-drift cross laminations	rare to absent; restricted to shaly siltstones
11. Crossbedding	absent
12. Sand wave structures	absent
13. Ripple marks	absent
14. Scour-and-fill structures	rare to absent
15. Concretions/nodules	very abundant; sideritic, randomly distributed to bedded; highly mineralized; very fossiliferous with brachiopods, bryozoans, pelmatozoan detritus, conularids, and mollusks (especially cephalopods)

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Table 3.—Continued

FEATURES	
16. Soft-sediment structures	rare to absent
17. Mudstone/shale clasts	absent
18. Plant fragments	absent
19. Load casts	rare to common; particularly common on soles of interbedded thin sandstone turbidite beds
20. Associated fauna	rare to common; most common in sideritic nodules and restricted horizons; whole and fragmented fossils consist of brachiopods, bryozoans, conularids, pelmatozoan detritus, and mollusks, especially cephalopods; some megafossils pyritized; conodonts present
21. Bioturbation	very abundant; churned types of burrows dominate (commonly destroy bedding and produce mottling or complete homogenization); many diverse types of burrows; horizontal burrows most common; vertical burrows rare; most traces found in beds marking the transition from turbidite to prodelta deposition
22. Trace fossil associations	low diversity, high abundance
23. Ichnogenera	<u>Chondrites</u> <u>Conichnus</u> <u>Cylindrichnus</u> <u>Helminthoida</u> <u>Scalarituba</u> <u>Teichichnus</u> <u>Zoophycos</u> Type-1 Type-2

Table 3.—Continued

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Table 4.—Summary of Bedding Features, Sedimentary Structures, Associated Fauna, and Trace Fossils of the Prodelta Lithofacies of the Nancy Member.

PRODELTA Features	NANCY MEMBER Similar	Partly Similar	No Basis for Comparison
1. Fine-grained sediments	√		
2. Silty mudstones, shales, and shaly siltstones	√		
3. Cross laminations		√	
4. Parallel laminations		√	
5. Coarser-grained layers with even lamination		√	
6. Cross-stratification			√
7. Sideritic nodules and bands	√		
8. Load casts	√		
9. Vertical burrows rare	√		
10. Horizontal burrows common	√		
11. Bioturbation restricted to certain horizons	√		
12. Small burrows	√		
13. Burrow mottling or complete homogenization	√		
14. Low diversity and high abundance of trace fossils	√		
15. Body fossils scarce		√	
16. Plant remains			√

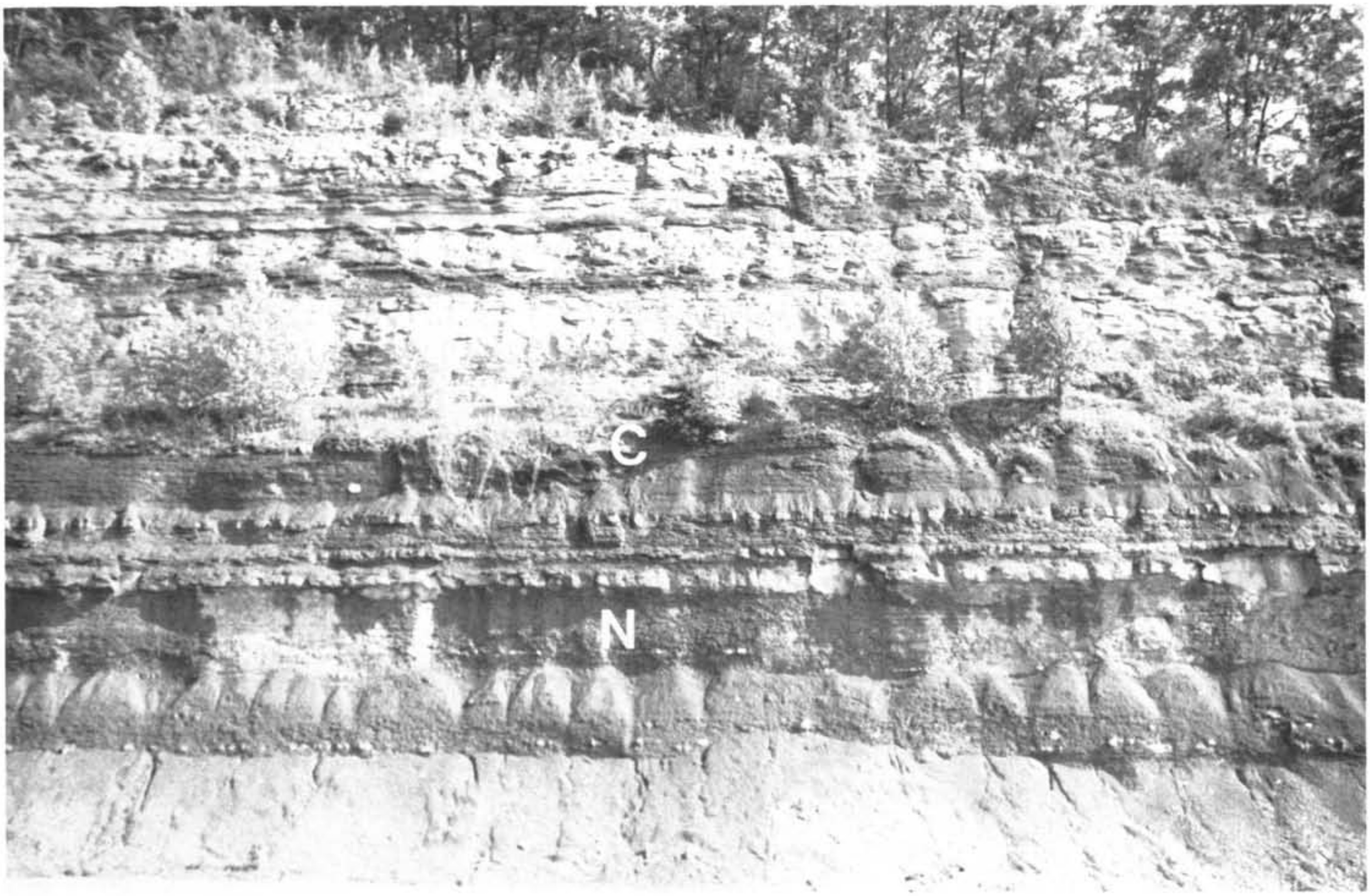

Figure 24. Gradational contact of Nancy (N) and Cowbell (C) Members at junction of Interstate 64 and Ky. Highway 32.

tion from fine to coarser grain size and the increase of the proportion of dwelling burrows, particularly *Cylindrichnus*, points toward a shallowing-upward, higher-energy environment for the upper Cowbell and overlying Nada Member. The presence of animal escape burrows and the high concentration of vertical burrows near the tops of some beds in the Cowbell suggest periods of rapid sedimentation.

The *Cruziana* assemblage of the Borden Formation is similar to that described from the Oquirrh Formation (Pennsylvanian) of central Utah (Chamberlain and Clark, 1973), from the Pennsylvanian of the Arkoma Basin in Oklahoma (Chamberlain, 1971a, 1978), and from the Lower Mississippian Logan Formation in Ohio (Middleman, 1976).

Interpretation

The classic model of trace-fossil assemblages shows that the *Skolithos-Cruziana* assemblages are indicative of shallow marine deposits, the *Zoophycos* assemblage is indicative of intermediate depths, and the *Nereites* assemblage is indicative of deeper water (Seilacher, 1964). The *Zoophycos* assemblage has been interpreted, more specifically, as ranging from below wave base to the beginning of turbidite sedimentation. The assemblage also is typical of outer shelf to upper slope deposits. The *Nereites* assemblage, in contrast, occurs within the turbidite or bathyal-abyssal zone (Seilacher, 1967; Crimes, 1970; Chamberlain, 1971a). These models were derived from body fossil evidence, by studying particular stratigraphic sequences and lithofacies, by observing traces made by extant forms, and by comparing trace fossil associations with one another. Despite all of this, the bathymetric implications of these associations are commonly unclear, especially for the *Zoophycos* and *Nereites* assemblages (Crimes, 1970).

The presence of a *Nereites* assemblage in the lower units of the Borden suggests deposition in a deep-water environment. The exact depth is difficult to determine because *Nereites* assemblages may occur where there is persistent and widespread advantage for deposit feeding; however, this generally occurs below the photic zone. Bathyal depths associated with epeiric sea sedimentation are indicated by the presence of turbidites in contact with sediment that bears the *Nereites* assemblage over a broad area and through a great

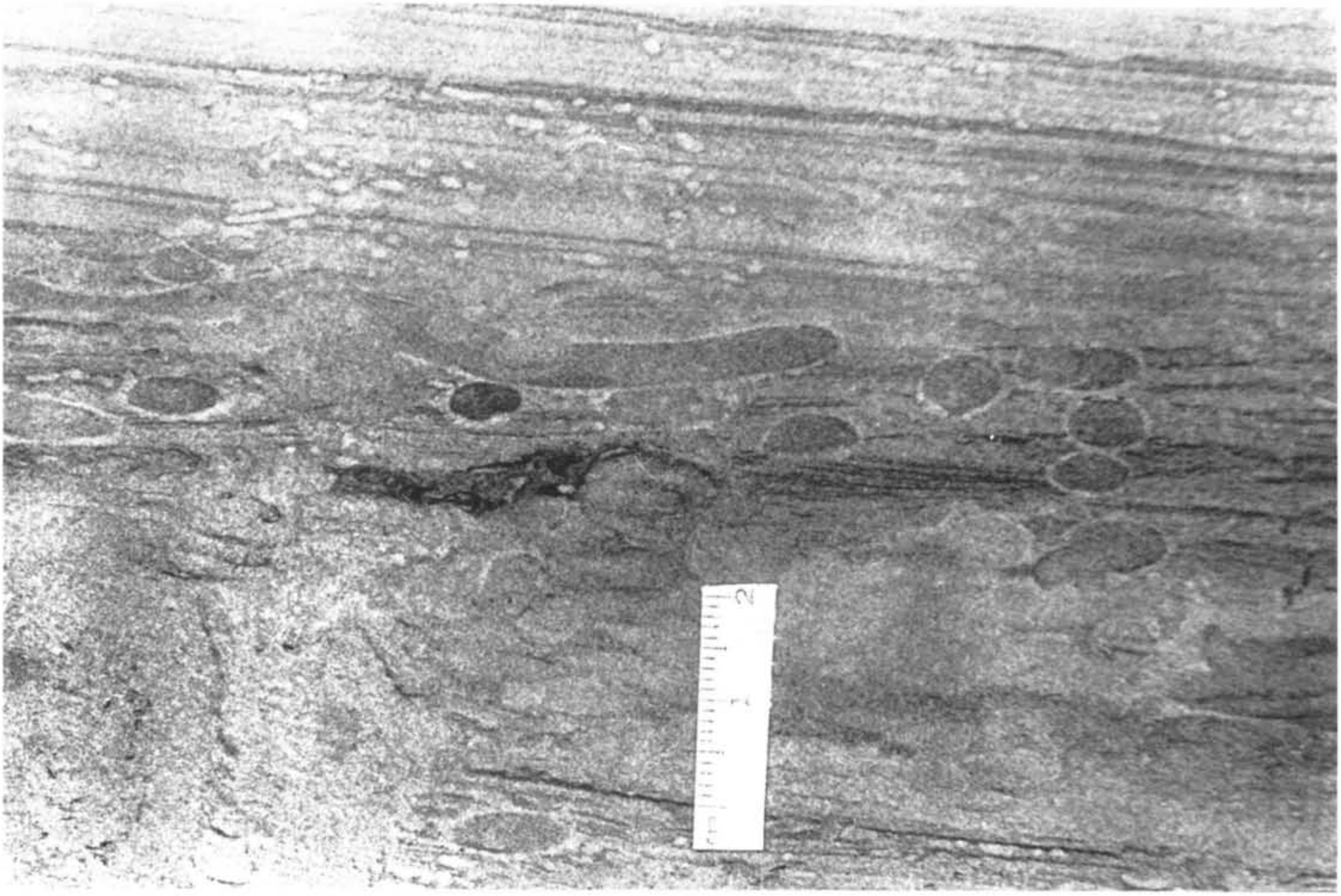

Figure 25. Polished slab cut perpendicular from Cowbell Member, Unit 1, at Haney Branch section (Day 1, Stop 2) shows "communal tubes."

thickness of section, and by the absence of any diagnostic indigenous skeletal fossils and shallow-water sedimentary features.

The *Zoophycos* assemblage indicates an intermediate depth at the transition from shallow shelf to deeper basin. A more precise bathymetry, other than below wave base and above turbidite sedimentation, seems difficult to determine.

The *Cruziana* assemblage clearly is shallow marine and distal bar, interdeltaic bay, and skeletal carbonate bank environments are represented. The predominance of gastropod-like trails and resting traces of pelecypods provides strong evidence of a nearshore molluscan fauna.

Trace-fossil assemblages in the Borden Formation define a basin-to-shoal bathymetric profile. At least five sedimentary environments and three indicative trace fossil assemblages are present. They are (1) basin-floor and turbidite facies of the Henley Bed, Farmers Member, and Farmers-Nancy transitional beds, with a *Nereites* assemblage; (2) prodelta facies of the Nancy Member, with a *Zoophycos* assemblage; and (3) delta front and delta platform facies of the Cowbell and Nada Members, respectively, with a *Cruziana* assemblage.

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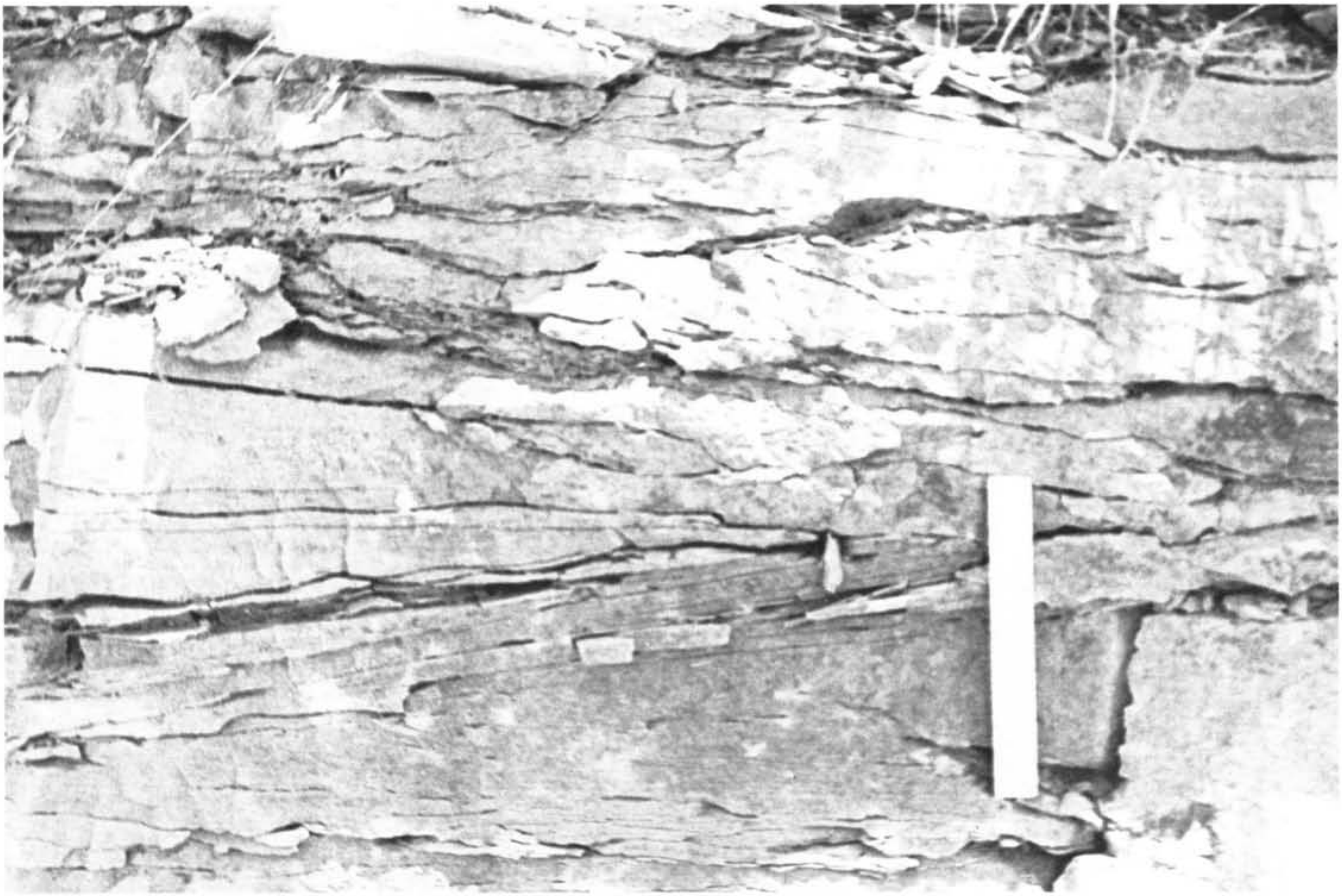

Figure 26. Planar crossbedding in Unit 3, Cowbell Member, at Haney Branch section 1A (Day 1, Stop 2). Ruler is approximately 15 centimeters long.

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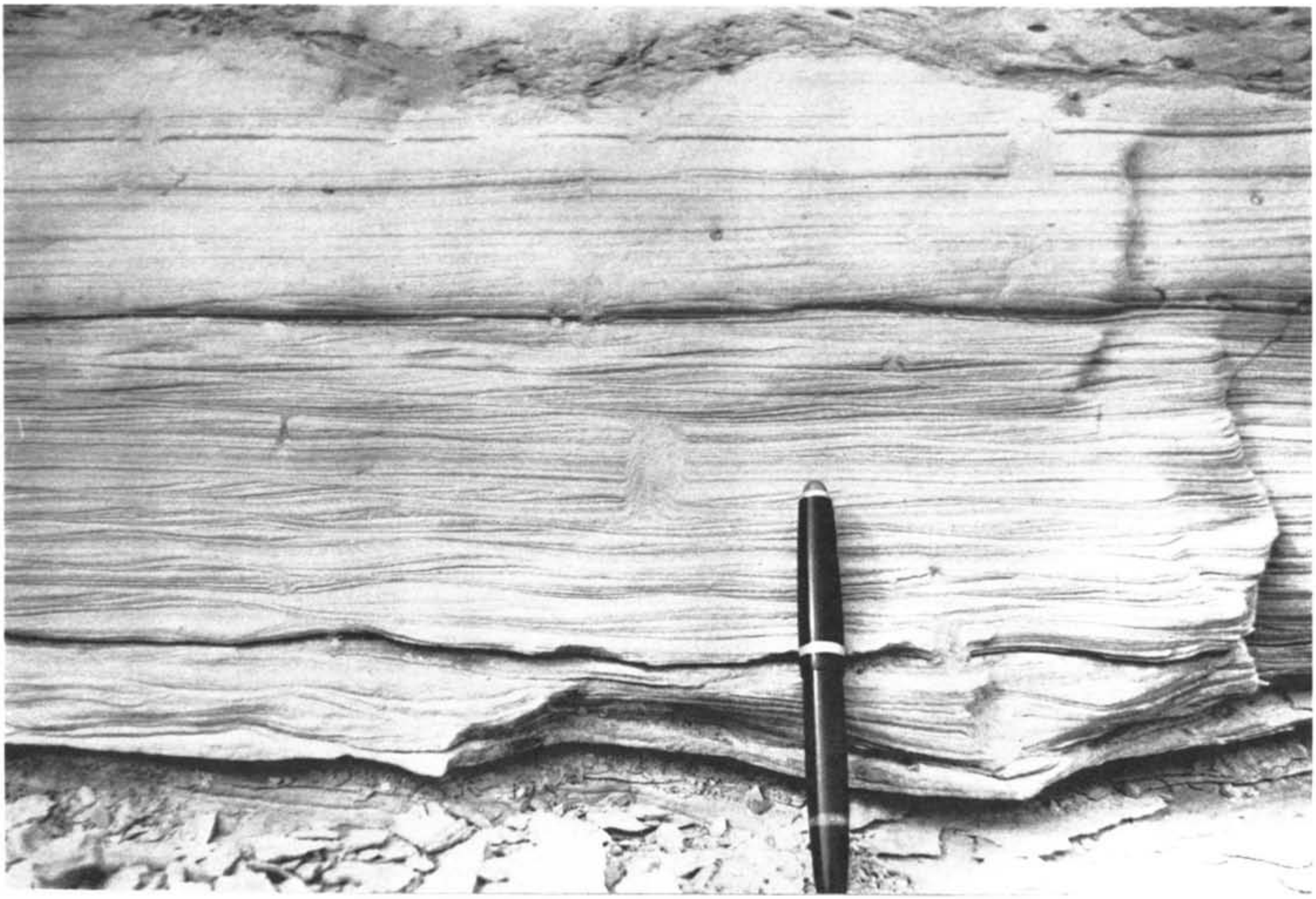

Figure 27. Ripple-drift cross laminations, vertical escape burrows, and parallel laminations in Unit 3, Cowbell Member, at Haney Branch section 1A (Day 1, Stop 2). Note bioturbation at top of photograph.

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Figure 28. Scour-and-fill and sand wave structures in Unit 3, Cowbell Member, at Haney Branch section 1A (Day 1, Stop 2).

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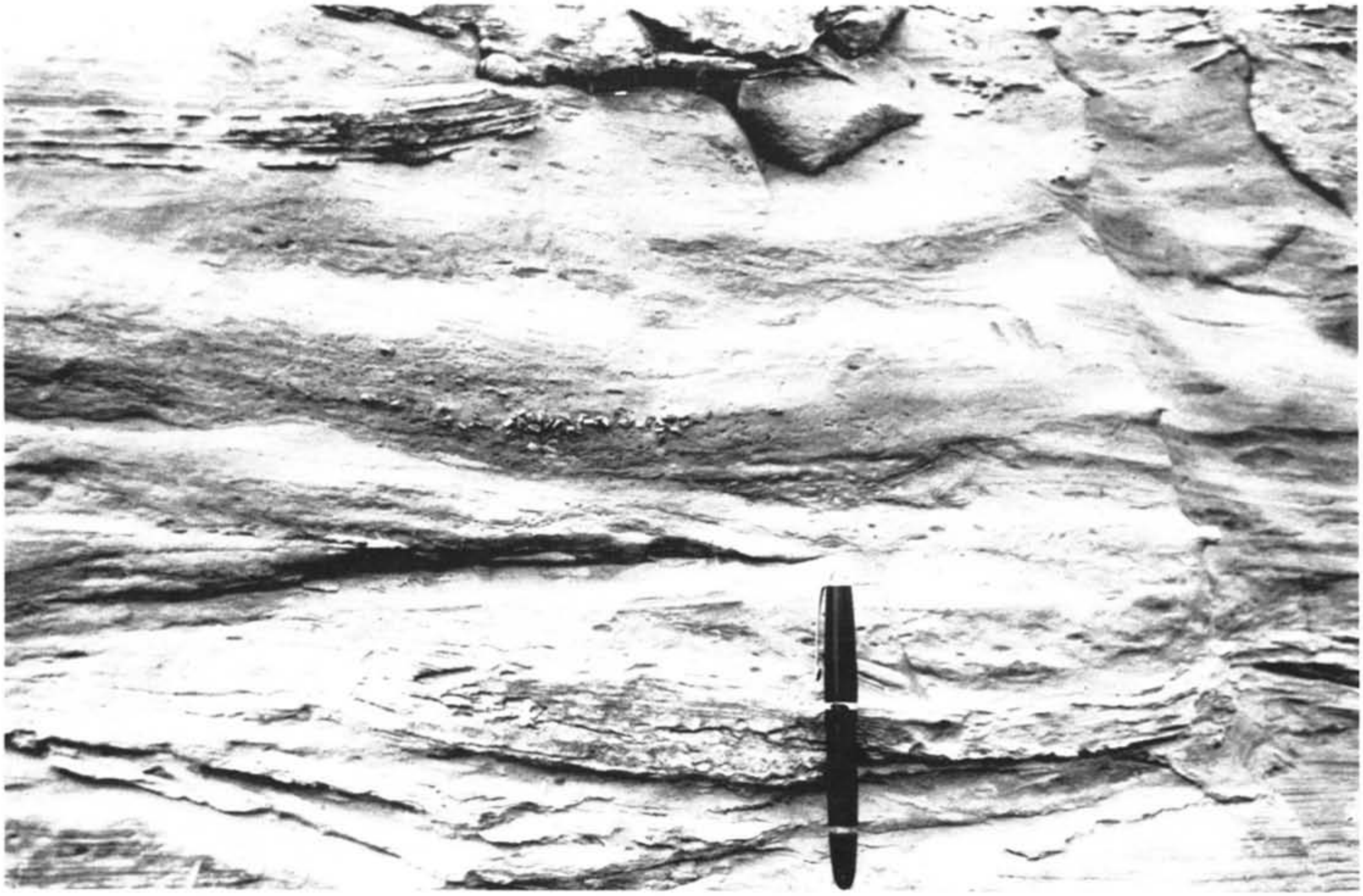

Figure 29. Scour-and-fill structures infilled with pelmatozoan detritus in Unit 3, Cowbell Member, at Haney Branch section 1A (Day 1, Stop 2).

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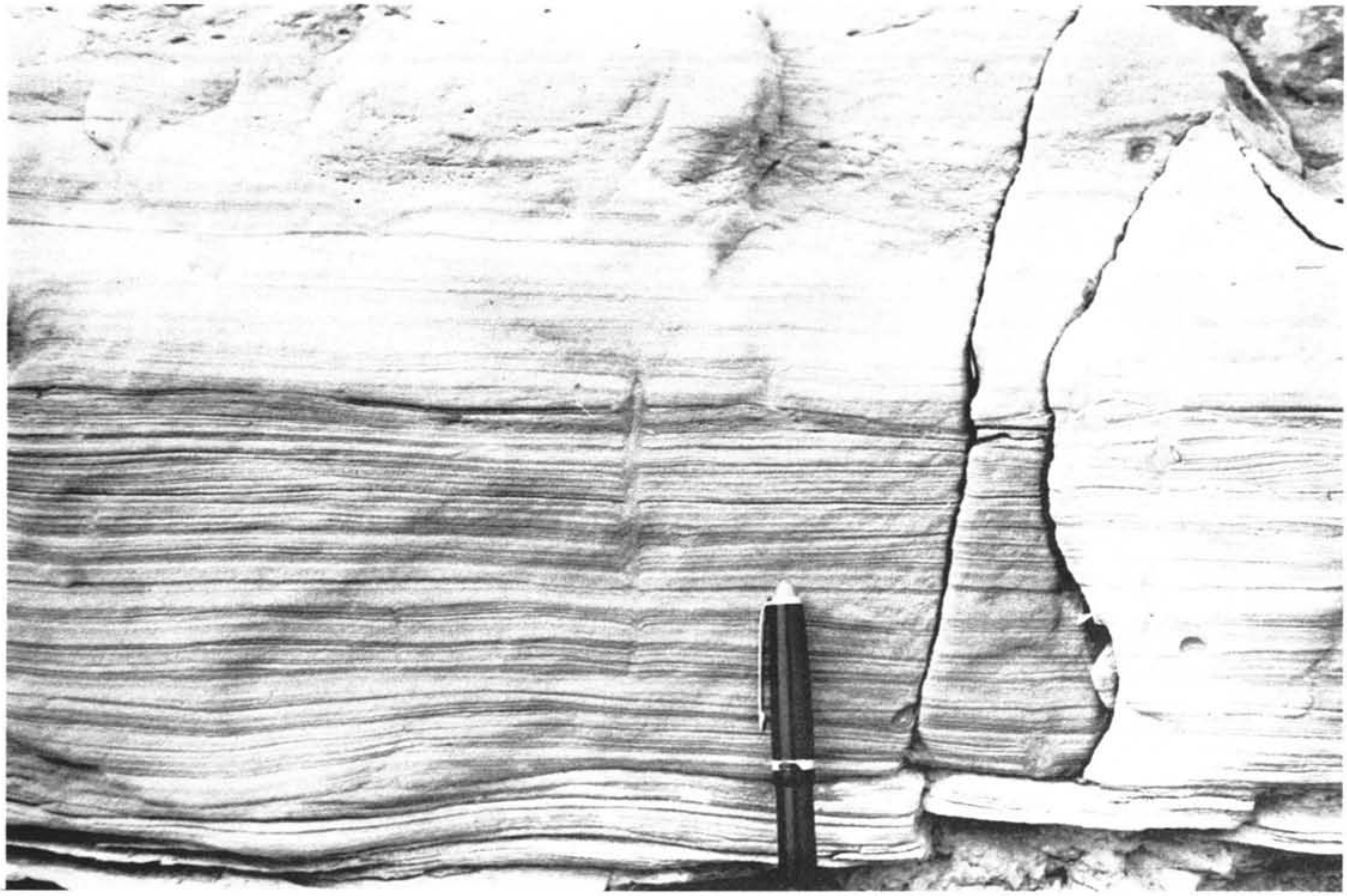

Figure 30. Parallel laminations are bent downward along trace of vertical burrow in Unit 3, Cowbell Member, at Haney Branch Section 1A (Day 1, Stop 2).

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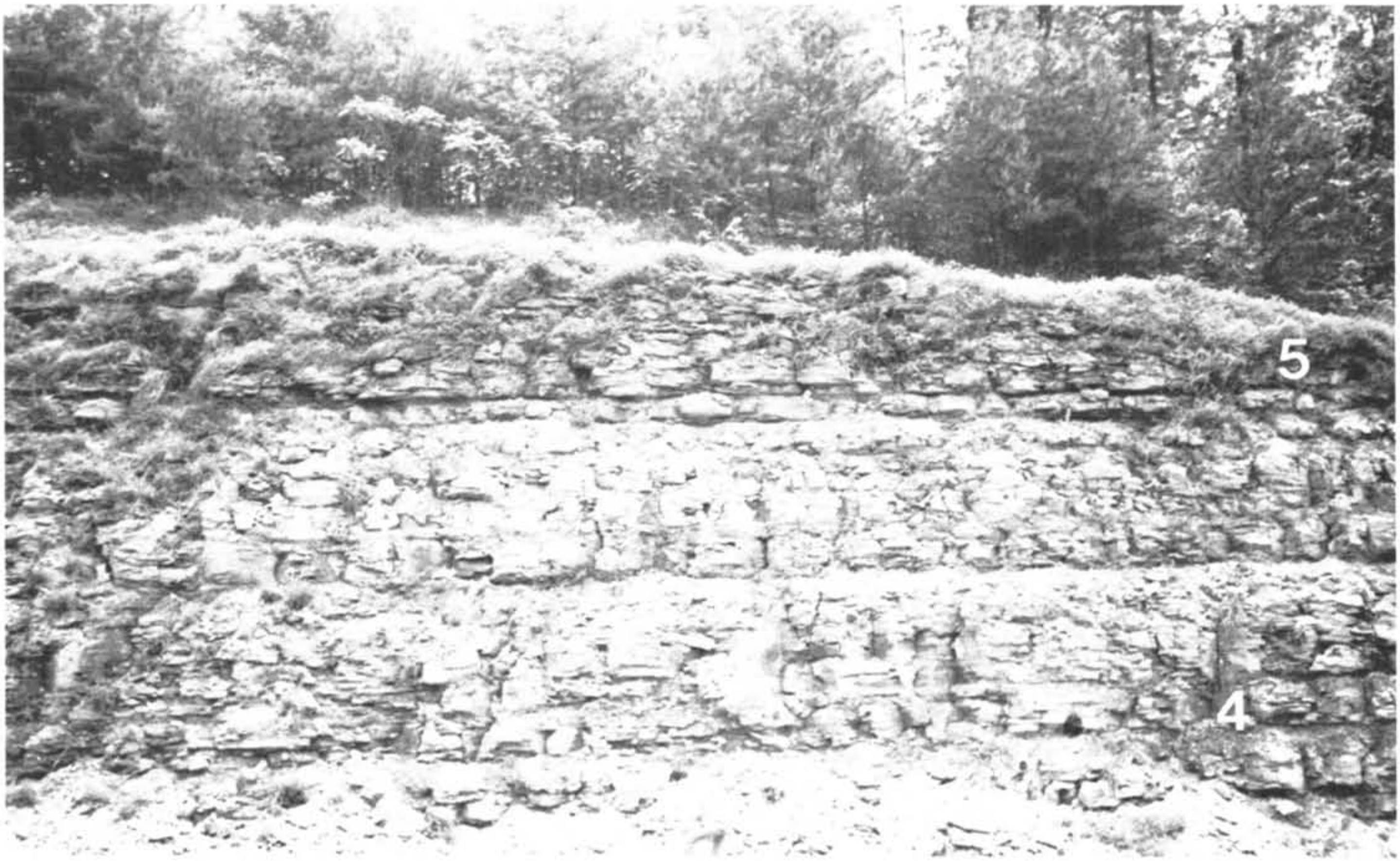

Figure 31. Alternating beds of siltstone and shale in Unit 4, Cowbell Member, along Interstate 64, at milepost 145.9. Unit 5 is exposed at top.

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Table 5.—Characteristics of Delta Front (Distal Bar) and Interdeltaic Bay Deposits in Ancient and Modern Environments Compared with Features of the Cowbell Member of the Borden Formation. After van Straaten (1959), Coleman and Gagliano (1964, 1965), Fisher and others (1969), Donaldson and others (1970), Cotter (1975), Reading (1978), and Others.

FEATURES	COWBELL MEMBER		
Distal Bar	Similar	Partly Similar	No Basis for Comparison
1. Alternating siltstones and silty clays	√		
2. High sedimentation rates	√		
3. Increase in coarseness of material upward		√	
4. Erosional truncations	√		
5. Channel-like features		√	
6. Graded beds		√	
7. Even, parallel lamination	√		
8. Cross lamination	√		
9. Ripple-drift cross laminations	√		
10. Crossbedding	√		
11. Contorted bedding		√	
12. Ripple marks		√	
13. Scour-and-fill structures	√		
14. Small and large burrows	√		
15. Completely bioturbated layers	√		
16. Vertical burrows common	√		
17. Low faunal diversity and abundance		√	
18. Rare plant fragments	√		
19. Scattered shell remains	√		
Interdeltaic Bay	√		
1. Silty shales and shaly siltstones	√		
2. Lenticular bedding	√		
3. Parallel bedding		√	
4. Laminations lacking	√		
5. Gradational contacts	√		
6. Current ripple marks			√
7. Scour-and-fill structures		√	
8. Sideritic nodules and bands	√		
9. Burrow-mottled texture	√		
10. Burrows abundant	√		
11. Abundant shell remains		√	

Table 6.—Summary of Bedding Features, Sedimentary Structures, Associated Fauna, and Trace Fossils of the Interdeltaic Bay (Trough) and Distal Bar Lithofacies of the Cowbell Member.

COASTAL LITHOFACIES

Cowbell Member

Features	Interdeltaic Bay	Distal Bar
1. Bedding	lenticular to parallel	laterally continuous to lenticular
2. Bedding thickness	interbedded thick shales with minor silty shale and shaly siltstone interbeds	interbedded, thick (massive) siltstones with minor silty shale and shaly siltstone interbeds
3. Color	light-olive-gray to bluish-gray, mottled when fresh; may weather to dark-yellowish-orange	greenish-gray to light-bluish-gray when fresh; weathers to dark-yellowish-orange
4. Contacts	gradational, minor erosional	gradational, minor erosional
5. Composition	immature silty shale, shaly siltstone; micaceous, organic material	submature to mature siltstones, silty shale
6. Grain size	mean grain size 0.002-0.007 mm; poor sorting	mean grain size 0.015-0.053 mm; well to moderately well sorted
7. Parallel laminations	rare, burrows commonly have modified or destroyed bedding	common to abundant; massive units; commonly disrupted downward along traces of vertical burrows; often varved-like
8. Cross laminations	rare to common	common to abundant
9. Convolute laminations	absent	rare; confined to thin, restricted intervals
10. Ripple-drift cross laminations	rare to absent	common to abundant; confined to thin horizons in massive units
11. Crossbedding	rare to absent	rare to common; small-scale, low-angle; primarily planar-type
12. Sand wave structures	absent	common; internal structure of low-angle crossbedding; trough behind sand wave commonly filled with fossil fragments
13. Ripple marks	rare to absent	rare to common; primarily current
14. Scour-and-fill structures	rare to common	common to abundant; scoured surfaces frequently filled with fossil fragments

Table 6.—Summary of Bedding Features, Sedimentary Structures, Associated Fauna, and Trace Fossils of the Interdeltaic Bay (Trough) and Distal Bar Lithofacies of the Cowbell Member.

COASTAL LITHOFACIES

Cowbell Member

Features	Interdeltaic Bay	Distal Bar
1. Bedding	lenticular to parallel	laterally continuous to lenticular
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3. Color	light-olive-gray to bluish-gray, mottled when fresh; may weather to dark-yellowish-orange	greenish-gray to light-bluish-gray when fresh; weathers to dark-yellowish-orange
4. Contacts	gradational, minor erosional	gradational, minor erosional
5. Composition	immature silty shale, shaly siltstone; micaceous, organic material	submature to mature siltstones, silty shale
6. Grain size	mean grain size 0.002-0.007 mm; poor sorting	mean grain size 0.015-0.053 mm; well to moderately well sorted
7. Parallel laminations	rare, burrows commonly have modified or destroyed bedding	common to abundant; massive units; commonly disrupted downward along traces of vertical burrows; often varved-like
8. Cross laminations	rare to common	common to abundant
9. Convolute laminations	absent	rare; confined to thin, restricted intervals
10. Ripple-drift cross laminations	rare to absent	common to abundant; confined to thin horizons in massive units
11. Crossbedding	rare to absent	rare to common; small-scale, low-angle; primarily planar-type
12. Sand wave structures	absent	common; internal structure of low-angle crossbedding; trough behind sand wave commonly filled with fossil fragments
13. Ripple marks	rare to absent	rare to common; primarily current
14. Scour-and-fill structures	rare to common	common to abundant; scoured surfaces frequently filled with fossil fragments

Table 6.—Continued

COASTAL LITHOFACIES

Cowbell Member

15. Concretions/nodules	very abundant; sideritic; scattered to bedded; fossiliferous with molds of pelmatozoan detritus, brachiopods, bryozoans, and corals; rare conularids, cephalopods, and conodonts	common, very silty, sideritic; often fossiliferous with molds of pelmatozoan detritus, brachiopods, corals, and bryozoans; cephalopods rare
16. Soft-sediment deformation	rare	common; small-scale features
17. Mudstone/shale clasts	rare	rare to common; randomly oriented
18. Plant fragments	absent	absent
19. Associated fauna	common to abundant whole and fragmented brachiopod, bryozoan, and pelmatozoan detritus megafossils; most common in nodules and shaly siltstone interbeds	common to very abundant whole and fragmented megafossils; most common in nodules and restricted horizons; include brachiopods, bryozoans, corals, pelmatozoan detritus, and mollusks; some fossil lag deposits
20. Bioturbation	very abundant; churned types of burrows dominate (commonly destroy bedding); many diverse types of burrows (vertical, irregular tube-like, and horizontal); horizontal types dominate	common to abundant; vertical-type burrows abundant, often truncated; horizontal and churned-types of burrows common; most intense in shaly interbeds; horizontal and oblique silt-filled burrows
21. Trace fossil associations	moderate diversity, high abundance	moderate to high diversity, low to moderate abundance
22. Ichnogenera	Arthrophycus Asteriacites Bergaueria Chondrites Cylindrichnus Helminthoida Lockeia Phycodes-like Phycosiphon Planolites Scalarituba Scalarituba-view Zoophycos Type-1	Archaeichnium-like Arthrophycus Bergaueria Calycraterion Chondrites Cruziana Cylindrichnus Diplocraterion Gyrochorte Helminthoida Helminthopsis Lophoctenium Monocraterion Palaeophycus Phycosiphon Planolites Radionereites-like Rusophycus Scalarituba Scalarituba-view Teichichnus Zoophycos Type-1 Type-2

Table 6.—Continued

COASTAL LITHOFACIES

Cowbell Member

15. Concretions/ nodules	very abundant; sideritic; scattered to bedded; fossiliferous with molds of pelmatozoan detritus, brachiopods, bryozoans, and corals; rare conularids, cephalopods, and conodonts	common, very silty, sideritic; often fossiliferous with molds of pelmatozoan detritus, brachiopods, corals, and bryozoans; cephalopods rare
16. Soft-sediment deformation	rare	common; small-scale features
17. Mudstone/shale clasts	rare	rare to common; randomly oriented
18. Plant fragments	absent	absent
19. Associated fauna	common to abundant whole and fragmented brachiopod, bryozoan, and pelmatozoan detritus megafossils; most common in nodules and shaly siltstone interbeds	common to very abundant whole and fragmented megafossils; most common in nodules and restricted horizons; include brachiopods, bryozoans, corals, pelmatozoan detritus, and mollusks; some fossil lag deposits
20. Bioturbation	very abundant; churned types of burrows dominate (commonly destroy bedding); many diverse types of burrows (vertical, irregular tube-like, and horizontal); horizontal types dominate	common to abundant; vertical-type burrows abundant, often truncated; horizontal and churned-types of burrows common; most intense in shaly interbeds; horizontal and oblique silt-filled burrows
21. Trace fossil associations	moderate diversity, high abundance	moderate to high diversity, low to moderate abundance

22. Ichnogenera	Arthrophycus
	Asteriacites
	Bergaueria
	Chondrites
	Cylindrichnus
	Helminthoida
	Lockeia
	Phycodes-like
	Phycosiphon
	Planolites
	Scalarituba
	  Scalarituba-view
	Zoophycos
	  Type-1
		Archaeichnium-like
		Arthrophycus
		Bergaueria
		Calycraterion
		Chondrites
		Cruziana
		Cylindrichnus
		Diplocraterion
		Gyrochorte
		Helminthoida
		Helminthopsis
		Lophoctenium
		Monocraterion
		Palaeophycus
		Phycosiphon
		Planolites
		Radionereites-like
		Rusophycus
		Scalarituba
		  Scalarituba-view
		Teichichnus
		Zoophycos
		  Type-1
		  Type-2

Table 7.—Summary of Bedding Features, Sedimentary Structures, Associated Fauna, and Trace Fossils of the Delta Platform Lithofacies of the Nada Member.

Features	
1. Bedding	parallel to lenticular
2. Bedding thickness	silty clays interbedded with thin, discontinuous shaly and calcareous siltstone
3. Color	greenish-gray and dark-reddish-brown
4. Contacts	gradational
5. Composition	mudstone, silty shale, shaly, calcareous siltstone, and crinoidal skeletal carbonates; glauconite streaks and grains abundant
6. Grain size and sorting	siltstones 0.02-0.06 mm; carbonates, coarsely crystalline
7. Parallel laminations	faint in siltstones
8. Cross laminations	common in crinoidal skeletal carbonates
9. Crossbedding	rare in crinoidal, skeletal carbonates; small-scale, low-angle
10. Associated fauna	primarily suspension-feeding organisms (brachiopods, corals, bryozoans, and crinoids); low to moderate diversity and abundance
11. Bioturbation	common to abundant; burrows produce mottling or complete homogenization in mudstones and shales
12. Trace fossil associations	moderate diversity, high abundance (especially Scalarituba and Zoophycos
13. Ichnogenera	Arthrophycus Cruziana Cylindrichnus Helminthoida Lophoctenium Monocraterion Palaeophycus Phycodes-like Phycosiphon Planolites Psammichnites Scalarituba Scalarituba-view Teichichnus Zoophycos Type-1 Type-2

Table 8.—Toponomy, Ethologic Type, Stratigraphic Occurrence, and Relative Abundance of Trace Fossils in the Borden Formation of Northeastern Kentucky. R = RARE: Found Infrequently, but May Be Conspicuous When Present. C = COMMON: Typically, but Not Always Present; May Be Mixed or Replaced by Something Else. A = ABUNDANT: Present Virtually All the Time.

Ichnogenera	Toponomy (Martinsson, 1970)				Ethologic Type (Seilacher, 1953)					Stratigraphic Occurrence	Borden Formation					
	Epichnia (upper surface)	Endichnia (within bed)	Hypichnia (lower surface)	Exichnia (between beds)	Repichnia (crawling trace)	Cubichnia (resting trace)	Domichnia (dwelling burrow)	Fodinichnia (feeding trace)	Pascichnia (grazing trace)	Henley Bed	Farmers Member	Farmers - Nancy transitional	Nancy Member	Cowbell Member	Nada Member	Renfro Member
Archaeichnium - like	✓	✓					✓				R			R-C		
Arthrophycus			✓					✓						C	R	
Asteriacites			✓			✓								R		
Belorhaphe	✓				✓						R					
Bergaueria			✓				✓							C-A		
Biformites		✓	✓					✓			R	R				
Bifungites			✓					✓			R	R-C				
Calycraterion			✓				✓							R-C		
Chondrites		✓						✓			C-A		C-A	C-A		
Conichnus		✓					✓					R-C	C			
Cruziana	✓		✓		✓									C-A	C-A	
Cylindrichnus		✓				✓	✓				C-A	C	R	A	C-A	
Diplocraterion		✓				✓								R-C		
Gyrochorte	✓		✓		✓									R-C		
Helminthoida	✓	✓	✓						✓		C	C-A	A	A	A	
Helminthopsis		✓	✓						✓		R-C	C-A		R		
Lockeia			✓			✓								R-C		
Lophoctenium	✓	✓		✓				✓			C-A	C-A		R	R	
Monocraterion		✓					✓				R-C	C-A		R-C	C	
Paleodictyon		✓	✓						✓		R					
Palaeophycus	✓				✓						C	C-A		R-C	R-C	
Phycodes - like			✓					✓						R	R-C	
Phycosiphon	✓	✓	✓					✓						C	C-A	
Planolites		✓	✓		✓						R	C		C-A	C-A	
Protopaleodictyon		✓	✓						✓		R-C					
Psammichnites	✓				✓										R	
Radionereites - like			✓					✓						R		
? Rhizocorallium - like	✓	✓						✓			R					
Rind burrow		✓									R-C	R				
Rusophycus			✓			✓								R-C		
Scalarituba																
Scalarituba - view	✓	✓	✓						✓		C	C-A	A	A	A	
Neonereites - view			✓						✓		C	C				
Phyllodocites - view	✓								✓		C	C				
Spirorhaphe		✓							✓		R					
Teichichnus	✓	✓						✓			C-A	C-A	R	R	R-C	
Zoophycos																
Type-1 (helicoidal)	✓	✓	✓	✓					✓		A	A	C	R-C	R-C	
Type-2 (planar)	✓	✓	✓	✓					✓		C	A	R-C	R-C	C-A	

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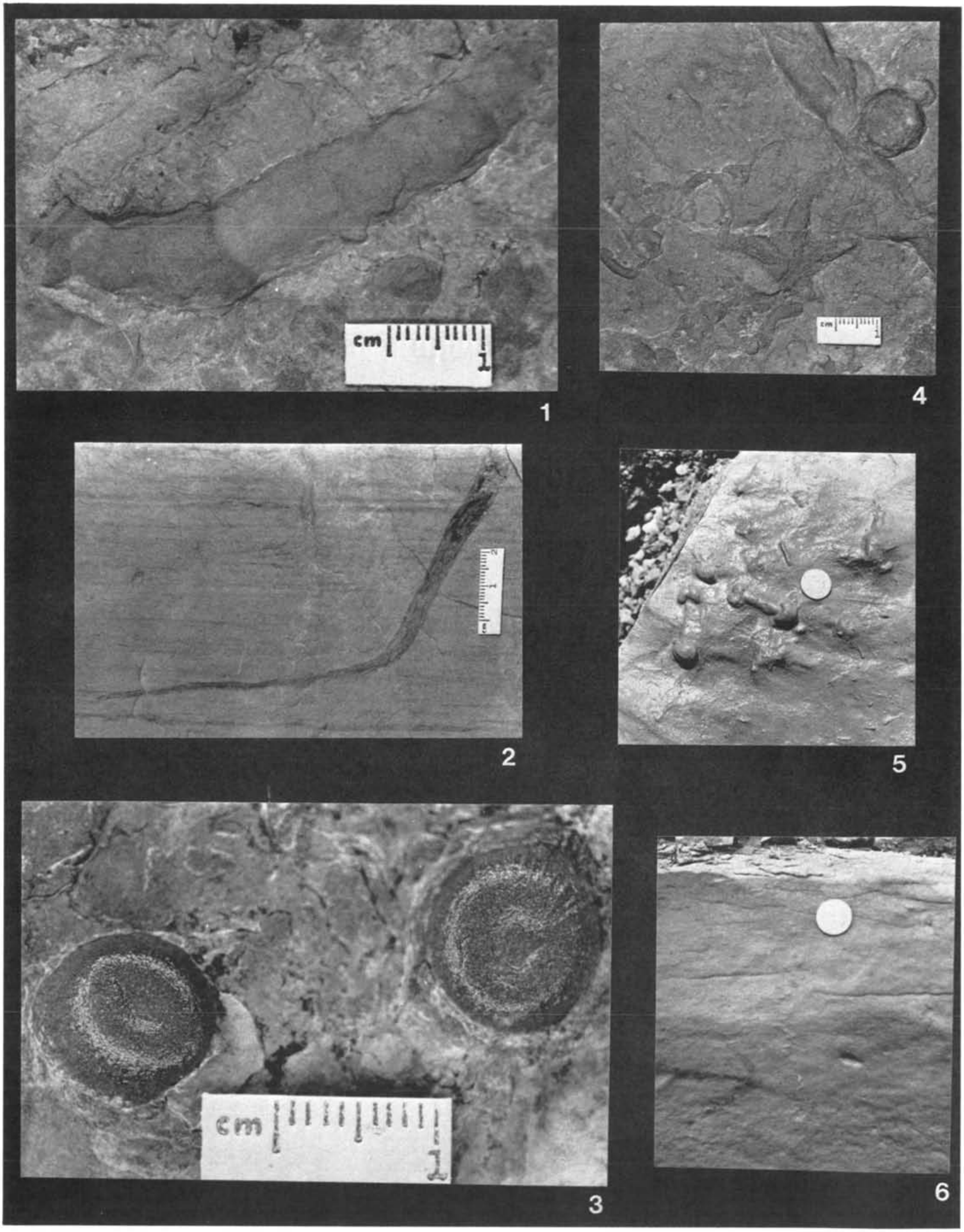
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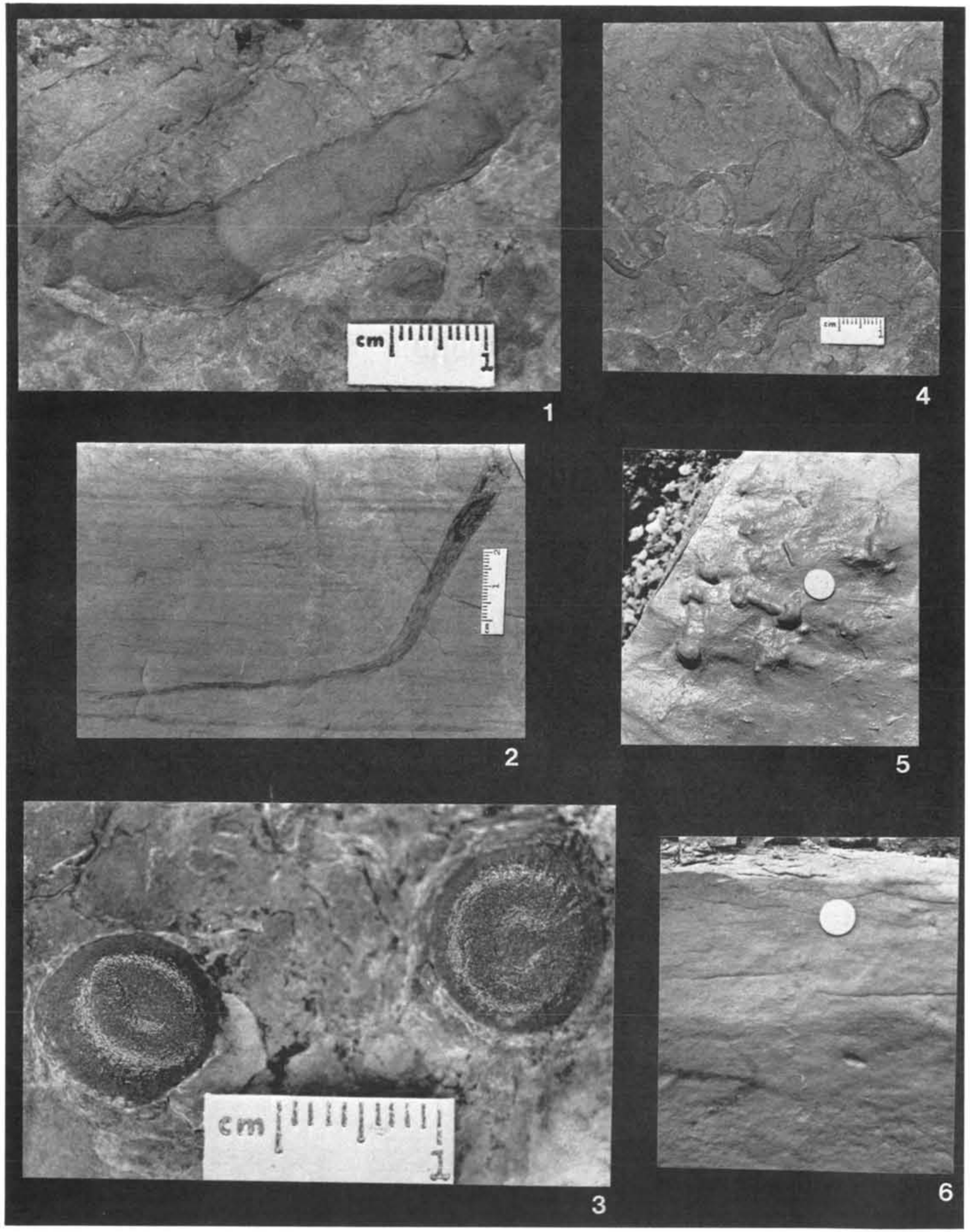

PLATE 1

Trace fossils from the Borden Formation.

1. *Arthrophycus*, a lower-surface (hypichnia) feeding trace of an arthropod or annelid. From Cowbell Member, Unit 3, at Trace Creek section.

2. *Archaeichnium*-like trace, a within-bed (endichnia) dwelling burrow. Note faint longitudinal striations of cylindrical burrow. Found in Cowbell Member, Unit 3, at Trace Creek section.

3. *Bergaueria*, a lower-surface (hypichnia) trace fossil. This trace was the permanent or semipermanent dwelling burrow of what was probably an actinian (sea anemone). From Cowbell Member, Unit 1, at Trace Creek section.

4. *Asteriacites*, resting trace (cubichnia) of asterozoans. It was preserved in the lower surface (hypichnia). From Cowbell Member, Unit 3, along U.S. Highway 23 near Siloam, Greenup County.

5. *Bifungites*, a lower-surface (hypichnia) feeding trace. This may be a special kind of preservation of the retrusive, vertical, "U"-shaped feeding burrow of *Diplocraterion*. Dime is for scale. From sole of turbidite bed 45 of Nancy Member at Ramey section.

6. *Belorhaphe*, an upper-surface (epichnia), sharply zigzag-shaped locomation trail. Dime is for scale. From bed 7 of Farmers Member along Interstate 64 at milepost 134.8.

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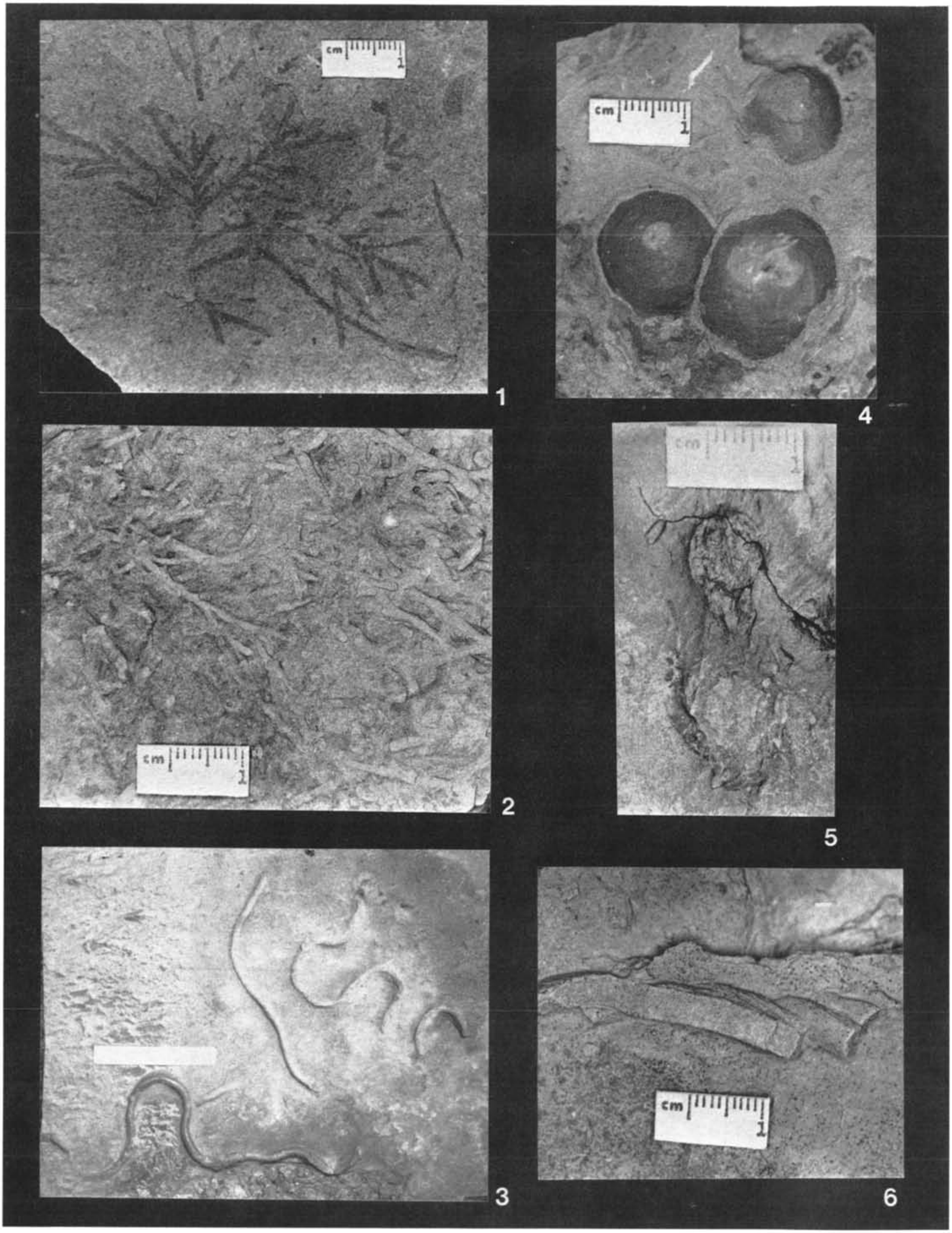
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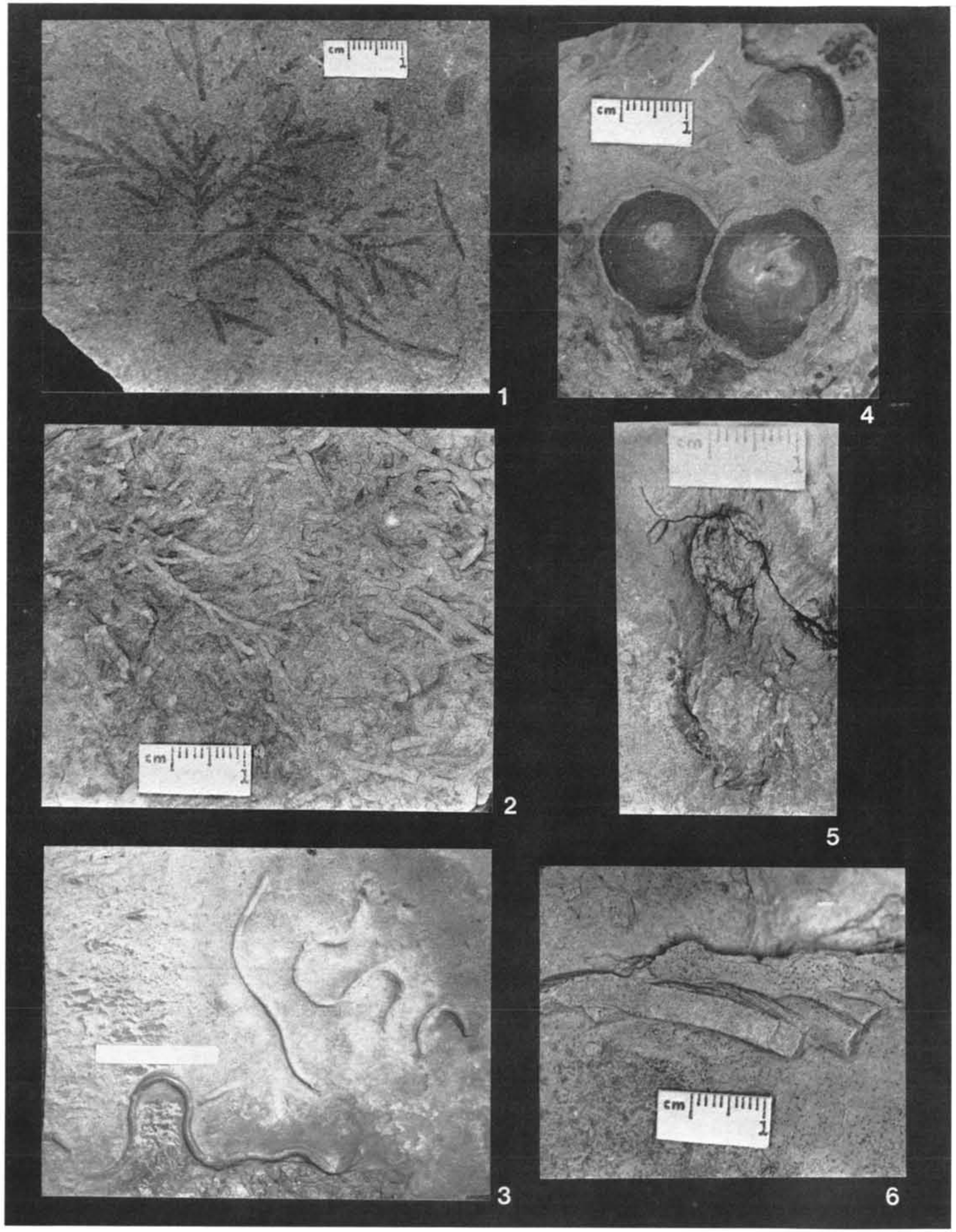

PLATE 2

Trace fossils from the Borden Formation.

1. *Chondrites*, a within-bed (endichnia), three-dimensional, branching feeding trace system. From Farmers Member, at Ramey section.

2. *Chondrites*, within-bed (endichnia) feeding trace. The dendritic pattern of small, cylindrical, ramifying tunnels is plant-like. From Cowbell Member, Unit 3, at Haney Branch section 1A.

3. *Helminthopsis*, a lower-surface (hypichnia) grazing trace. The simple, meandering, smooth trails were originally within bed (endichnia), but were preserved as sand casts on lower surfaces of beds. Ruler is approximately 15 centimeters long. From sole of turbidite bed 45 of Nancy Member at Ramey section.

4. *Calycraterion*, a lower-surface (hypichnia) dwelling burrow. *Calycraterion* is a regular, calyx-shaped depression that has a circular depression on its bottom, which is the outlet of a filled burrow. From Cowbell Member, Unit 1, along U.S. Highway 23 near Siloam, Greenup County.

5. *Diplocraterion*, a within-bed (endichnia) dwelling burrow. It is a vertical "U"-shaped burrow, and resembles a pair of tubes with a connecting structure between in this transverse section. From Cowbell Member, Unit 2, along U.S. Highway 23 near Siloam, Greenup County.

6. *Phycodes*-like trace, a lower-surface (hypichnia) feeding trace. The bundled, flabellate structures are horizontal tunnels with distal tunnels that divide at acute angles. From Nada Member at Trace Creek section.

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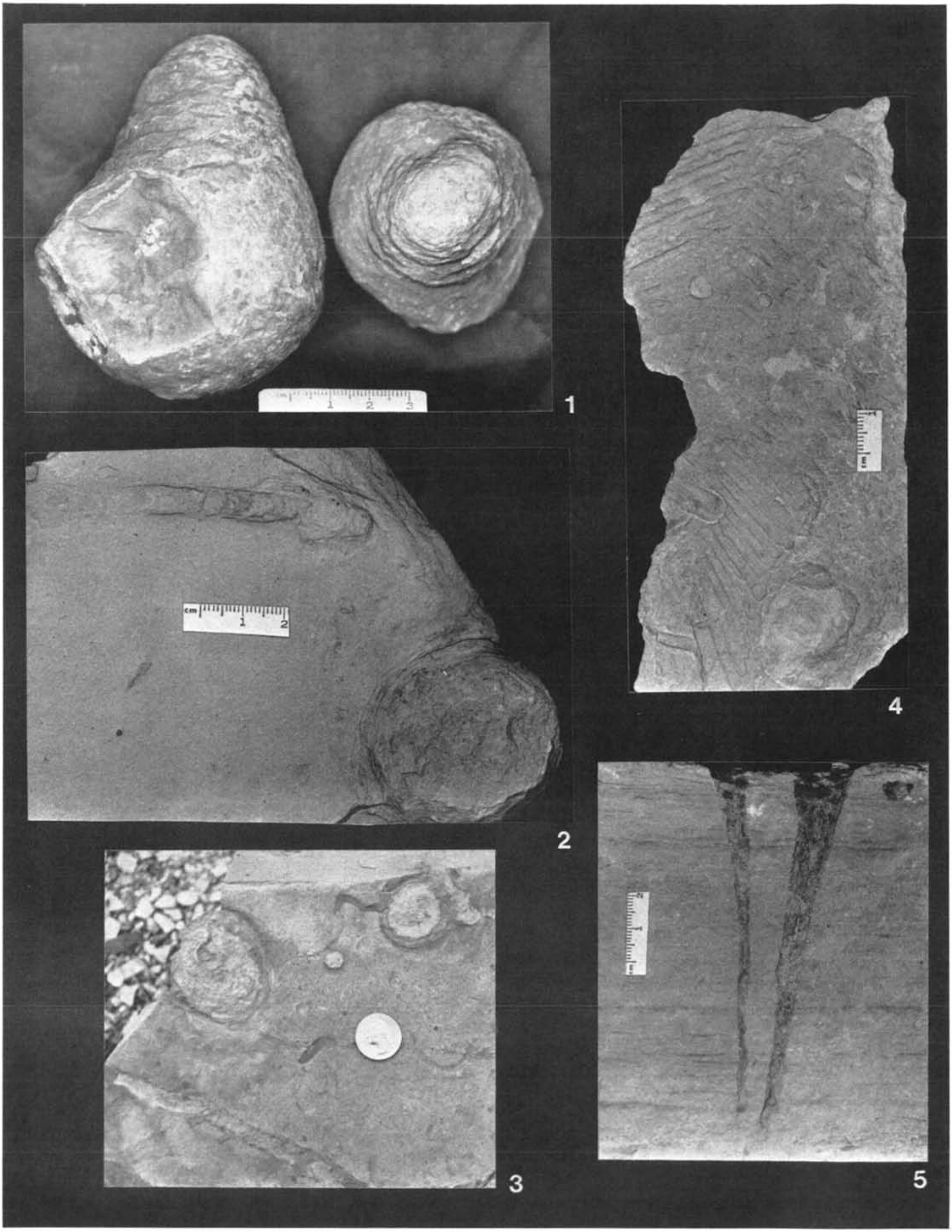
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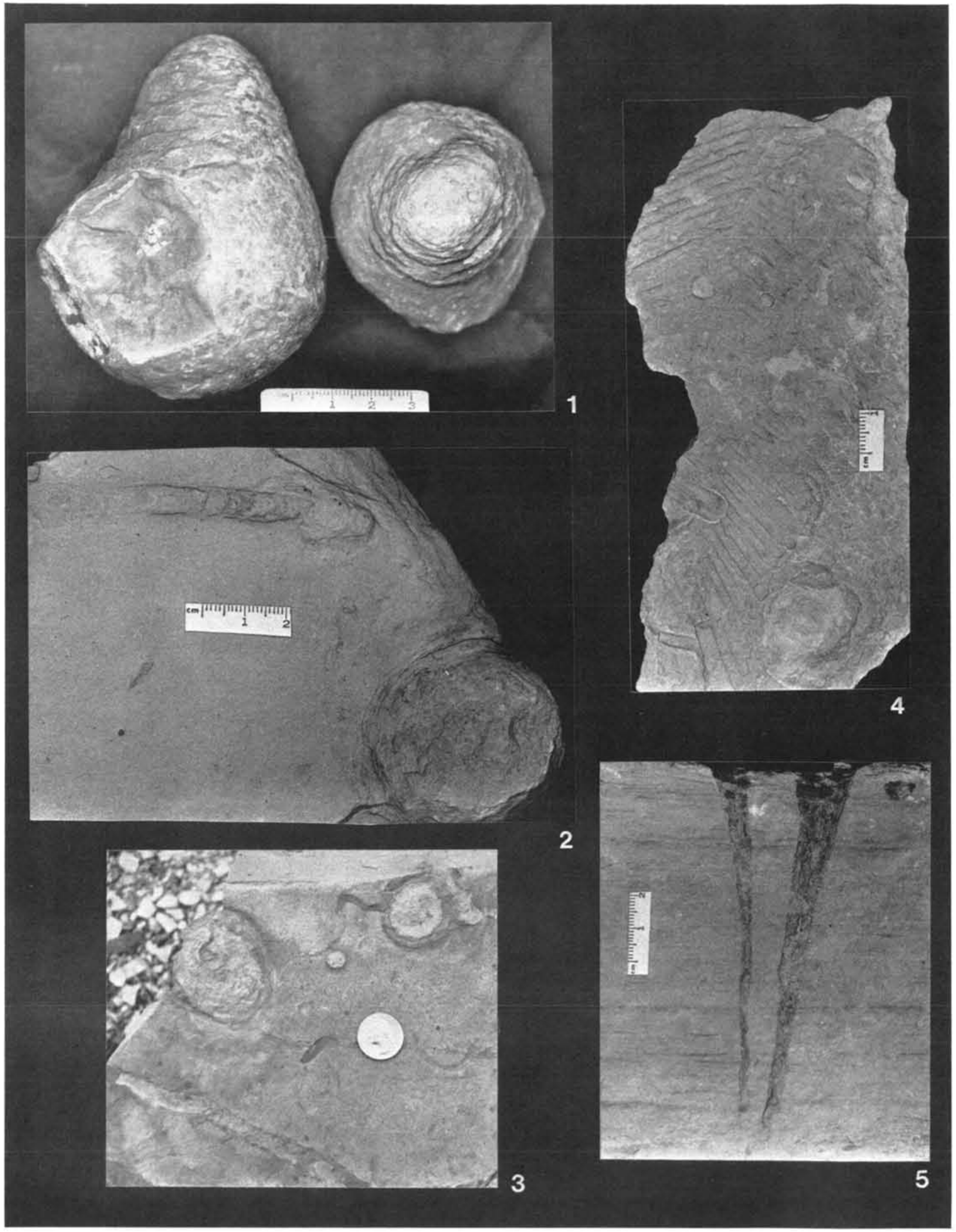

PLATE 3

Trace fossils from the Borden Formation.

1. *Conichnus*, a within-bed (endichnia) dwelling burrow. This trace is composed of the filling from a conical or cone-like burrow. Note the concentric, wrinkled lamellae and the tapered, rounded lower end. From Farmers-Nancy transitional beds along Interstate 64 at milepost 142.0.

2. *Cylindrichnus*, a within-bed (endichnia) resting or dwelling burrow. This transverse burrow truncates the top of the burrow and reveals the wrinkled, concentric laminations of the burrow wall. *Teichichnus* is visible at the top of the photograph; it is a series of long, horizontal burrows stacked vertical to bedding. It resembles stacked, flat, "U"-shaped roof gutters. From Farmers-Nancy transitional beds along Interstate 64 at milepost 134.5.

3. *Cylindrichnus*, a within bed (endichnia) resting or dwelling burrow. This transverse section truncates the tops of the burrows and reveals *Cylindrichnus* to be concentric sand and clay sheaths that have central, sand-filled tubes. From Farmers-Nancy transitional beds along Interstate 64 at milepost 134.5.

4. *Cruziana*, the upper-surface (epichnia) crawling trace of an arthropod. The bilobate ploughing trail is composed of closed-space, diametrically opposed striae, or ridges, separated by a well-developed median furrow. From Nada Member along U.S. Highway 23 near Siloam, Greenup County.

5. *Cylindrichnus*, a within-bed (endichnia) resting or dwelling burrow. There are poorly developed laminations in the longitudinal section running through the burrow. The burrow is tapered, and its top has been truncated. From Cowbell Member, Unit 3, at Trace Creek section.

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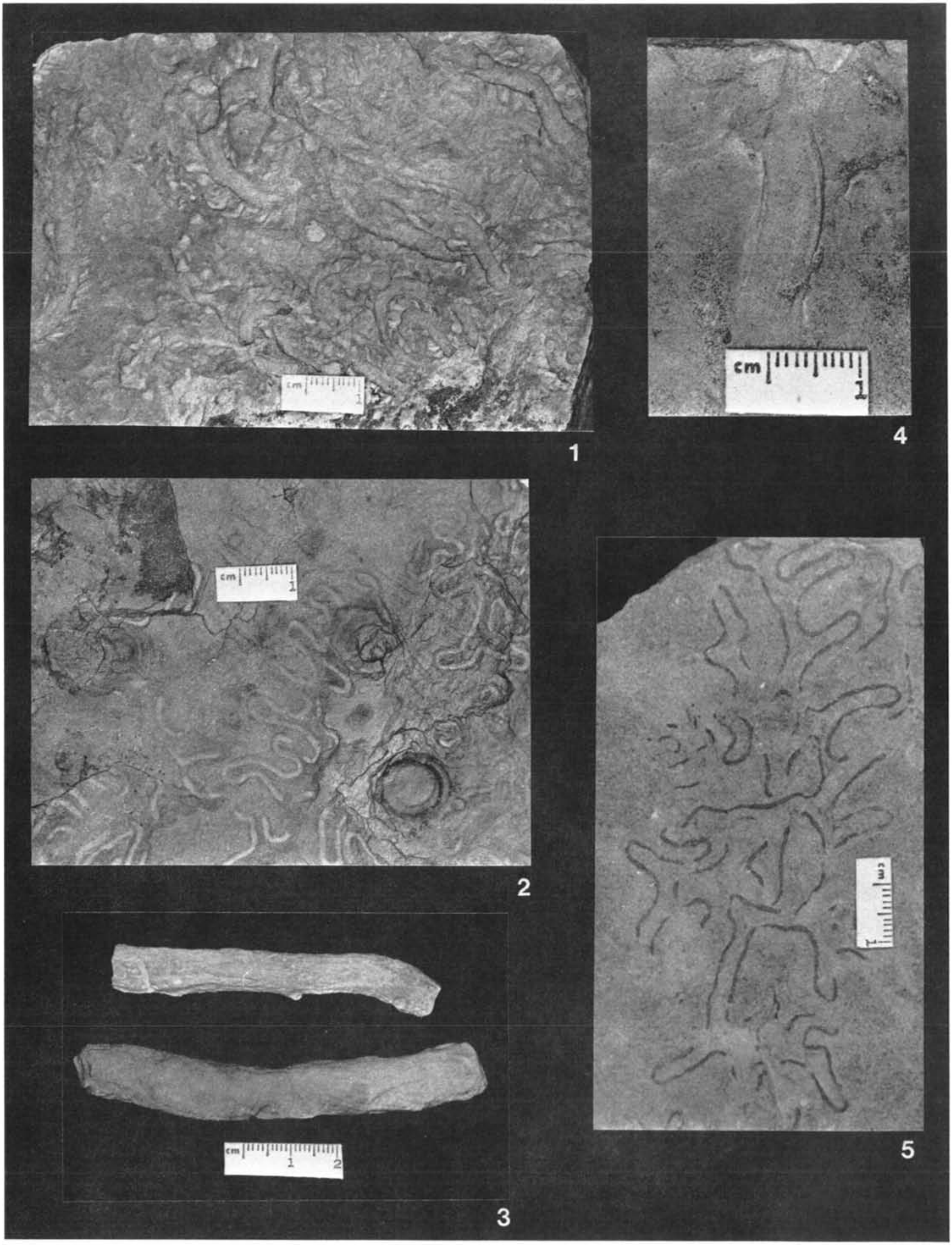

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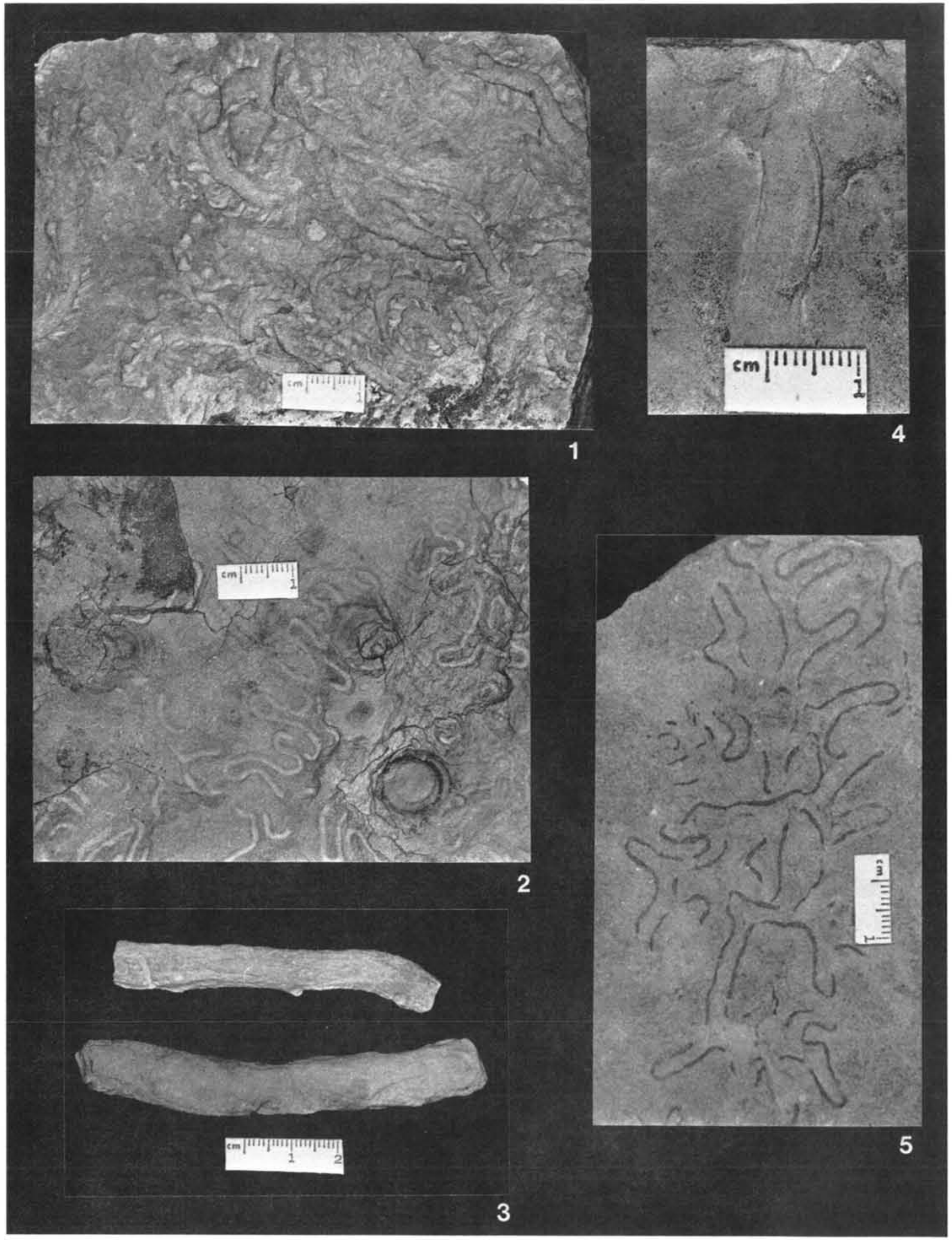

PLATE 4

Trace fossils from the Borden Formation.

1. *Gyrochorte*, an upper-surface (epichnia) crawling trace. Plaited ridges are biserially arranged, and obliquely aligned pads of sediment are separated by a median ridge. The trace is strongly winding, and its direction changes sharply; this was probably caused by tunnelling through sediment. From Cowbell Member, Unit 1, at Haney Branch section 1B.

2. *Helminthoida*, an upper-surface (epichnia) grazing trace. The frequently meandering, tightly-looping fecal ribbons are regular, parallel, and closely spaced. From Cowbell Member, Unit 4, along Interstate 64, at milepost 145.9.

3. *Planolites*, a lower-surface (hypichnia) crawling trace. Burrows are unbranched, slightly curving to straight, and oval in cross section. The surface is usually smooth. From Cowbell Member, Unit 5, along Interstate 64, at milepost 145.9.

4. *Psammichnites*, an upper-surface (epichnia) crawling trace. It is a large, ribbon-like trail with a narrow, longitudinal median ridge. Commonly, very fine ridges transverse it. *Psammichnites* was probably made by a burrowing gastropod. From Nada Member at Perry Branch section.

5. *Phycosiphon*, an upper-surface (epichnia) feeding trace. It is composed of small, "U"-shaped loops of approximately equal length; they define an area of reworked sediment. Branching lends an antler-shaped appearance. The spreite characteristic of this genus have not been preserved, but there is a distinct color difference in the area within the loops. From Nada Member, at Trace Creek section.

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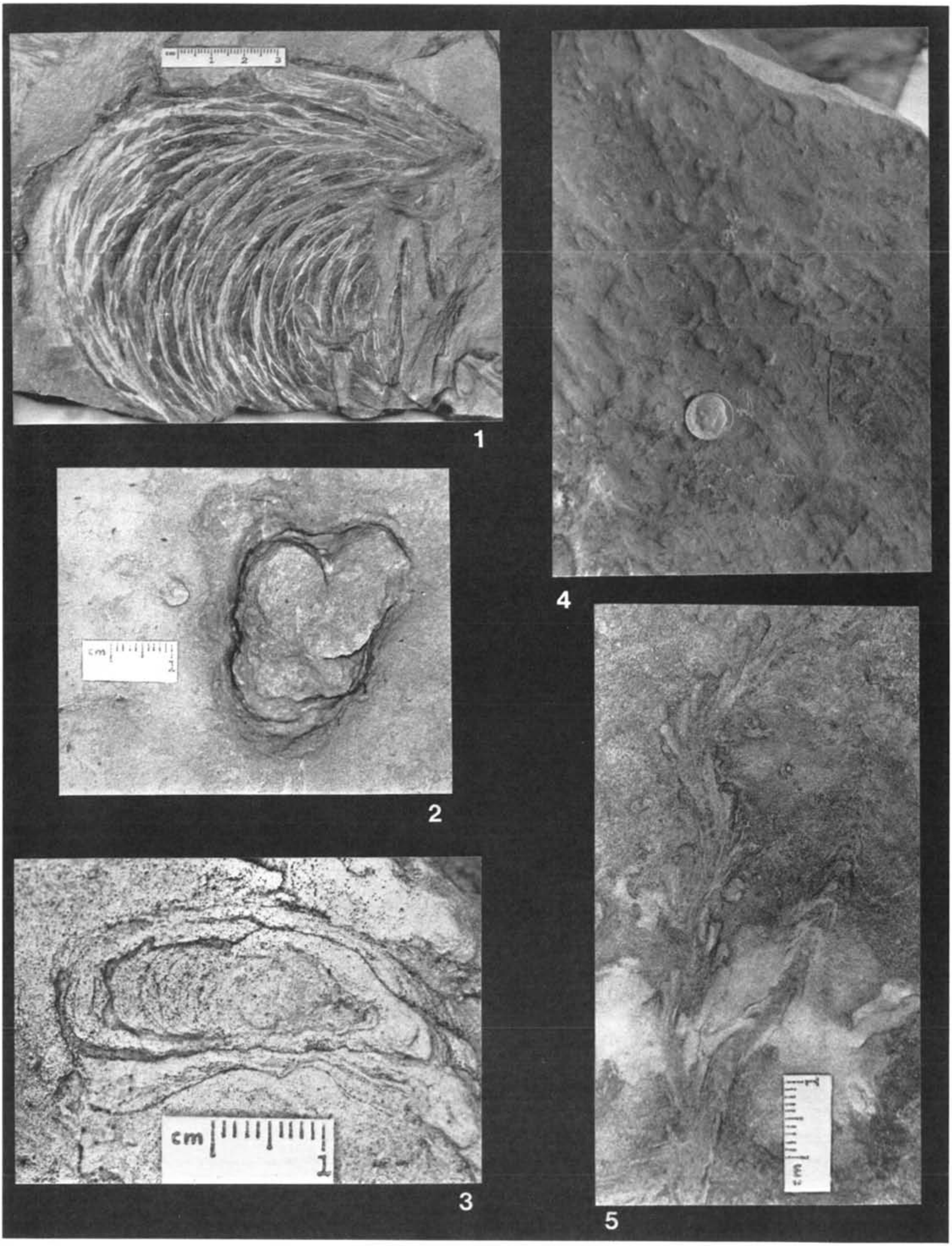

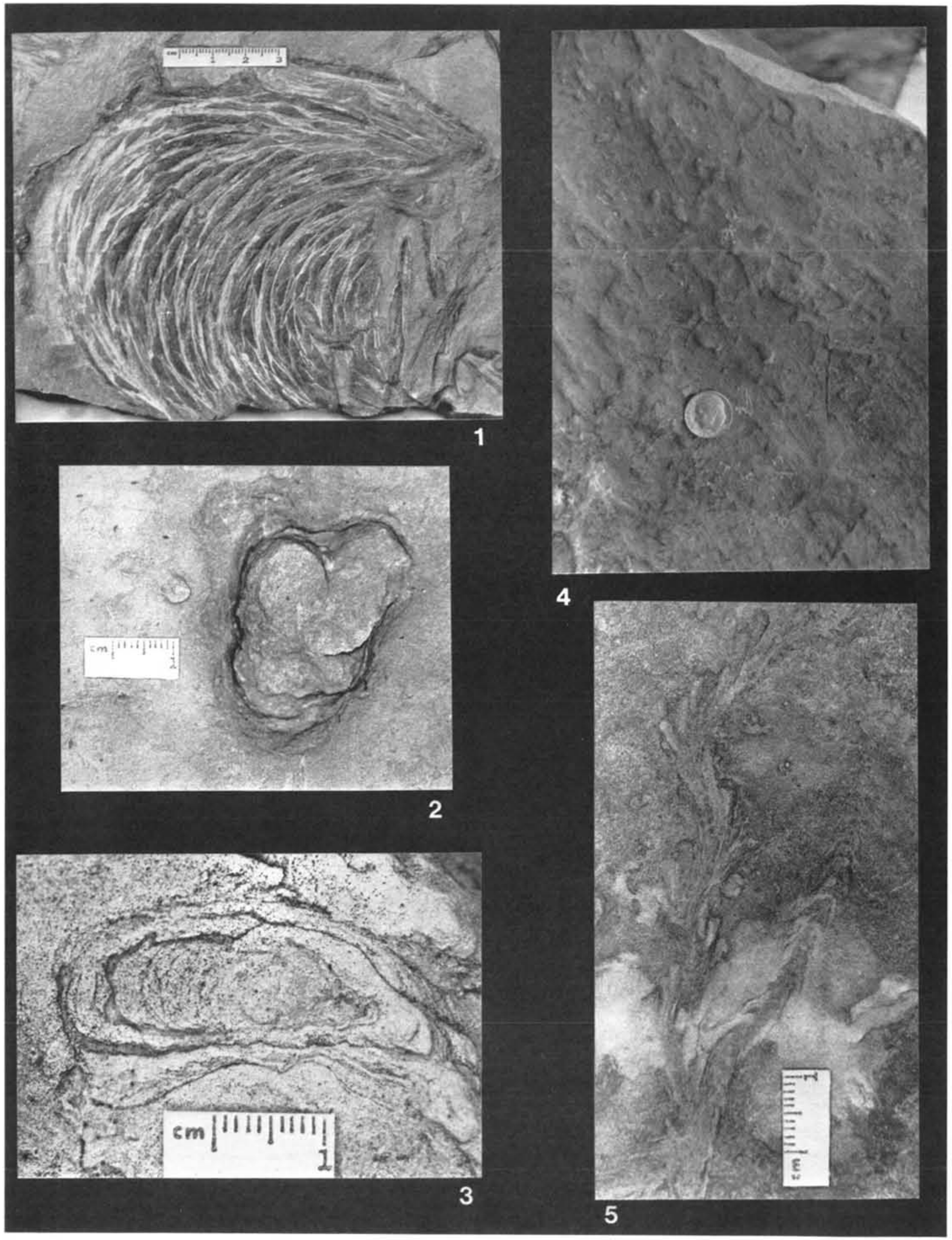

PLATE 5

Trace fossils of the Borden Formation.

1. *Lophoctenium*, an upper-surface (epichnia) feeding trace. The trace is an arcuate, spreite-filled gallery. The gallery is composed of concentric, curved, asymmetric ridges. The major ridges are built up of smaller ridges of oblique laminae, which, when sectioned, display tabular structures with corrugated top and bottom meniscae boundaries. It is common for forms to be transitional to *Zoophycos*. From Farmers Member, along Interstate 64, at milepost 138.4.

2. *Rusophycus*, a lower-surface (hypichnia) resting trace of an arthropod. Note the short, bilobate, buckle-like form and the shallowly-dug, bilobate pit. From Cowbell Member, Unit 2, along U.S. Highway 23 near Siloam, Greenup County.

3. *Rhizocorallium*-like trace, an upper-surface (epichnia) feeding trace. The trace is composed of horizontal, "U"-shaped tubes with spreite between parallel shafts. The curvature of the lamellae within the spreite indicates a protrusive shifting of the terminal bend of the tube through the sediment. The burrow is vague because there is very little contrast between the burrow and the matrix. From bed 13 of Farmers Member at Bull Fork section.

4. *Protopaleodictyon*, a lower-surface (hypichnia) grazing trace. The trace was originally preserved within bed (endichnia), but was later preserved as a sand cast on the sole of the bed. *Protopaleodictyon* is an irregular form of *Paleodictyon*, wherein only parts of the hexagonal, net-like burrows have been preserved. It was a systematic, deposit-feeding burrow. From bed 7 of Farmers Member, at Ramey section.

5. *Radionereites*-like trace, a lower-surface (hypichnia) feeding trace. It has a feather-like structure of uniform size, and is arranged in radiating clusters of sand-filled tubes. It is flanked bilaterally by closely-set, opposed, leaf-shaped, lobate extensions which diverge at acute angles. On the right side of the photograph is a chevron-shaped segment of *Arthrophycus* backfill structure. From Cowbell Member, Unit 1, at Trace Creek section.

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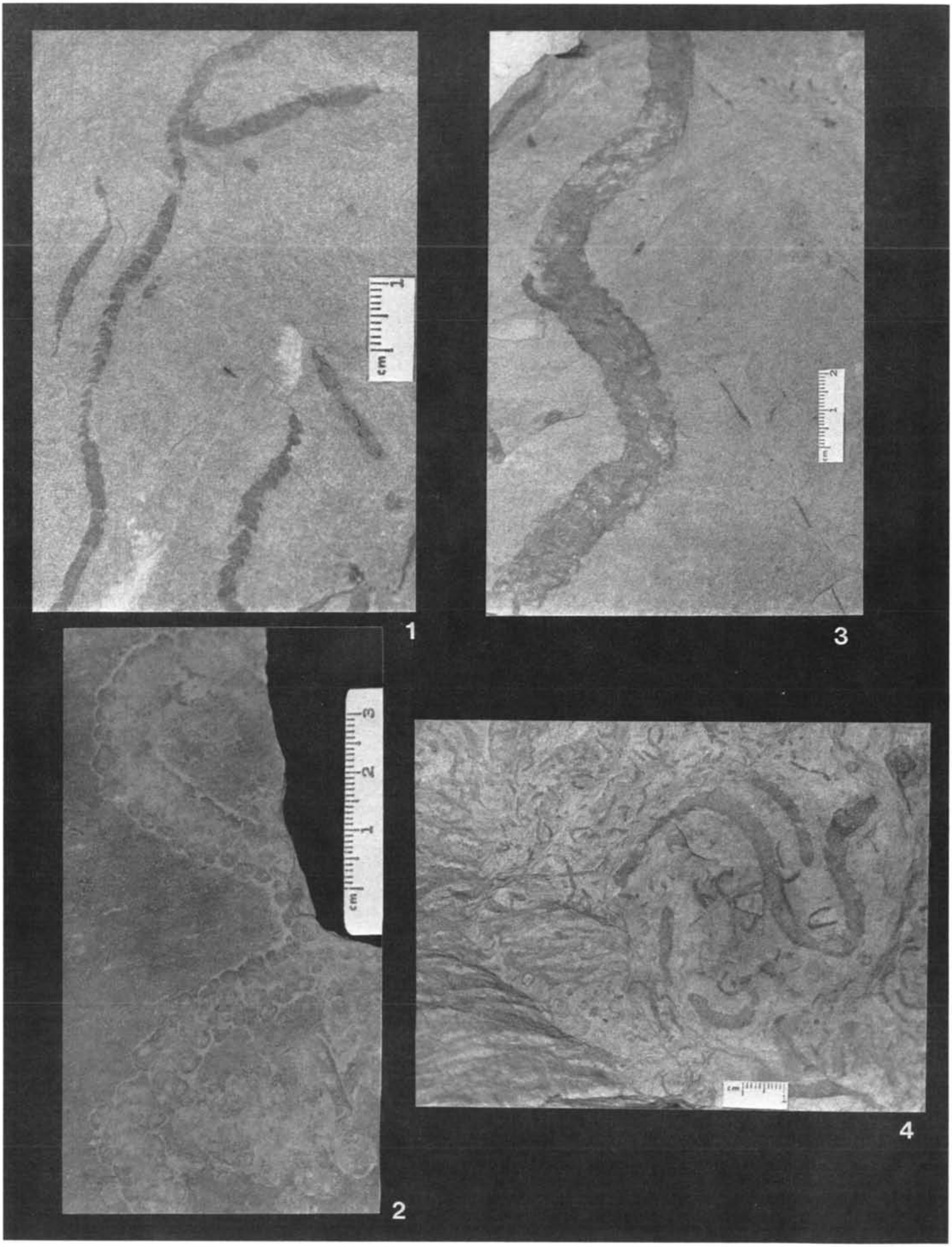

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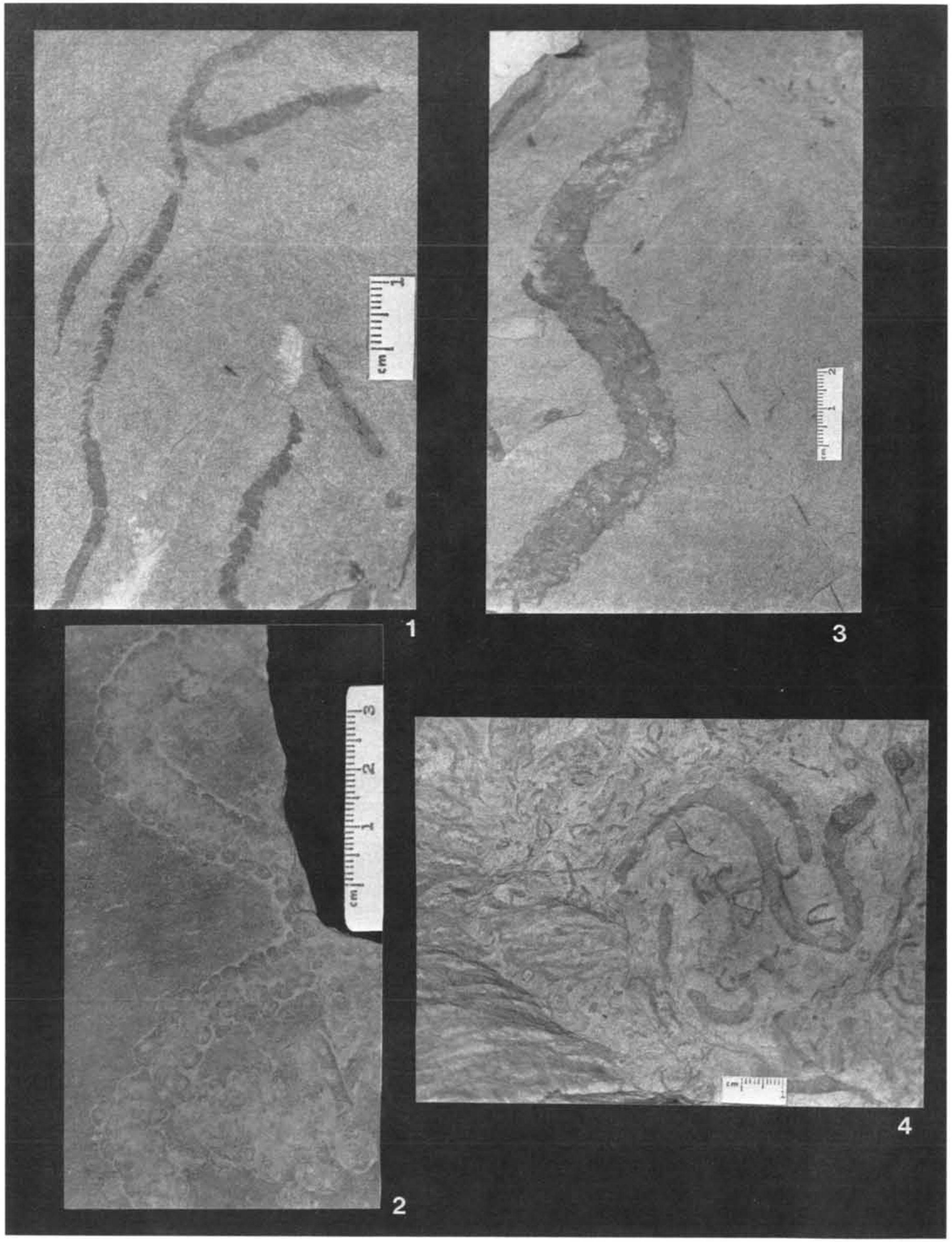

PLATE 6

Trace fossils from the Borden Formation.

1. *Scalarituba* (*Scalarituba*-view), a within-bed (endichnia) grazing trace. This form of *Scalarituba* is a continuous series of chevron-shaped segments which actually are the surface expression of alternating sand and mud endocones. It was the burrow of a deposit-feeding organism that was probably worm-like. From Farmers Member, along Interstate 64, at milepost 138.4.

2. *Scalarituba* (*Neonereites*-view), a lower surface (hypichnia) grazing trace. This form of *Scalarituba* is a continuous series of regular or irregular, biserially-arranged sand lobes and pustules. Float from Farmers Member at Triplett Creek, near Morehead.

3. *Scalarituba* (*Phyllodocites*-view), a lower-surface (hypichnia) grazing trace. This form of *Scalarituba* is a median furrow with lateral lobes on both sides, arranged biserially or in an alternating pattern. On the outer margins of most lateral lobes is a thin, hemi-circular crevasse. From Farmers Member, along Interstate 64, at milepost 138.4.

4. *Scalarituba* (*Scalarituba*-view), a within-bed (endichnia) grazing trace. This is the form of *Scalarituba* most often seen. It is a median furrow with low, transverse, meniscate ridges; occasionally, there is a lateral disturbed zone. In the upper left of the photograph there are broken segments of the looping *Helminthoida* ribbons. In the lower left of the photograph is part of a *Zoophycos* spreite field. From Cowbell Member, Unit 3, at Haney Branch section 1A.

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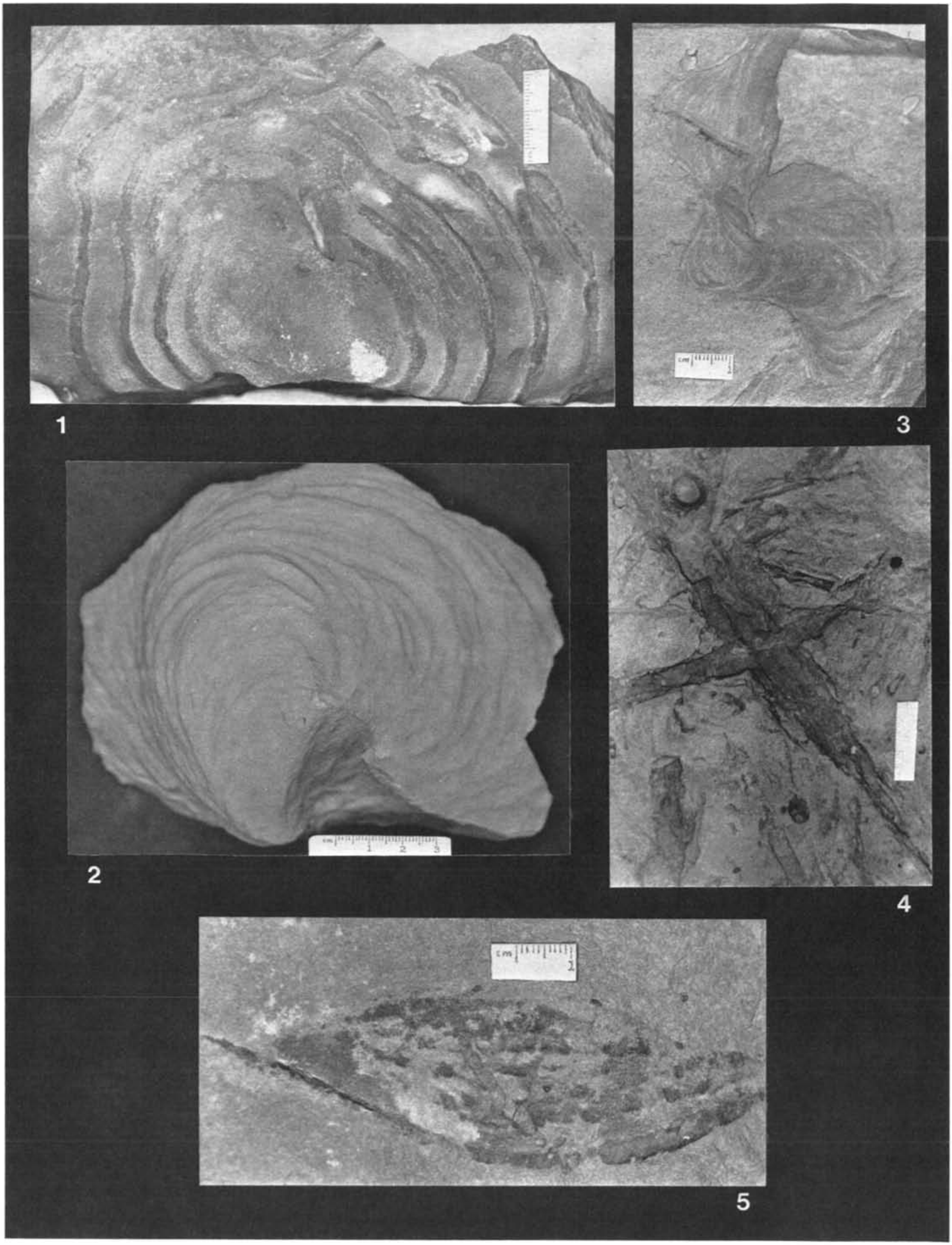
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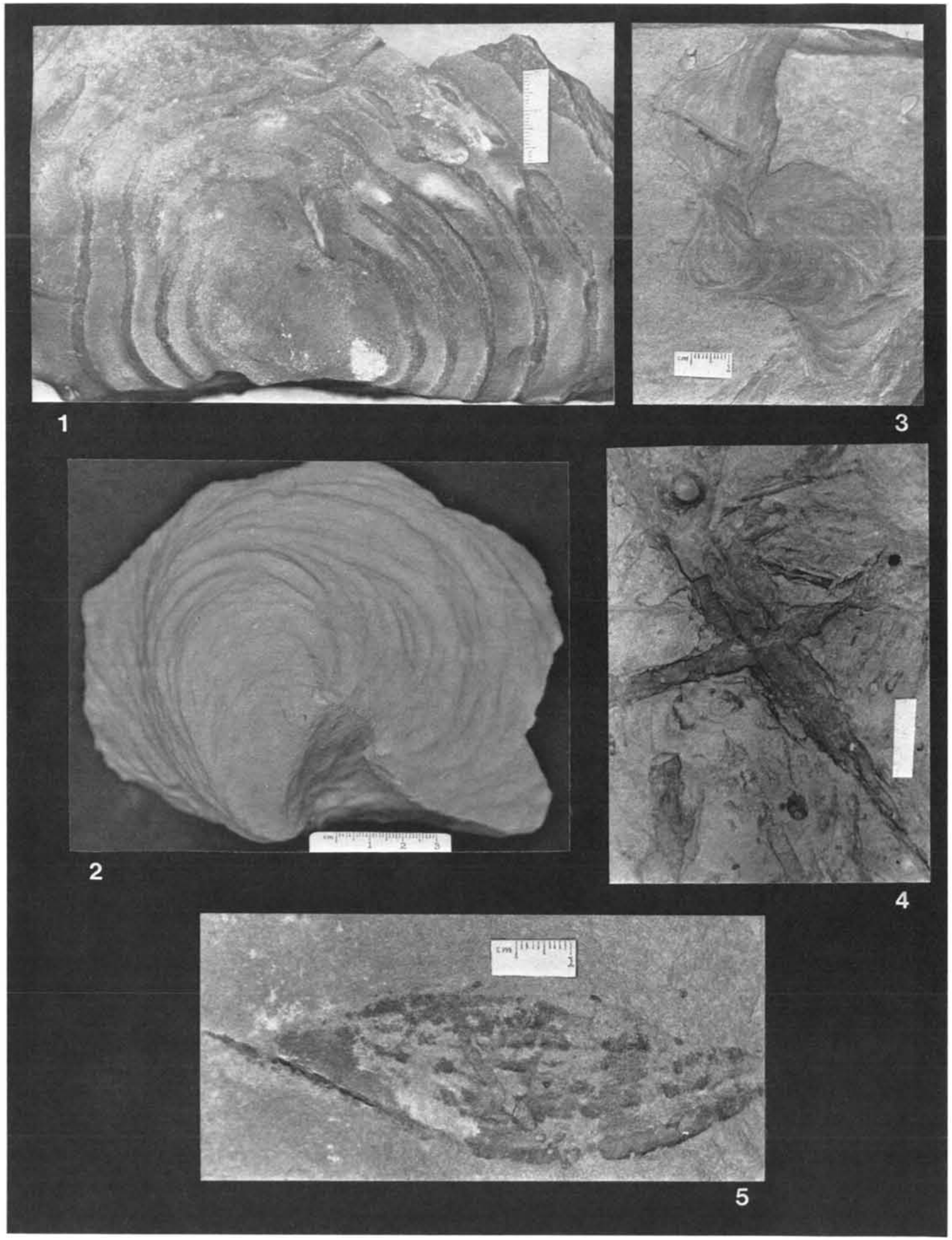

PLATE 7

Trace fossils from the Borden Formation.

1. *Spirorhaphe*, a within-bed (endichnia) grazing trace. It is a multifloored, three-dimensional, spirally coiled tunnel system. The simple, closely coiled spirals run from the outside inward. From Farmers Member, along Interstate 64, at milepost 138.4.

2. *Zoophycos* (type-1), a within-bed (endichnia) grazing trace. It is a helicoidal, arcuate system of protrusive spreite. The spreite was produced by lateral shifting of an essentially "U"-shaped burrow through the sediment. It was probably made by a sediment-eating worm. From Farmers Member, at Ramey section.

3. *Zoophycos* (type-2), a within-bed (endichnia) grazing trace. In this flat, or planar, form of *Zoophycos* the spreite, which are comprised of whorls, are lobate in outline. Note the marginal tube along the left perimeter of the system. From Farmers Member, at Ramey section.

4. *Palaeophycus*, an upper-surface (epichnia) crawling trace. It is made up of cylindrical to subcylindrical burrows, commonly unbranched, which characteristically intersect one another to form an "X" pattern. The surfaces of walls are smooth or faintly longitudinally striated. It commonly occurs profusely on bedding plane surfaces. From bed 13 of Farmers Member at Ramey section.

5. *Teichichnus*, a within-bed (endichnia) feeding trace. Its sigmoidal form displays wavy, long, protrusive laminae that merge upward at the ends. From Farmers Member, at Ramey section.

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ROAD LOG
First Day of Field Trip

The route for the first day of the field trip will traverse portions of the Tygarts Valley, Grahn, Olive Hill, Soldier, Cranston, Morehead, Farmers, and Colfax quadrangles. The buses will depart from the parking lot of Carter Caves State Resort Park Lodge at 8:00 a.m.

Road log begins at intersection of U.S. Highway 60 and Interstate 64.

Summary

The first day of the excursion will introduce the general succession of Borden rocks in the southwestern part of the field trip area. The interval from the Henley Bed at the base of the Borden Formation through the Farmers Member, Nancy Member, Cowbell Member, Nada Member, and the Renfro Member will be examined at five stops. Specific features of interest are: (1) lithologic character, internal sedimentary structures, and trace fossil associations in the relatively deeper part of a sedimentary basin that is associated with a prograding delta complex; (2) lithologic character, bedding thickness, internal sedimentary structures, and trace fossil associations in a distal turbidite facies; (3) variable vertical and lateral characteristics in a shallowing-upward sequence from a basin-floor environment through distal turbidites in a basin-floor environment, distal turbidites in a prodeltaic deposit, prodeltaic deposits, delta front deposits, delta platform deposits, and high intertidal deposits. Figure 2 summarizes the lithostratigraphic units that will be examined.

DESCRIPTION

MILEAGE	MILEPOST	DESCRIPTION
0.0		Intersection of U.S. Highway 60 and entrance ramp to westbound lane of Interstate 64; proceed west on Interstate 64.
0.5	161.0	Milepost.
0.6	160.9	Bridge over Tygarts Creek; on the left and right, Reelsville-Beech Creek (Newman Limestone) through lower dark shale of the Pennington Formation (Mississippian).
1.6	160.0	Milepost.
2.1	159.5	Warix Run through Reelsville-Beech Creek Members of Newman Limestone.
2.4	159.2	Bridge
2.6	159.0	Milepost.
2.8	158.8	Warix Run through Reelsville-Beech Creek Members of Newman Limestone.
3.5	158.1	Bridge; Warix Run through Reelsville-Beech Creek Members of Newman Limestone.
3.6	158.0	Milepost.
3.8	157.8	Siltstones of Cowbell Member (Borden Formation) through Warix Run-Reelsville-Beech Creek Members of Newman Limestone.
4.2	157.4	Siltstones of Cowbell Member (Borden Formation) through Warix Run-Reelsville-Beech Creek Members of Newman Limestone.
4.5	157.1	Warix Run through Reelsville-Beech Creek Members of Newman Limestone.
4.6	157.0	Milepost.
4.8	156.8	Brecciated Cowbell (Borden Formation) at west end of cut through Warix Run-Reelsville-Beech Creek Members of Newman Limestone.
5.2	156.4	Exit ramp, Ky. Highways 59-2.
5.4	156.2	Overpass, Ky. Highways 59-2; siltstones of upper Cowbell Member (Borden Formation).
5.5	156.1	Shales and siltstones of Nada Member and siltstones of Cowbell Member (Borden Formation) exposed along entrance ramp to Interstate 64.
5.6	156.0	Milepost.
6.0	155.6	Gradational shales and siltstones of Nada and Cowbell Members of Borden Formation.
6.6	155.0	On the right, crevasse splay in interdistributary bay deposits of Breathitt Formation (Pennsylvanian). Common trace fossils in the bay-fill deposits are *Asterosoma*, *Conostichus*, and *Phycodes*; common trace fossils in the crevasse splay include *Rhizocorallium*, *Skolithos*, *Conostichus*, and meandering annelid trails. All these traces have affinities to marine or brackish marine conditions; thus, this part of the delta was near the Pennsylvanian shoreline (Basan and others, 1979).
7.6	154.0	Milepost.
8.2	153.4	On the right, the upper orthoquartzite tidal delta of Breathitt Formation. Two unfilled channels can be seen on the upper surface of the upper delta. Two coarsen-

ing-upward, dark, silty bay fills overlie the coarser rocks; each is capped by burrowed siderite bands and siltstones. A channel cut through the burrowed sandstone at top of the cut contains numerous slump blocks (Horne and others, 1971).

8.6 153.0 On the left, Breathitt Formation (Pennsylvanian); dark carbonaceous siltstones intertongue with orthoquartzite stringers and overlie red and green shales (Nada) and siltstones (Cowbell) at base of cut.

9.2 152.4 On the left and right, burrowed, bay-fill shales overlying orthoquartzitic tidal deltas of Breathitt Formation; the tidal deltas overlie red and green shales of Nada Member (Borden Formation).

9.6 152.0 Milepost.

9.8 151.8 On the left, siltstones of Cowbell Member of Borden Formation.

10.0 151.5 Bridge.

10.2 151.3 On the left, dark bay-fill shales (Breathitt Formation) overlying red and green shales (Nada) and siltstones (Cowbell) of Borden Formation.

10.5 151.0 Breathitt Formation overlying Nada and Cowbell Members of Borden Formation.

10.9 150.6 On the right, Cowbell Member of Borden Formation.

11.1 150.4 On the right, Cowbell Member of Borden Formation.

11.4 150.1 On the right, Cowbell Member of Borden Formation.

11.5 150.0 Bridge. On the left, a long cut; siltstones (Cowbell) and prominent red and green shales (Nada) exposed at east end; cut is overlain by orthoquartzitic sandstone (Breathitt) at west end.

12.2 149.3 On the left, at west end of cut, bituminous, orthoquartzitic sandstone (Breathitt) of front side of barrier overlying red and green mudstones of the Nada Member (Borden Formation); note loading phenomena of orthoquartzitic sandstone on underlying clays.

12.5 149.0 Breathitt Formation; burrowed, even-bedded sandstone with ripples and cross-bedding (interdistributary mouth bar facies) capped by siderite nodules and bay-fill shales. Trace fossils common to the interdistributary mouth bar facies include *Arenicolites*, *Conostichus*, and *Laevicyclus* (Basan and others, 1979).

12.9 148.6 Rowan-Carter County line. On the left, channel cutting into burrowed, even-bedded sandstones and bay-fill shales of Breathitt Formation.

13.4 148.1 Base of large, bay-fill sequences of previous cuts underlain by red and green shales (Nada); no orthoquartzitic sandstones are present here.

13.5 148.0 Milepost.

13.6 147.9 Westbound entrance to weigh station.

14.2 147.3 On the left and right, tidal-flat deposits of the Newman Limestone overlain by Pennington clastics; dark, back-barrier shales, orthoquartzitic sandstones, and siderite nodules of the Breathitt Formation are present at top of cut.

14.5 147.0 Milepost.

15.2 146.3 On the right, tidal-flat carbonates and shales on subaerial exposure surfaces in Newman Limestone.

15.4 146.1 STOP 1—PERRY BRANCH SECTION (Fig. 32).

Location:

Interstate 64, mile 146.1, westbound lane. Carter coordinate location 18-V-74, 2,600 feet FNL, 2,300 feet FWL. Cranston quadrangle. Rowan County, Kentucky.

Stratigraphy:

Cowbell Member (top of Unit 4 and Unit 5), Nada Member, Renfro Member of Borden Formation; Newman Limestone (Fig. 33).

Petrology and Physical Sedimentary Structures:

Cowbell Member, Unit 4: Note alternating beds of glauconite-streaked siltstone and silty shale (Fig. 34). Faint parallel laminations in siltstone, but most primary sedimentary structures absent due to bioturbation.

Cowbell Member, Unit 5: Glauconite-streaked siltstone, massive in lower part, becoming more shaly at top. Greenish-gray shale clasts throughout. Some siltstones display parallel laminations.

Nada Member: Apparent sharp contact with Cowbell Member. Highly variable lithologies consisting of primarily mudstone and shale with intercalations of thin-bedded, ripple-marked siltstone and lenses of crinoidal pack-

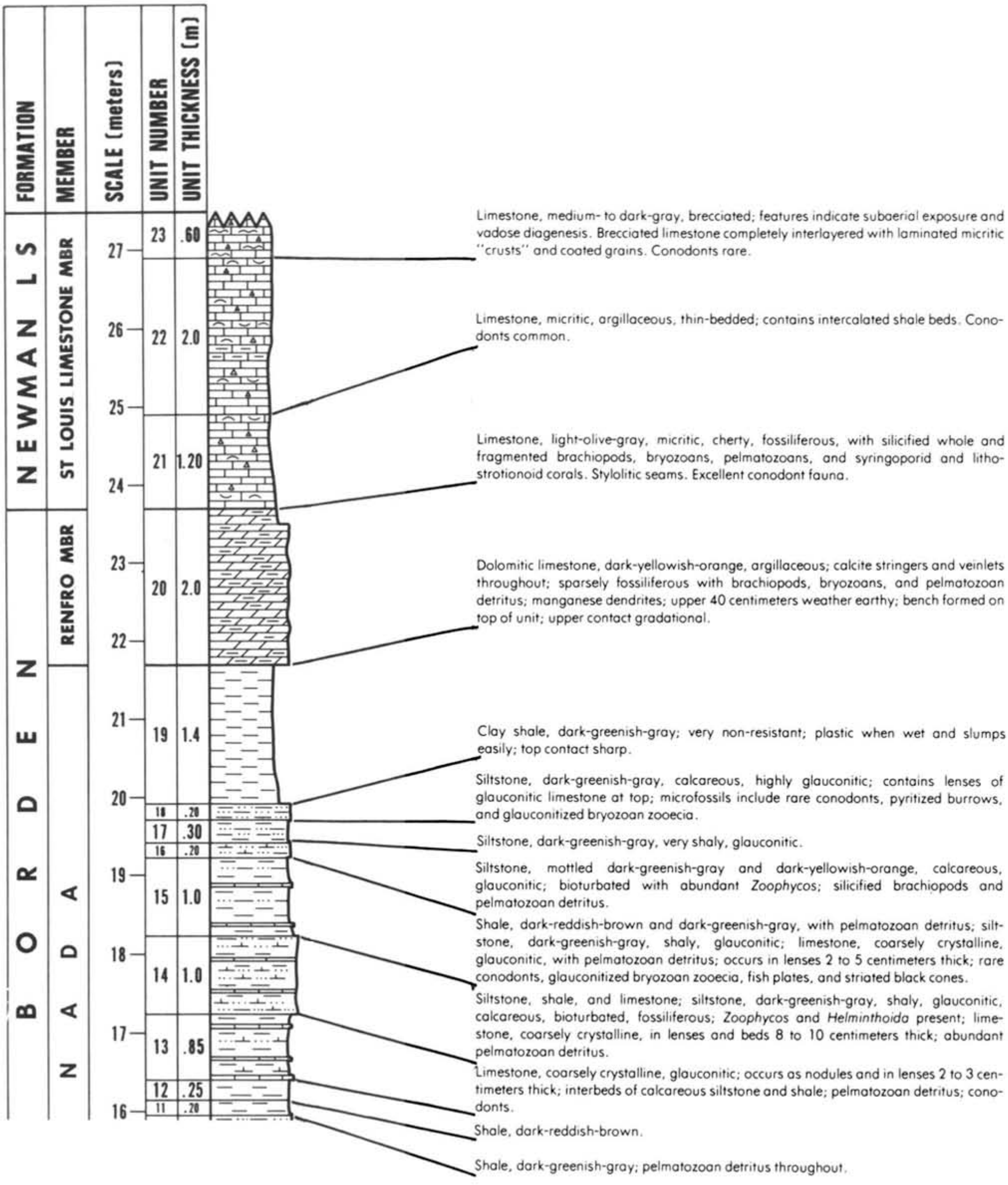


Figure 32. Stratigraphic section at Perry Branch on Interstate 64, milepost 146.1, westbound. Carter coordinate location 18-V-74, 2,600 feet FNL, 2,300 feet FWL, Cranston quadrangle, Rowan County, Kentucky.

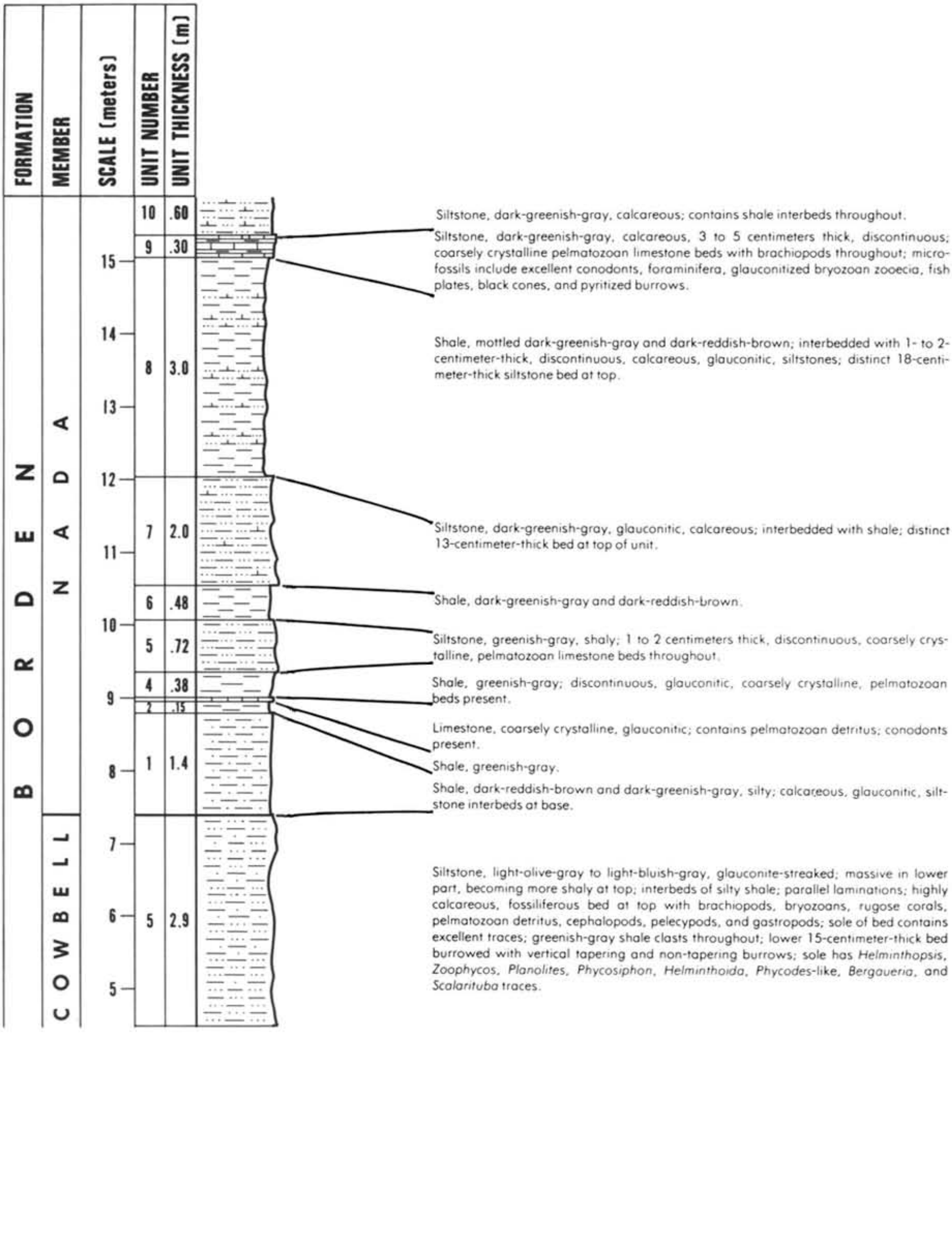


Figure 32. Continued

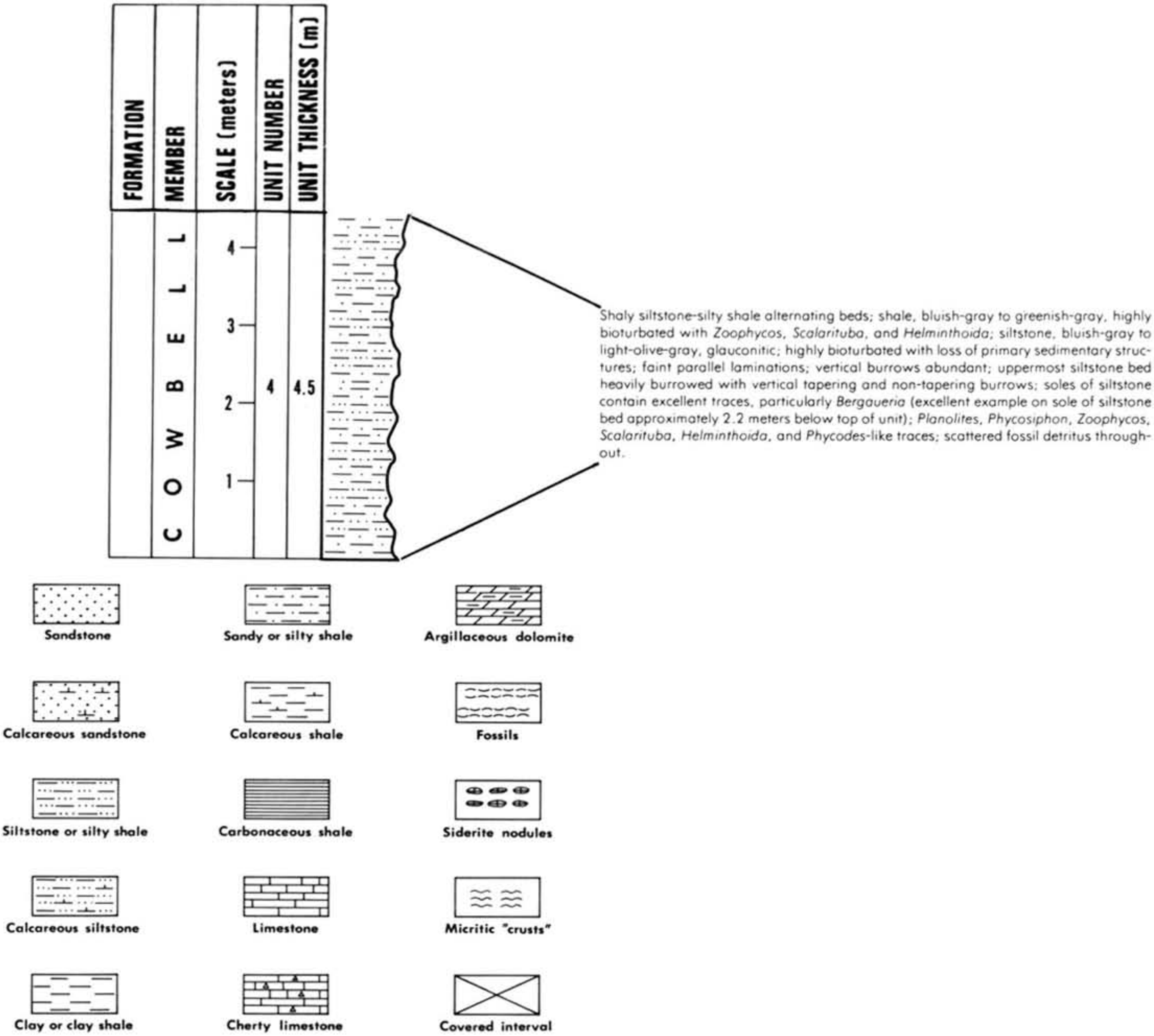


Figure 32. Continued

stones and grainstones. Carbonate lenses cross laminated. Prominent red and green shale intervals. Glauconite-rich layers and bored phosphatic nodules.

Renfro Member: Sharp contact with Nada below and Newman Limestone above. Dolomitic limestone with irregular patches and vugs of calcite spar (birdseye structures). Parallel laminations broken by vertical veinlets.

Body Fossils:

Cowbell Member, Unit 4
- *brachiopods
- *bryozoans
- gastropods
- *pelmatozoan detritus
- rugose corals

*abundant

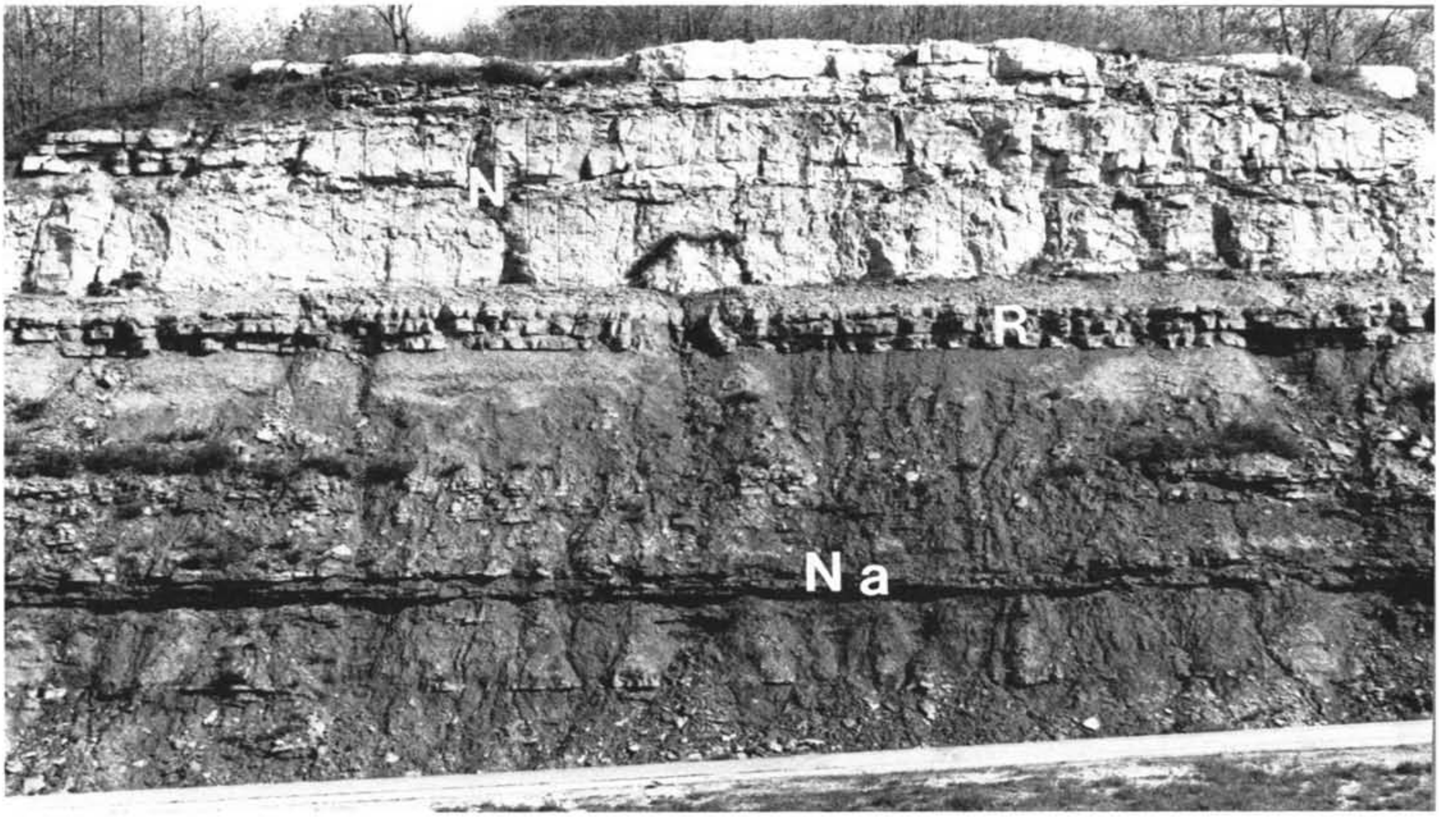


Figure 33. Nada Member (Na) is overlain by Renfo Member (R) and Newman Limestone (N) at Perry Branch section (Day 1, Stop 1).

Cowbell Member, Unit 5
- *brachiopods
- *bryozoans
- cephalopods
- gastropods
- pelecypods
- *pelmatozoan detritus
- rugose corals

Nada Member
- *brachiopods
- *bryozoans
- gastropods
- pelecypods
- *pelmatozoan detritus
- rugose corals

Renfro Member
- brachiopods
- bryozoans

Trace Fossils:

Cowbell Member, Unit 4
- **Bergaueria*

*abundant

- **Helminthoida*
- *Phycosiphon*
- *Phycodes*-like
- **Planolites*
- **Scarlarituba* (*Scalarituba*-view)
- *vertical tapering and non-tapering burrows
- *Zoophycos* (mainly type-2)

Cowbell Member, Unit 5
- **Bergaueria*
- **Helminthoida*
- *Helminthopsis*-like
- *Phycosiphon*
- *Phycodes*-like
- **Planolites*
- **Scalarituba* (*Scalarituba*-view)
- *vertical tapering and non-tapering burrows
- **Zoophycos*

Nada Member
- arthropodan trail (cf. *Psammichnites*)

*abundant

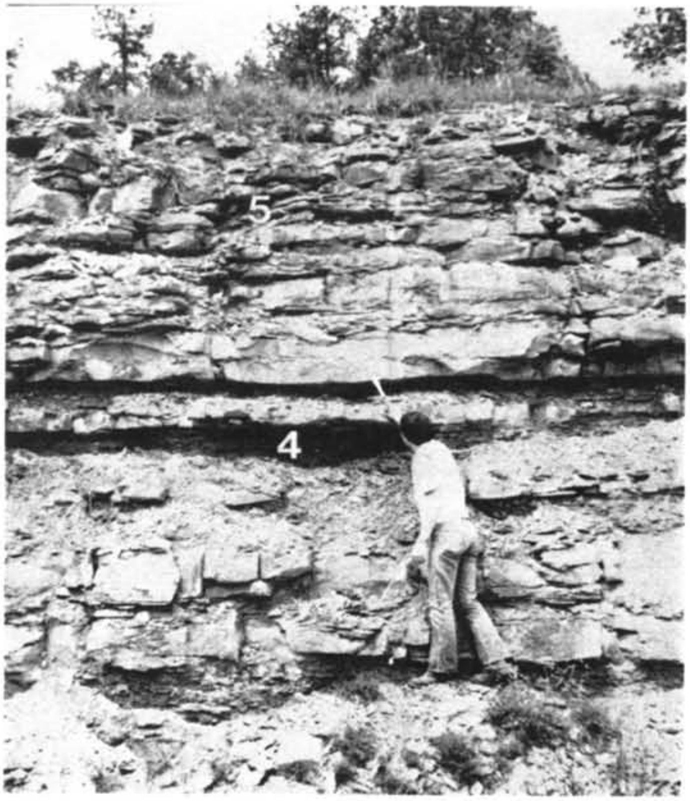


Figure 34. Contact between Unit 4 and Unit 5 of Cowbell Member along Interstate 64, at milepost 145.9.

*Helminthoida
Phycosiphon
*Scalarituba (Scalarituba-view)
*Zoophycos (mainly type-2)

Renfro Member
None ?

Interpretation:

Cowbell Member, Unit 4: Interdeltaic bay.
Cowbell Member, Unit 5: Distal bar (?).
Nada Member: Delta platform (interdeltaic bay and skeletal carbonate facies).
Renfro Member: High intertidal.

15.3 146.0 Milepost.
15.4 145.9 Overpass, Ky. Highway 799 (Big Perry); on the left and right, Unit 4 and Unit 5 of the Cowbell Member (Borden Formation).
16.0 145.3 STOP 2—HANEY BRANCH SECTION 1A (Fig. 35).

*abundant

Location:
Interstate 64, mile 145.3, westbound lane. Carter coordinate location 17-V-74, 1,800 feet FSL, 1,500 feet FEL. Cranston quadrangle. Rowan County, Kentucky.

Stratigraphy:
Cowbell Member: Unit 1 (upper part), Unit 2, and Unit 3 (Fig. 36).

Petrology and Physical Sedimentary Structures:
Cowbell Member, Unit 1: Massive, sandy siltstone displaying small, soft-sediment deformation features, cross laminations, parallel laminations, climbing ripple laminations, and convolute bedding. Varved-like bedding; parallel laminations often bent downward along traces of vertical burrows.

Cowbell Member, Unit 2: Gradational contact with Unit 1. Highly bioturbated, dark-gray, silty shale and shaly siltstone. Siltstone with varved-like bedding. Sedimentary structures include cross laminations, parallel laminations, and scour-and fill features.

Cowbell Member, Unit 3: Gradational base with Unit 2. Massive siltstone with silty shale intervals. Sedimentary structures well developed and include scour-and-fill features infilled with fossil detritus, small-scale crossbedding, wavy laminations, parallel laminations, climbing-ripple laminations, and small soft-sediment deformation features (Figs. 37 and 38). Parallel laminations commonly bent downward along traces of vertical burrows.

Body Fossils:
Cowbell Member, Unit 1
*brachiopods
*bryozoans
*pelmatozoan detritus

Cowbell Member, Unit 2
*brachiopods
*bryozoans
*crinoid detritus
gastropods
goniatites

*abundant

nautiloids
pelecypods

Cowbell Member, Unit 3
*brachiopods
*bryozoans
*pelmatozoan detritus

Trace Fossils:

Cowbell Member, Unit 1
**Helminthoida*
**Scalarituba* (*Scalarituba*-view)
**Zoophycos* (mainly type-2)

Cowbell Member, Unit 2
**Chondrites*
**Cylindrichnus*
**Helminthoida*
Monocraterion
**Scalarituba* (*Scalarituba*-view)
**Zoophycos*

Cowbell Member, Unit 3
**Chondrites*
Cylindrichnus
**Helminthoida*
?*Lophoctenium*
**Scalarituba* (*Scalarituba*-view)
**Zoophycos* (mainly type-2)
excellent examples of cross-sectional views of the traces *Helminthoida, Scalarituba,* and *Zoophycos.*

Interpretation:

Cowbell Member, Unit 1: Delta front (distal bar facies).

Cowbell Member, Unit 2: Interdeltaic bay facies.

Cowbell Member, Unit 3: Delta front (distal bar facies).

16.2 145.1 On the right, upper part of Unit 1 of Cowbell Member (Borden Formation).

16.3 145.0 On the right, upper part of Unit 1, Unit 2, and Unit 3 of Cowbell Member.

16.5 144.8 On the right, lower part of Unit 1 of Cowbell Member.

16.6 144.7 On the right, lower part of Unit 1 of Cowbell Member.

16.7 144.6 On the right, east end of cut, lower part of Unit 1 of Cowbell Member and upper part of Nancy Member (Borden Formation).

16.9 144.4 On the right, lower part of Unit 1 of Cowbell Member and Nancy Member; lithic contact between Nancy and Cowbell Members is placed at top of first bench.

*abundant

17.0 144.3 STOP 3—HANEY BRANCH SECTION 1B (Fig. 39).

Location:

Interstate 64, mile 144.3, westbound lane. Carter coordinate location 16-V-74, 300 feet FSL, 1,800 feet FEL. Cranston quadrangle. Rowan County, Kentucky.

Stratigraphy:

Nancy Member (upper part), Cowbell Member, Units 1, 2, and 3 (lower part) (Fig. 40).

Petrology and Physical Sedimentary Structures:

Nancy Member: Bluish-gray, silty, highly bioturbated shale. Sedimentary structures destroyed by intense burrowing. Burrow mottling and churned sediments. Scattered thin, discontinuous siltstones and very fine-grained sandstone beds. Some sandstone beds display parallel and wavy laminations.

Cowbell Member, Unit 1: Base gradational with Nancy Member. Primarily massive, sandy siltstone with scattered horizons of shaly siltstone and silty shale. Medium to coarse grained. Mud and shale clasts throughout. Sedimentary structures are well developed and include parallel laminations, wavy laminations, cross laminations, climbing ripples, and scour-and-fill features. In particular horizons intense bioturbation has destroyed sedimentary structures.

Cowbell Member, Unit 2: Base gradational with Unit 1. Silty shale and shaly siltstone. Siltstone lenses display varved-like bedding.

Cowbell Member, Unit 3 (lower part): Base gradational with Unit 2. Massive siltstone with well-developed sedimentary structures including parallel laminations, wavy laminations, climbing ripples, scour-and-fill features, and cross laminations. Silty shale interbeds in basal part of unit.

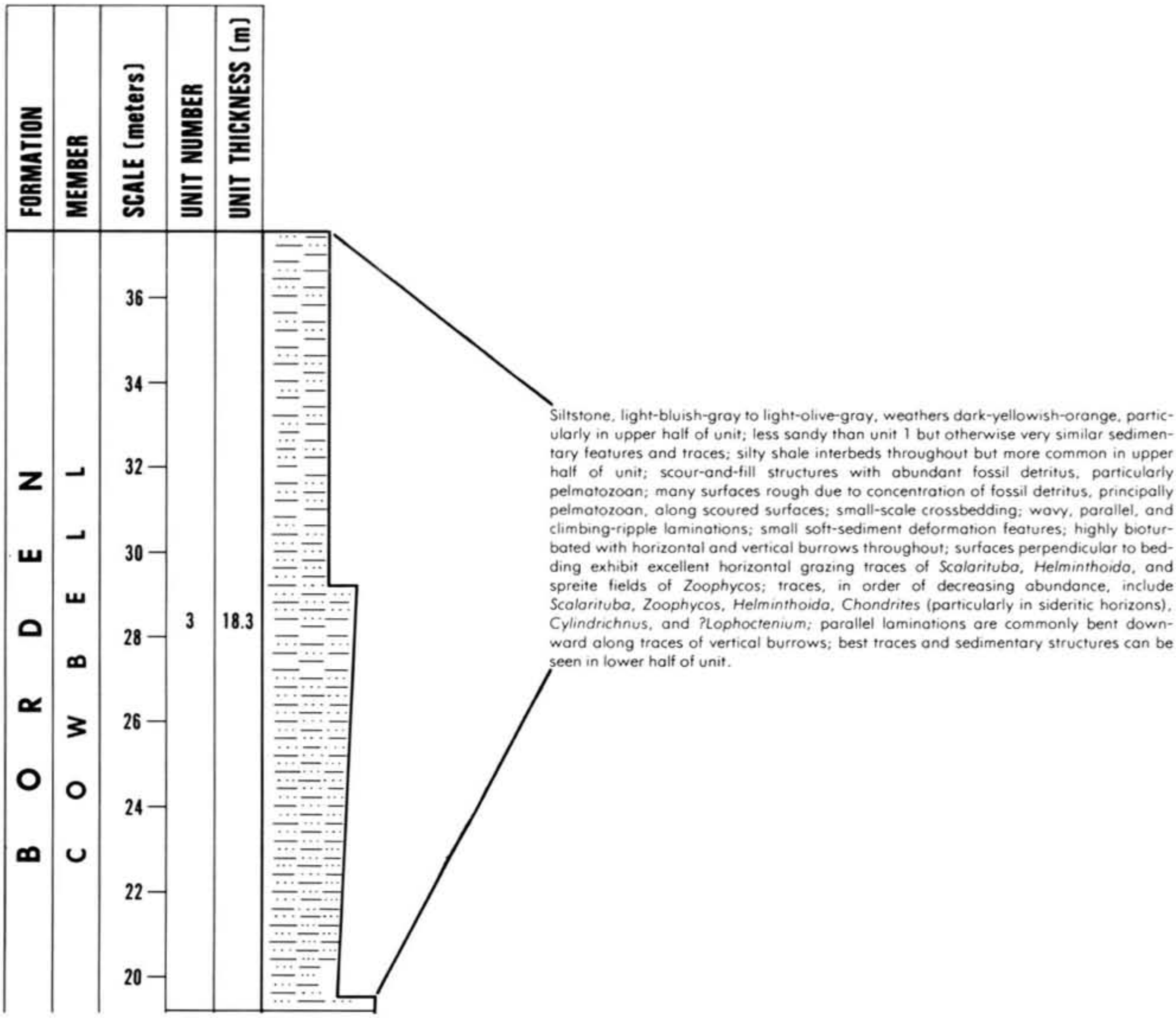
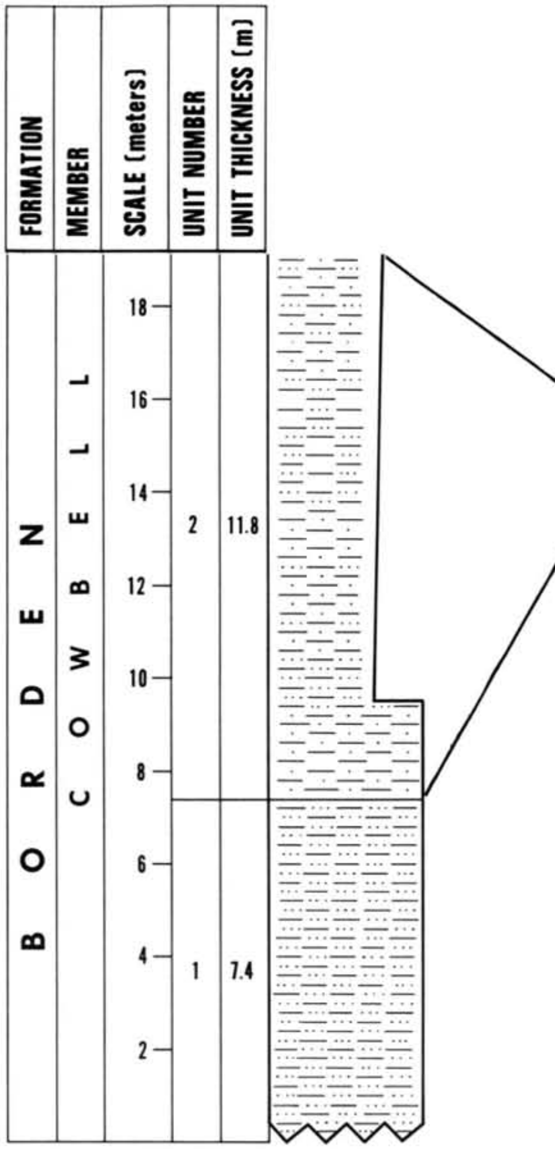


Figure 35. Stratigraphic section at Haney Branch (1A) on Interstate 64, milepost 145.3, westbound. Carter coordinate location 17-V-74, 1,800 feet FSL, 1,500 feet FEL, Cranston quadrangle, Rowan County, Kentucky. See Figure 32 for explanation of symbols.



Silty shale and shaly siltstone; shale, light-olive-gray, weathers dark-yellowish-orange; very silty, micaceous; highly bioturbated; sideritic beds, lenses, and nodules are highly fossiliferous with nautiloids, goniatites, pelecypods, gastropods, brachiopods, bryozoans, crinoid detritus, and the trace *Chondrites*; siltstone, shaly, cross laminated; parallel laminations (varved-like); scour-and-fill structures; large fossiliferous sideritic concretions; unit bioturbated throughout with traces *Scalarituba*, *Zoophycos*, *Chondrites*, *Helminthoida*, *Monocraterion*, and *Cylindrichnus*; top gradational with unit 3.

Siltstone, light-olive-gray, weathers to dark-yellowish-orange; more silty than lower 5.5 meters; small soft-sediment deformation features; climbing ripple laminations and parallel laminations; sideritic horizons with abundant fossil detritus; bioturbated; vertical burrows common.

Siltstone, light-olive-gray to greenish-gray, sandy, micaceous, massive; small soft-sediment deformation features; cross laminations; climbing ripple laminations; parallel laminations produce varved-like appearance; many parallel laminations bent downward along traces of vertical escape burrows; thin horizons of convolute bedding; lenticular bedding; sideritic beds, nodules, and lenses with abundant fossil detritus; bioturbated throughout; surfaces perpendicular to bedding exhibit the traces *Helminthoida*, *Scalarituba*, and spreite fields of *Zoophycos*; top gradational with unit 2.

Figure 35. Continued

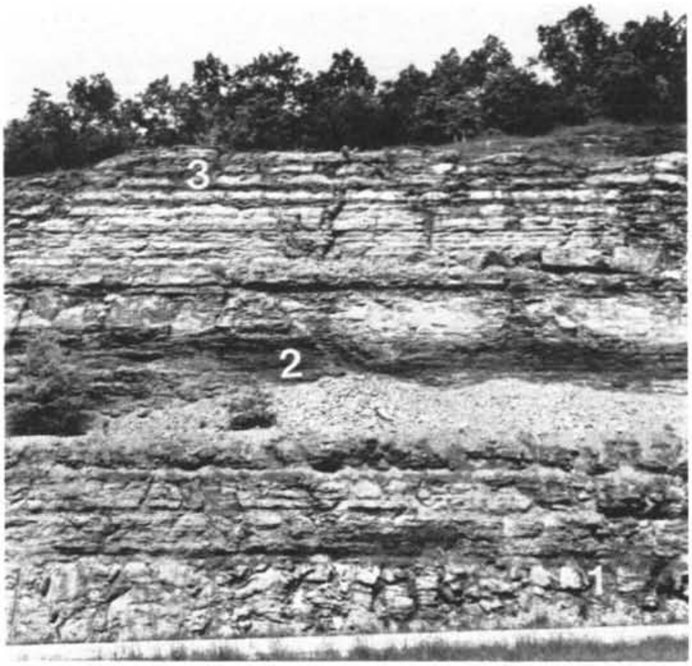


Figure 36. Top of Unit 1 and Units 2 and 3 of the Cowbell Member at Haney Branch section 1A (Day 1, Stop 2).

Body Fossils:

Nancy Member (upper part)
- *brachiopods
- *bryozoans
- cephalopods
- conularids
- rugose corals
- *pelmatozoan detritus

Cowbell Member, Unit 1
- brachiopods
- bryozoans
- pelmatozoan detritus

Cowbell Member, Unit 2
- *brachiopods
- *bryozoans
- *crinoid detritus
- gastropods
- goniatites

*abundant

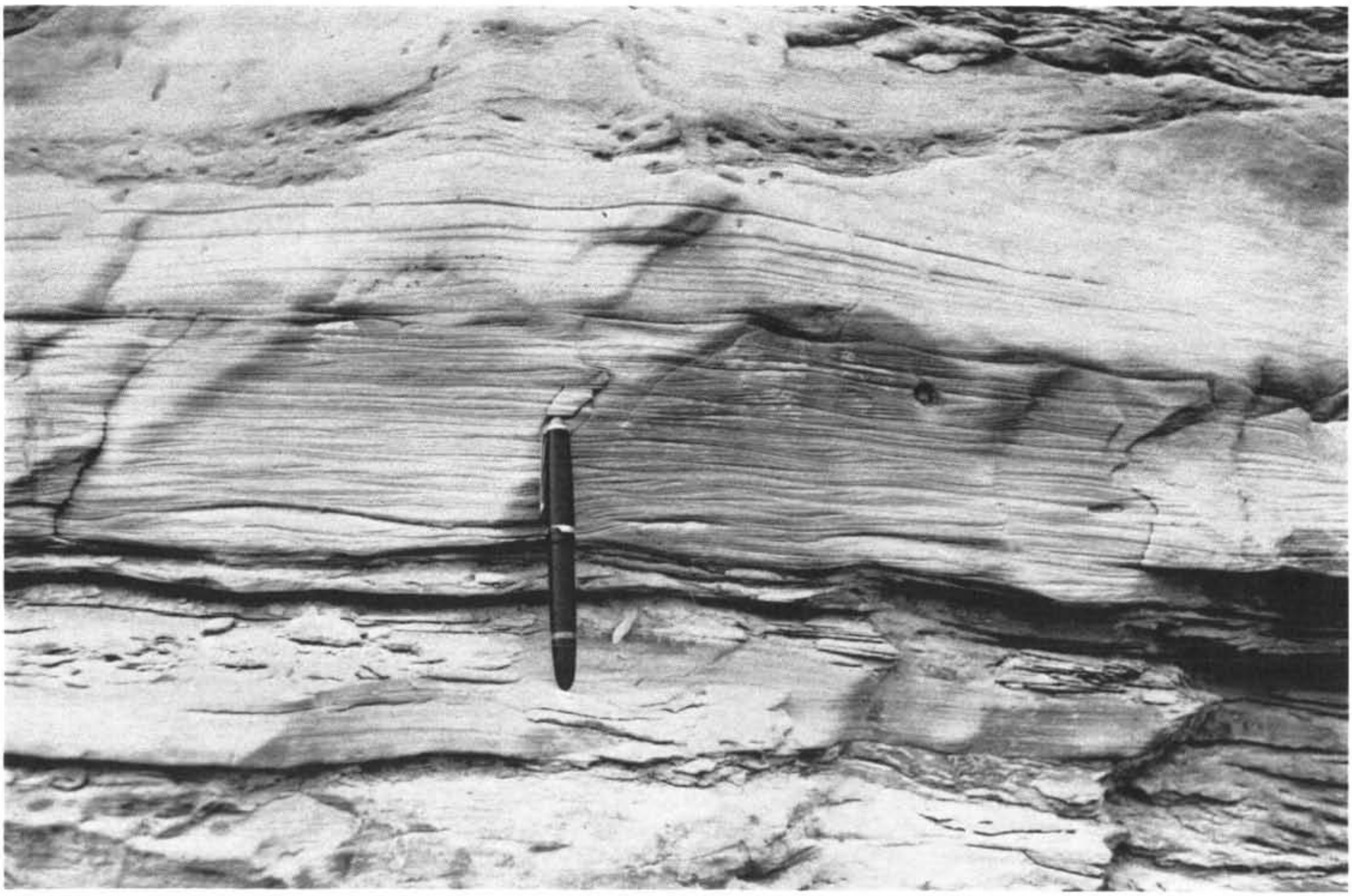


Figure 37. Climbing-ripple laminations and bioturbated outcrop surface in Unit 3, Cowbell Member, at Haney Branch section 1A (Day 1, Stop 2).

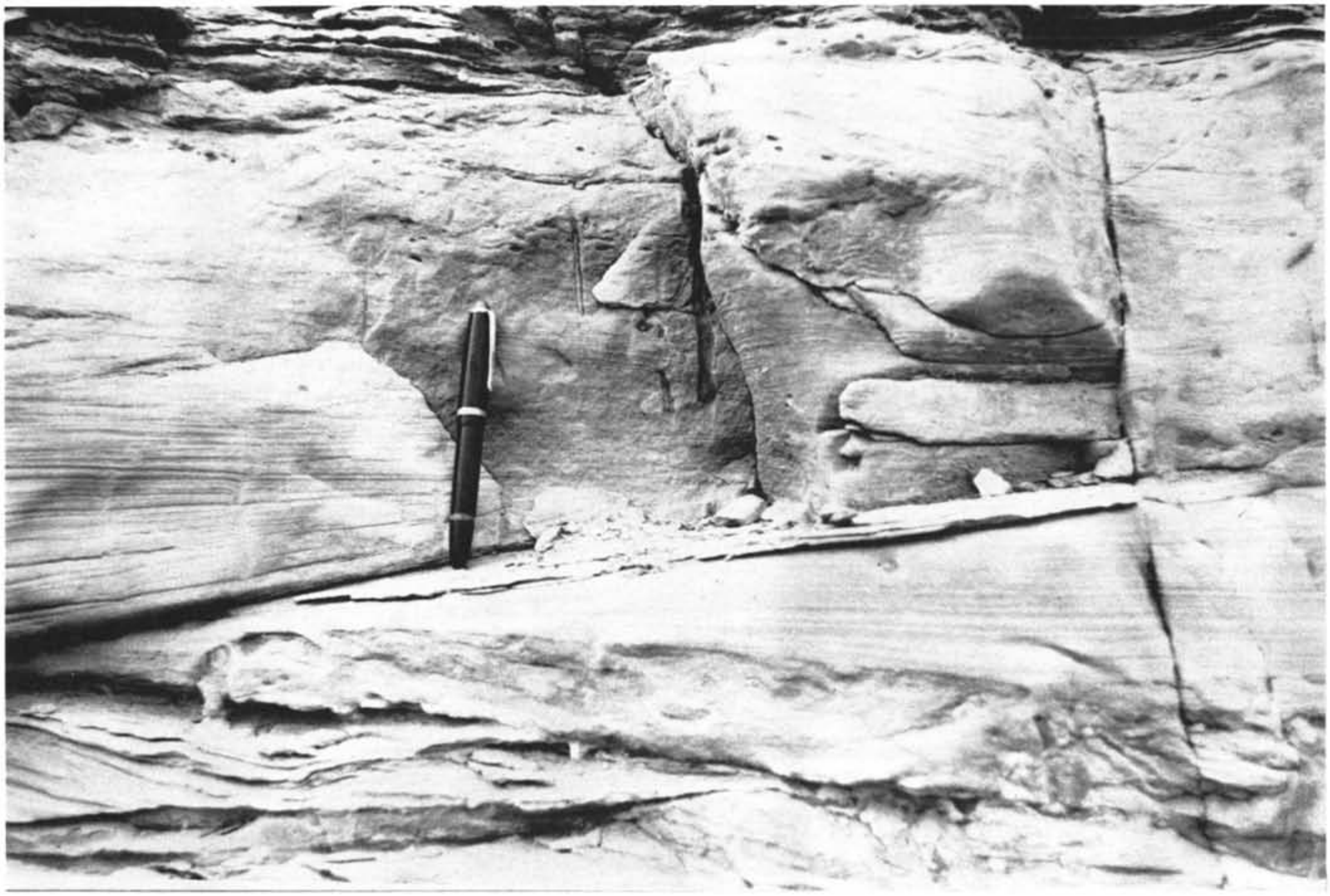


Figure 38. Planar crossbedding and vertical burrows in Unit 3, Cowbell Member, at Haney Branch section 1A (Day 1, Stop 2).

nautiloids
pelecypods

Cowbell Member, Unit 3
brachiopods
bryozoans
pelmatozoan detritus

Trace Fossils:

Nancy Member (upper part)
**Helminthoida*
**Scalarituba* (*Scalarituba*-view)
vertical burrows
**Zoophycos* (mainly type-2)

Cowbell Member, Unit 1
Archaeichnium-like
Chondrites
*"communal tubes"
**Cylindrichnus*
?*Diplocraterion*

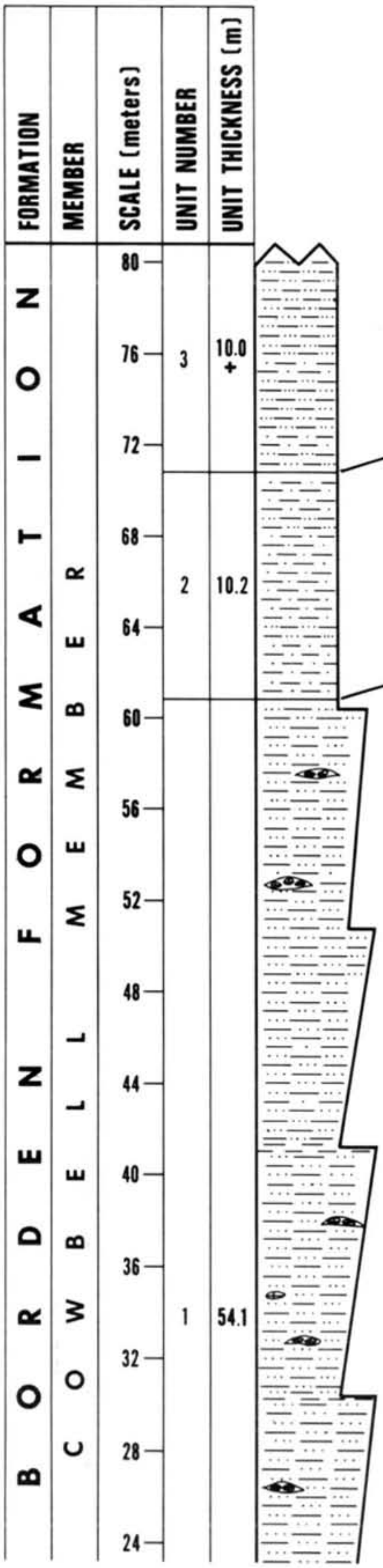
*abundant

Gyrochorte
**Helminthoida*
Monocraterion
**Scalarituba* (*Scalarituba*-view)
*vertical and oblique silt-filled burrows
Zoophycos (mainly type-2)

Cowbell Member, Unit 2
**Chondrites*
Cylindrichnus
*Helminthoida
**Scalarituba* (*Scalarituba*-view)
Zoophycos (mainly type-2)

Cowbell Member, Unit 3
**Chondrites*
**Cylindrichnus*
**Helminthoida*

*abundant



Siltstone, light-bluish-gray to light-olive-gray, weathers dark-yellowish-orange; abundant sedimentary structures and trace fossils; silty shale interbeds occur in basal part of unit; scour-and-fill features common; traces include *Scalarituba*, *Helminthoida*, *Zoophycos*, *Chondrites*, *Cylindrichnus*, and *Monocraterion*; upper part of unit is poorly exposed on hilltop.

Silty shale and shaly siltstone, light-olive-gray to reddish-brown; highly bioturbated; numerous reddish-brown, sideriteric siltstone lenses and nodules; siltstone lenses show varved-like bedding and contain abundant *Chondrites*; sideritic nodules very fossiliferous with nautiloids, goniatites, brachiopods, bryozoans, pelecypods, gastropods, and crinoid detritus; nodules heavily mineralized with galena, pyrite, sphalerite, barite, and calcite; contains a 1.5-meter-thick siltstone bed similar in lithology, sedimentary structures, and traces to unit 1 below; base gradational with unit 1; other traces include *Scalarituba*, *Helminthoida*, *Zoophycos*, and *Cylindrichnus*.

Siltstone, light-gray to medium-gray, fine- to medium-grained, massive; less bioturbated than unit 1; scour-and-fill features less common than in unit 1; parallel, wavy, and cross laminations more common than in unit 1; reddish-brown, sideritic, siltstone lenses contain fossils and are highly bioturbated; traces include rare vertical burrows, *Zoophycos*, *Scalarituba*, and *Helminthoida*; upper 1.3 meters heavily iron-stained dark-yellowish-orange.

Upper surface of bench 5 contains excellent traces, particularly "communal tubes" (i.e., sets of sand tubes that show general "U-in-U" arrangement but touch rather than cut into each other).

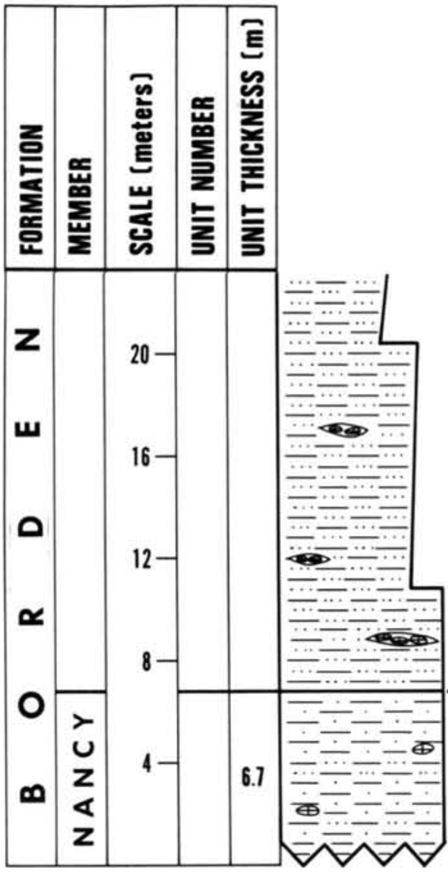
Siltstone, shaly, fine- to medium-grained, massive; parallel, wavy, and cross laminations; scour features common; traces include *Cyrochorte*, *Scalarituba*, *Chondrites*, *Cylindrichnus*, *Zoophycos*, and vertical and oblique silt-filled burrows.

Shale, shaly siltstone, bioturbated just below and above bench 4; abundant *Helminthoida* and *Scalarituba*.

Siltstone, light- to medium-gray, medium- to coarse-grained, massive; parallel, wavy, and cross laminations more prominent than in units 2 and 3; climbing ripples; base shaly; sideritic siltstone lenses and concretions more common than in units 2 and 3; scattered fossiliferous horizons; traces include *Cylindrichnus*, *Scalarituba*, *Zoophycos*, *?Diplocraterion*, and fillings of vertical burrows with external longitudinal striations and faint transverse sculptures inside (*Archaeichnium*-like); small-scale scour features common.

Shale, shaly siltstone, yellowish-gray, highly bioturbated with abundant *Helminthoida* and *Scalarituba*; increase in grain size (from coarse silt to very fine sand) upward from bench 2 to bench 3; increase in vertical burrows upward from bench 2 to bench 3; mud and shale clasts throughout.

Figure 39. Stratigraphic section at Haney Branch (1B) on Interstate 64, milepost 144.3, westbound. Carter coordinate location 16-V-74, 300 feet FSL, 1,800 feet FEL, Cranston quadrangle, Rowan County, Kentucky. See Figure 32 for explanation of symbols.



Surface of bench 2 contains very abundant vertical burrows with crater-like tops.

Vertical- and oblique-oriented, silt-filled burrows; scattered pockets and lenses of reddish-brown, iron-stained, sideritic siltstone with fossil detritus; small-scale scour features.

Siltstone, light-olive-gray to yellowish-gray, sandy, micaceous, massive; highly bioturbated with loss of bedding features due to intensive burrowing; scattered discontinuous reddish-brown sideritic lenses, beds, and nodules which are fossiliferous; outcrop surfaces appear rough and pitted due to bioturbation; traces include *Helminthoida*, *Scalarituba*, *Zoophycos*, and *Cylindrichnus*; faint parallel and wavy laminations.

Shale, bluish-gray, very silty, micaceous; highly bioturbated; bioturbation has destroyed most bedding features; mottled with burrows; traces difficult to identify due to churned sediments; *Helminthoida* and *Scalarituba* very abundant; scattered sideritic nodules throughout, some with pyrite and fossiliferous with brachiopods, bryozoans, corals, and pelmatozoan detritus; discontinuous shaly siltstone and very fine-grained sandstone lenses, iron-stained reddish-brown, pyritic, bioturbated, and fossiliferous with brachiopods, bryozoans, and pelmatozoan detritus; very fine-grained sandstone lenses show parallel and wavy laminations; contain *Zoophycos* and vertical burrows.

Figure 39. Continued

Monocraterion
**Scalarituba* (*Scalarituba*-view)
Zoophycos (mainly type 2)

Interpretation:

Nancy Member: Prodeltaic deposits.
Cowbell Member, Unit 1: Delta front (Distal bar facies)
Cowbell Member, Unit 2: Interdeltaic bay
Cowbell Member, Unit 3: Delta front (distal bar facies)

17.3 144.0 On the right, lower part of Unit 1 of Cowbell Member and Nancy Member of Borden Member.
17.8 143.5 On the left, gradational contact of Nancy-Cowbell Members of Borden Formation.
18.3 143.0 Milepost.
18.6 142.7 On the left, Nancy Member.
19.0 142.3 On the left, Nancy Member with intrusions of thin turbidite beds.
19.3 142.0 On the left, transitional lithologies of Nancy-Farmers Members; it is in this stratigraphic interval that abundant and diverse trace fossils and cephalopods (goniatites and nautiloids) have been collected and are being studied (Chaplin and Mason, 1979).
20.3 141.0 On the left, rest area; the lithic contact between the Farmers and Nancy Members of the Borden Formation is poorly exposed at this locality.
20.5 140.8 On the right, rest area.
21.3 140.0 On the left, Nancy Member.
21.9 139.4 On the left, Nancy Member with characteristic fossiliferous sideritic nodules.
22.3 139.0 Milepost.
22.5 138.8 On the left, turbidites of Farmers Member (Borden Formation). Note flexure in Farmers Member. Thin sequence of Farmers Member on right. Rawls Branch section.
22.9 138.4 On the left and right, turbidites of Farmers Member. Note (1) monotonous sequence of alternating, tabular-bedded sandstones and mudstones; (2) lateral persistence of individual sandstone turbi-

*abundant

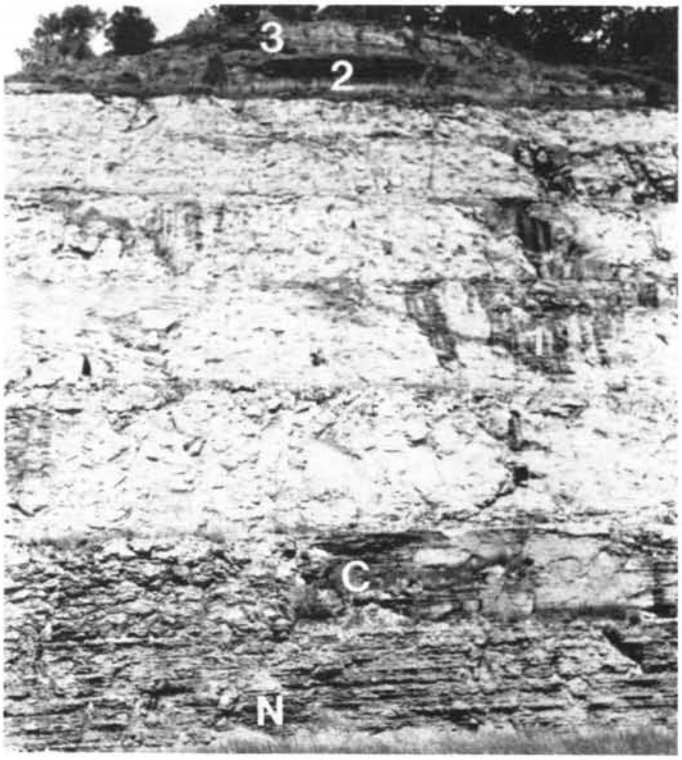


Figure 40. Contact of Nancy (N) and Cowbell (C) Members and Units 1 and 2 and base of Unit 3 of Cowbell Member at Haney Branch section 1B (Day 1, Stop 3).

dite beds; and (3) the relatively sharp bases and undulatory tops of individual sandstone turbidite beds. Time permitting, we will make a short stop at this locality on the return to Carter Caves State Resort Park to observe and collect excellent traces in distal turbidite sequence. Deer Lick Branch section.

23.3 138.0 Milepost.

23.8 137.5 Exit 137, Morehead-Flemingsburg, Ky. Highway 32. On the left and right, turbidites of the Farmers Member. The thickness of the Nancy Member reaches a minimum (20-30 feet) at this locality.

24.3 137.0 Milepost.

24.7 136.6 On the left and right, Farmers Member. Bratton Branch Church section.

25.0 136.3 Bridge, North Fork Triplett Creek-Bluestone Road.

25.3 136.0 Milepost.

25.7 135.6 On the left and right, upper part of Farmers Member, Farmers-Nancy transitional beds, and lower part of Nancy Member. On the left, the uppermost turbidite bed in the Nancy Member pinches out at top of cut.

26.3 135.0 STOP 4—BULL FORK SECTION (Fig. 41).

Location:

Interstate 64, mile 135.0, westbound lane. Carter coordinate location 19-U-72, 900 feet FSL, 1,400 feet FEL. Farmers quadrangle. Rowan County, Kentucky.

Stratigraphy:

Henley Bed, Farmers Member, Farmers-Nancy transitional beds, Nancy Member (lower part) (Figs. 42-44).

Petrology and Physical Sedimentary Structures:

Henley Bed: Shale-mudstone, light-olive-gray to light-gray; structureless; pyritic; contains thin interbeds of siltstone and very fine-grained sandstone in upper part; contains an excellent conodont fauna.

Farmers Member: Monotonous alternation of thick-bedded, very fine-grained sandstones and thin shales. Complete Bouma sesquences, but most common Tb-Te. Sandstone beds with sharp bases and gradational tops. Parallel laminations disrupted by vertical burrows. Tool marks, groove casts, load casts, and flutes.

Farmers-Nancy transitional beds: Thin-bedded, very fine-grained, glauconite-streaked sandstones separated by thick intervals of structureless shales and mudstones. Sandstone commonly structureless or with parallel laminations. Excellent tool marks, groove casts, load casts, and flutes on soles of sandstone beds.

Nancy Member (lower part): Bluish-gray, silty, bioturbated shale. Fine- to medium-grained, thick sandstone bed approximately 10 meters above base, with parallel laminations, mud clasts, and load casts and tool marks on sole.

Description:

Borden Formation

Farmers Member

Henley Bed

Shale—Mudstone, light-olive-gray to olive-gray, structureless; contains an excellent conodont fauna.

Farmers Member

Bed 1: Sandstone, light-olive-gray to light-gray, very fine-grained, silty; Tb-Te; base sharp, top undulatory; sole has load casts and groove casts; traces include *Zoophycos* and vertical and horizontal burrows.

Bed 2: Mudstone, light-olive-gray to olive-gray.

Bed 3: Sandstone, light-olive-gray to olive-gray, very fine-grained; structureless; base and top slightly undulatory; *Zoophycos* bed; *Helminthoida* present.

Bed 4: Shale, light-olive-gray to olive-gray, sandy.

Bed 5: Sandstone, medium-gray to olive-gray, very fine-grained, very silty; base and top slightly undulatory; *Zoophycos* bed; vertical burrows common.

Bed 6: Mudstone, light-olive-gray to olive-gray.

Bed 7: Sandstone, light-gray to light-olive-gray, very fine-grained; heavily iron-stained at base; base and top undulatory; sole with load casts, tool marks, and groove casts; traces include *Zoophycos* and vertical burrows.

Bed 8: Shale, light-olive-gray, silty; highly bioturbated.

Bed 9: Sandstone, light-gray to light-olive-gray, silty; Tb-Te; base sharp, top undulatory; sole has load casts; traces include *Zoophycos* and vertical burrows.

Bed 10: Mudstone, olive-gray to greenish-gray.

Bed 11: Sandstone, light-gray to light-olive-gray, very fine-grained, silty; Tc-Te; base and top undulatory; sole has large load casts, tool marks, and groove casts; *Zoophycos*.

Bed 12: Mudstone, light-olive-gray to greenish-gray.

Bed 13: Sandstone, light-olive-gray, very fine-grained, silty; iron-stained; Tb-Te; base and top undulatory; sole has load casts and horizontal, u-shaped, spreite-filled burrows; excellent vertical burrows, *Zoophycos*, *Teichichnus*, *Lophoctenium*, *Cylindrichnus*, and *Rhizocorallium*-like traces present.

Bed 14: Shale, olive-gray to greenish-gray; upper 10 centimeters has burrowed ironstone concretions.

Bed 15: Sandstone, light-olive-gray, very fine-grained, silty; Td-Te; base undulatory, top sharp; basal 8 centimeters very fossiliferous, with bryozoan and brachiopod fragments; sole has load casts, tool marks, groove casts, and horizontal non-branching burrows; traces include vertical burrows and *Zoophycos*.

Bed 16: Mudstone, light-gray to greenish-gray.

Bed 17: Sandstone, light-olive-gray, very fine-grained, silty; Tb-Te; base undulatory, top sharp; sole has tool marks and groove casts; traces include vertical and horizontal burrows and *Zoophycos*.

Bed 18: Mudstone, light-olive-gray to greenish-gray.

Bed 19: Sandstone, medium-gray to light-olive-gray, very fine-grained, silty; Tb-Te; base undulatory, top sharp; sole has load casts, tool marks, and horizontal, non-branching burrows.

Bed 20: Shale, light-olive-gray to greenish-gray, very silty; ironstone concretions at base contain *Zoophycos*.

Bed 21: Sandstone, light-olive-

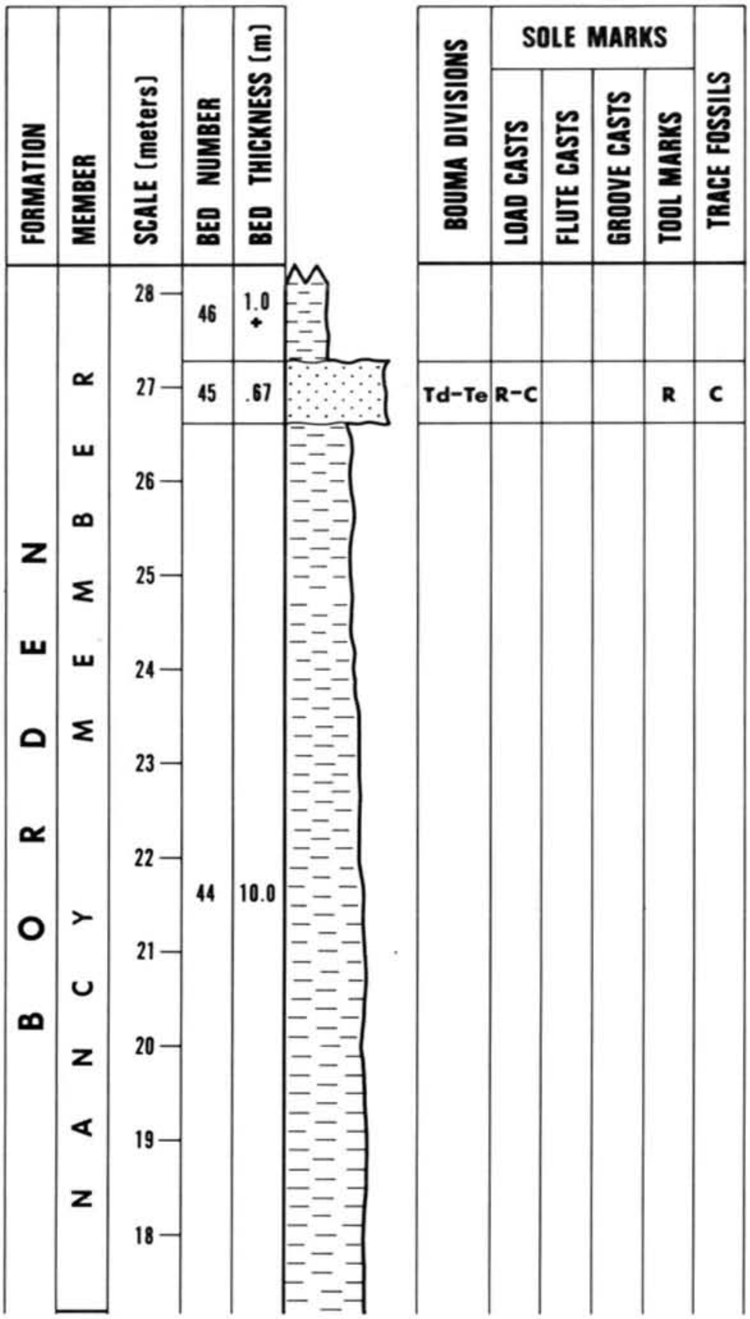
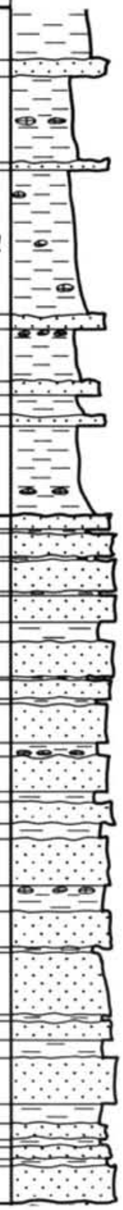


Figure 41. Stratigraphic section at Bull Fork on Interstate 64, milepost 135.0, westbound. Carter coordinate location 19-U-72, 900 feet FSL, 1,400 feet FEL, Farmers quadrangle, Rowan County, Kentucky. See Figure 32 for explanation of symbols.

FORMATION: BORDEN

MEMBER: TRANSITIONAL BEDS (upper part); FARMERS MEMBER (lower part)



BED NUMBER	BED THICKNESS (m)	BOUMA DIVISIONS	SOLE MARKS: LOAD CASTS	SOLE MARKS: FLUTE CASTS	SOLE MARKS: GROOVE CASTS	SOLE MARKS: TOOL MARKS	TRACE FOSSILS
43	.19	Td-Te	R-C		A	A	C
42	.91						
			C		A	A	A
40	1.52						
		Tb	C		A	A	
38	.56						
			A		A	A	A
36	.19						
		Tb	C		A	C	A
34	.95						
		Tb-Te					
31	.26	Tb-Te	R		R	R	C
29	.36	Tb-Te	A				C-A
27	.28	Tb-Te	C		A	A	R-C
25	.38	Tb-Te	C		R	R	R-C
23	.21	Tb-Te	C		C	R	R-C
21	.42	Tb-Te	C	A	A		C-A
19	.37	Tb-Te	R			R	R-C
17	.24	Tb-Te			R	R	C-A
16	.18						
15	.52	Td-Te	C		R	R-C	C
14	.28						
13	.39	Tb-Te	C				A
11	.67	Tc-Te	A		R	R	R-C
9	.21	Tb-Te	R				R-C
8	.19						
7	.47	Tc-Te	R		C	C	R-C
6	.20						
5	.17						A
							A
1	.40	Tb-Te	A		C		R-C

Figure 41. Continued

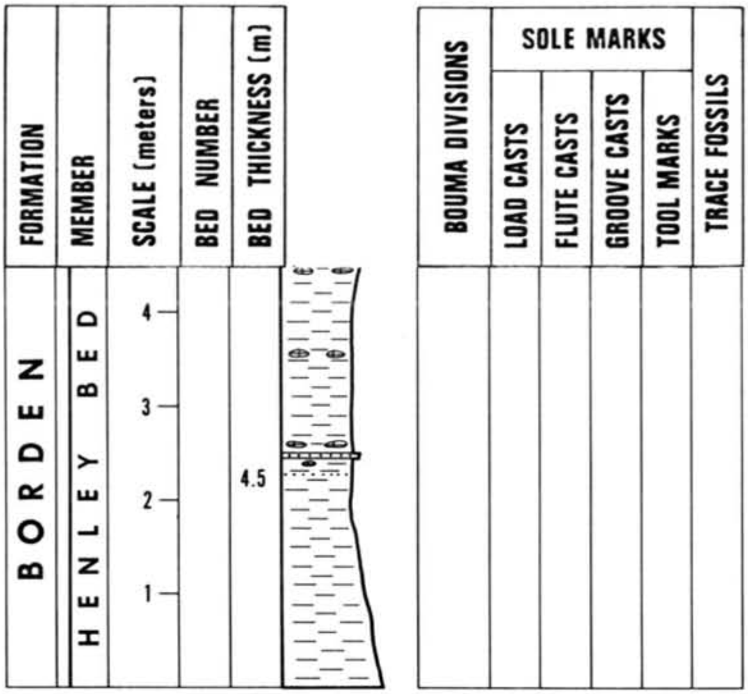


Figure 41. Continued

gray, very fine-grained, silty; Tb-Te; base undulatory, top sharp; sole has scoured load casts, groove casts, flutes, and crater-like depressions; traces include vertical and oblique burrows and *Zoophycos*.

Bed 22: Shale, greenish-gray, poorly exposed.

Bed 23: Sandstone, light-gray, very fine-grained, silty; Tb-Te; base undulatory, top sharp; sole has load casts, tool marks, and groove casts; *Zoophycos*.

Bed. 24: Shale, greenish-gray, silty, poorly exposed.

Bed. 25: Sandstone, light-olive-gray, very fine-grained, silty; Tb-Te; base undulatory, top sharp; sole has load casts, tool marks, and groove casts; vertical burrows and *Zoophycos*.

Bed 26: Mudstone, greenish-gray.

Bed 27: Sandstone, olive-gray, very fine-grained, silty; iron-stained; Tb-Te; base undulatory, top sharp; basal 10 centimeters contains fragmented brachiopods, bryozoans, and pelmatozoan detritus; sole has load casts, groove casts, tool marks, and horizontal, non-branching burrows; vertical burrows common.

Bed 28: Shale, olive-gray, silty; ironstone concretions throughout.

Bed 29: Sandstone, light-olive-gray, very fine-grained, silty; Tb-Te; base and top undulatory; sole scoured with load casts and horizontal, non-branching burrows; traces include *Zoophycos* and vertical burrows.

Bed 30: Mudstone, greenish-gray; contains ironstone nodules.

Bed 31: Sandstone, light-gray, very fine-grained, silty; Tb-Te; base and top undulatory; sole has load casts, groove

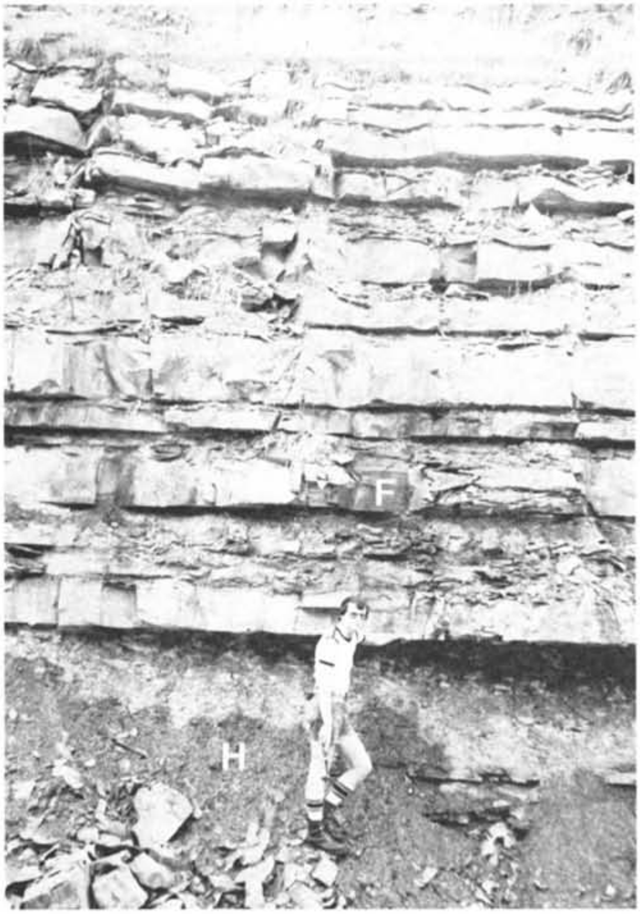


Figure 42. Henley Bed (H) is overlain by Farmers Member (F) at Bull Fork section (Day 1, Stop 4). Monotonous sequence of turbiditic sandstones and interbedded mudstones has sharp bases and individual turbidite beds have gradational tops. Bedding is regular.

Figure 43. Farmers Member at Bull Fork section (Day 1, Stop 4). Bases of individual turbidite beds are sharp and bedding is parallel. Haney mudstones separate these turbiditic sandstone beds.

casts, and tool marks; *Zoophycos* and vertical burrows.

Bed 32: Shale, light-olive-gray, silty.

Bed 33: Sandstone, medium-gray, very fine-grained, silty; Tb-Te; base sharp, top undulatory; *Zoophycos* at top.

Farmers-Nancy transitional beds

Bed 34: Shale, greenish-gray; bedded ironstone nodules 27 centimeters above base of bed.

Bed 35: Sandstone, light-gray, very fine-grained, glauconite-streaked; parallel laminations throughout; base sharp; sole has groove casts, tool masks, load casts, and crater-like depressions with plugs; traces include abundant type-2 *Zoophycos* and vertical burrows.

Bed 36: Shale, light-olive-gray; structureless.

Bed 37: Sandstone, light-olive-gray, very fine-grained, glauconite-streaked, iron-stained; structureless; base undulatory, top sharp; sole has load casts, tool marks,

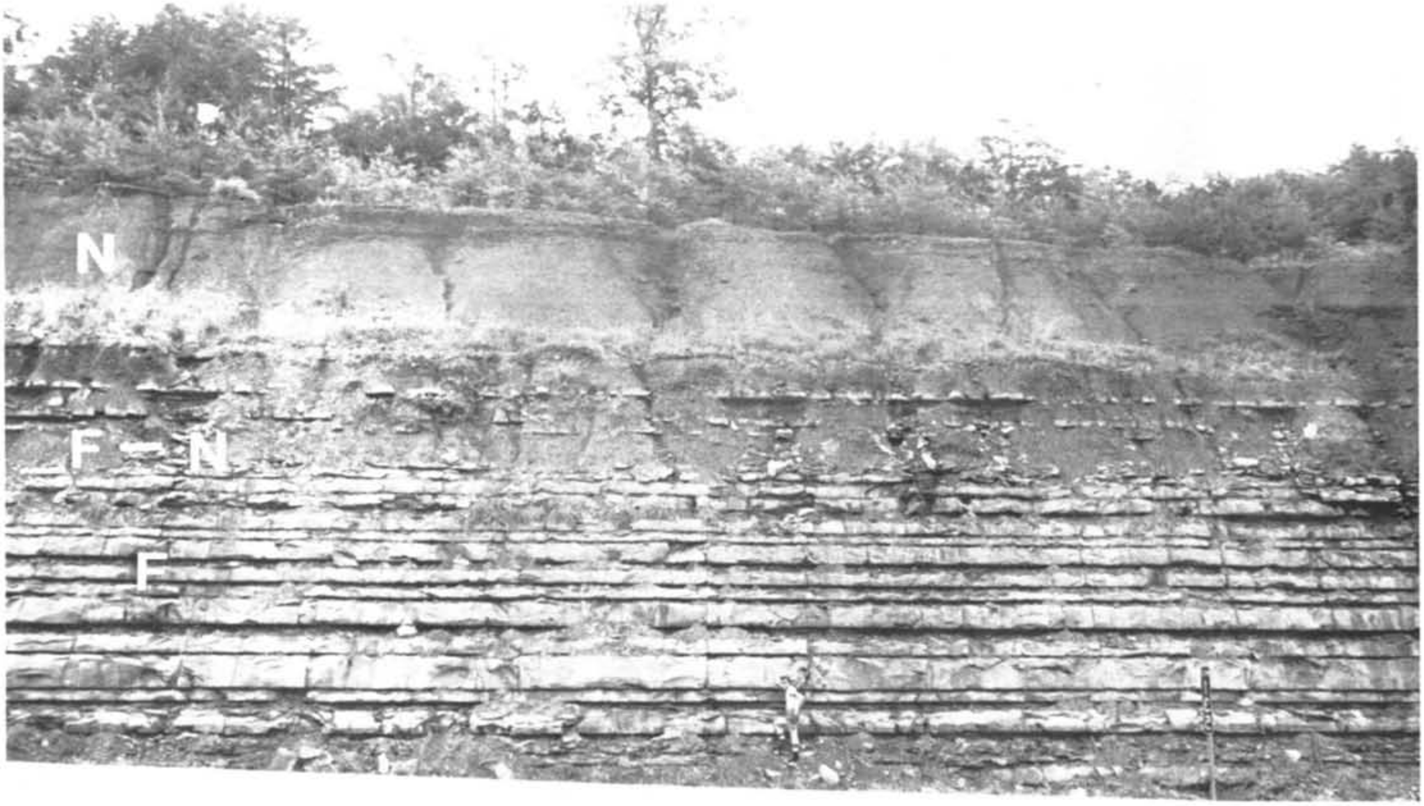


Figure 44. Farmers Member (F), Farmers-Nancy transitional beds (F-N), and Nancy Member (N) at Bull Fork section (Day 1, Stop 4).

groove casts, and crater-like depressions; type-2 *Zoophycos* bed; traces include *Lophoctenium*, *Teichichnus*, *Cylindrichnus*, and vertical burrows.

Bed 38: Shale, light-olive-gray; contains ironstone nodules.

Bed 39: Sandstone, light-olive-gray, very fine-grained, parallel laminations, base undulatory, top sharp; sole has load casts, tool marks, groove casts, and crater-like depressions; traces include *Zoophycos* and vertical burrows.

Bed 40: Shale, olive-gray; contains abundant ironstone nodules; some nodules burrowed and contain *Zoophycos*, *Scalarituba*, and *Helminthoida*.

Bed 41: Sandstone, medium-gray, very fine-grained, silty, glauconitic; iron-stained; structureless; base undulatory, top sharp; fossil detritus in lower part of bed; sole has excellent markings including groove casts, load casts, and tool marks; *Zoophycos* and vertical burrows abundant.

Bed 42: Shale, olive-gray; ironstone nodules concentrated in middle of bed.

Bed 43: Sandstone, light-gray, very fine-grained, silty; structureless except for parallel laminations in basal 2 centimeters; base undulatory, top sharp; excellent sole markings including groove casts, tool marks, and load casts present; fossil detritus includes bryozoans and brachiopods.

Nancy Member (lower part)

Bed 44: Shale, light-olive-gray, silty; contains burrowed sideritic nodules with orbiculoid-type brachiopods and rare goniatites.

Bed 45: Sandstone, grayish-orange to light-olive-gray, fine- to medium-grained, massive; base and top sharp; parallel laminations; contains mud clasts and abundant heavy minerals; sole has load casts, tool marks, and excellent *Helminthopsis*; locally contains deeply weathered, very fossiliferous, limonitic pockets with diverse fenestrate-type bryozoans, brachipods, trilobite fragments, pelecypods, goniatites, gastropods, and pelmatozoan detritus.

Body Fossils:

Henley Bed
- None?

Farmers Member
- brachiopods
- bryozoans
- pelmatozoan detritus

Farmers-Nancy transitional beds
- brachiopods
- bryozoans

Nancy Member
- brachiopods
- bryozoans
- gastropods
- goniatites
- pelecypods
- pelmatozoan detritus

Trace Fossils:

Henley Bed
- None?

Farmers Member
- *Cylindrichnus*
- **Helminthoida*
- horizontal branching and non-branching burrows.
- **Lophoctenium*
- ?*Rhizocorallium*-like
- **Teichichnus*
- *type-1 *Zoophycos*
- *type-2 *Zoophycos*

Farmers-Nancy transitional beds
- **Cylindrichnus*
- **Helminthoida*
- *Lophoctenium*
- **Scalarituba* (*Scalarituba*-view)
- *Teichichnus*
- *type-1 *Zoophycos*
- *type-2 *Zoophycos*

Nancy Member
- **Helminthoida*
- *Helminthopsis*
- **Scalarituba* (*Scalarituba*-view)
- *Zoophycos* (mainly type-2)

Interpretation:

Henley Bed: Basin-floor deposit.
Farmers Member: Distal turbidites in basin-floor deposits.
Farmers-Nancy transitional beds: Distal turbidites in prodeltaic deposits.
Nancy Member: Prodeltaic deposits.

26.5	134.8	Bridge, Bull Fork Road. Bull Fork Branch.
26.8	134.5	On the right, at east end of cut, Sunbury Shale, Henley Bed, Farmers Member; at middle of cut, transitional beds of Farmers-Nancy Members; at west end of cut, lower part of Nancy Member. Sand Branch section; thickness of Farmers Member, 7.4 meters; 33 individual beds.
27.3	134.0	End of Sand Branch section.
27.9	133.4	On the right, Nancy Member. Sanitary land-fill site for Rowan County just north of Interstate 64.
28.3	133.0	Milepost.
28.4	132.9	Overpass, Ky. Highway 801. East end of Ramey section.
28.9	132.4	STOP 5—RAMEY SECTION (Fig. 45).

*abundant

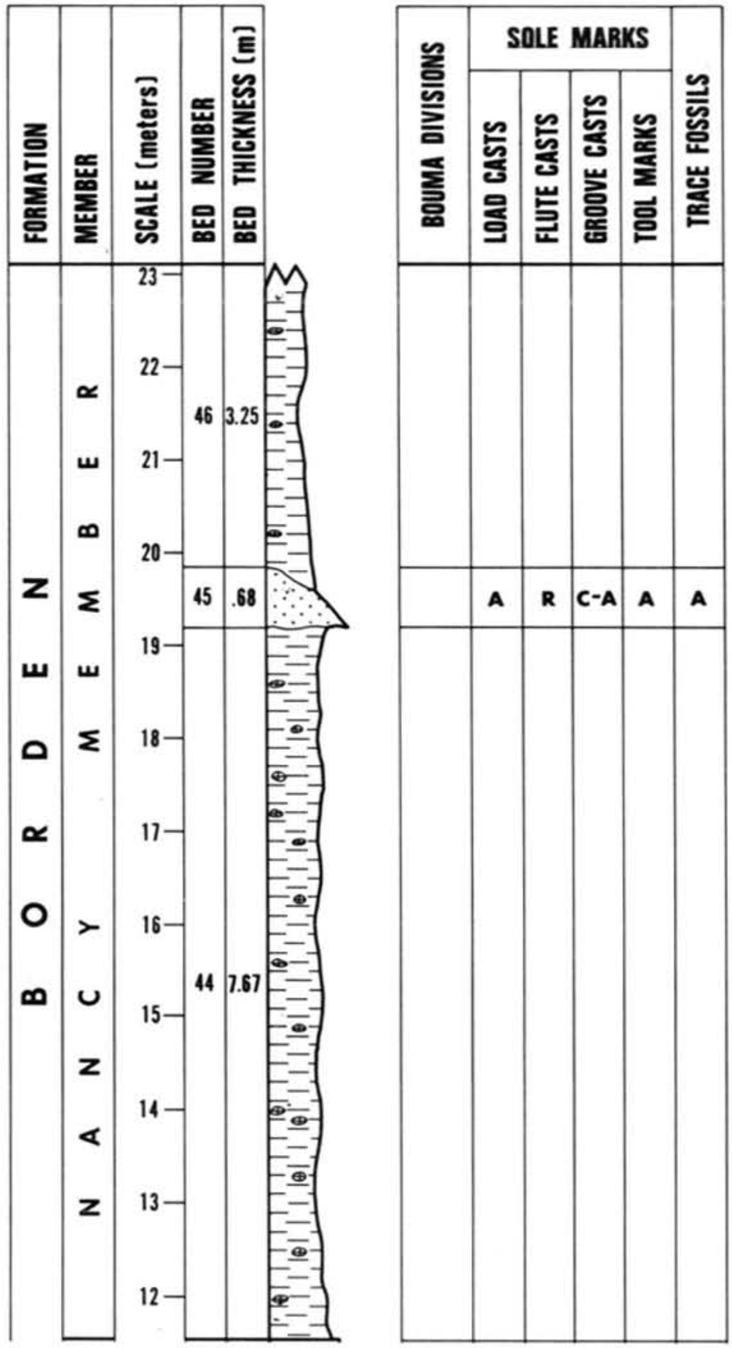


Figure 45. Stratigraphic section at Ramey on Interstate 64 from Ky. Highway 801 overpass (milepost 132.9) to milepost 132.5. Carter coordinate location 24-U-72, 300 feet FNL, 1,700 feet FWL, Farmers quadrangle, Rowan County, Kentucky. Elevation of base (Ohio Shale) is approximately 820 feet; elevation of top is approxiamtely 940 feet. See Figure 32 for explanation of lithologic symbols. See Figure 4A for explanation of Bouma divisions.

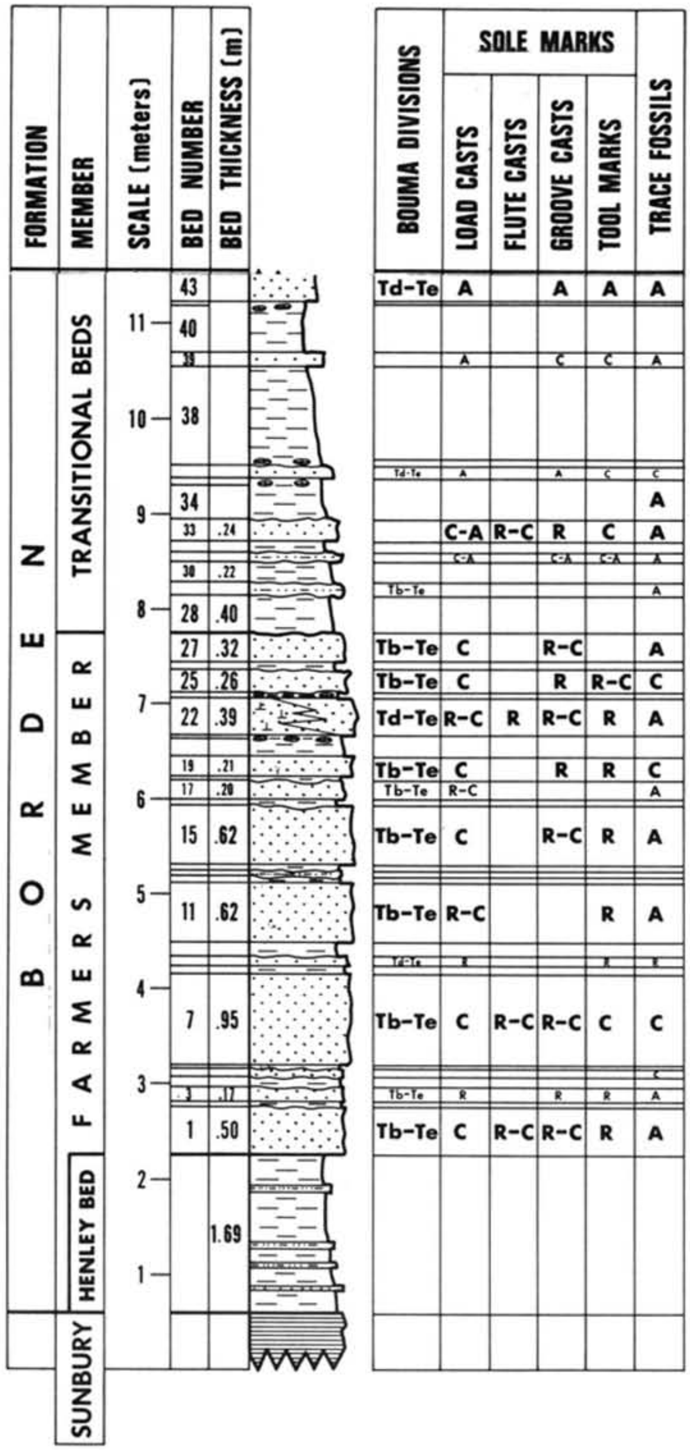


Figure 45. Continued

Location:

Section extends westward along westbound lane of Interstate 64 from Ky. Highway 801 overpass (mile 132.9) to mile 132.5. Carter coordinate location 24-U-72, 300 feet FNL, 1,700 feet FWL. Farmers quadrangle. Rowan County, Kentucky.

Stratigraphy:

Henley Bed, Farmers Member, Farmers-Nancy transitional beds, Nancy Member (lower part) (Figs. 46-47).

Petrology and Physical Sedimentary Structures (Table 9):

Henley Bed: Greenish-gray, clayey, pelagic sediments; structureless; pyritic; thin siltstones and very fine-grained sandstones in upper part.

Farmers Member: Monotonous alternation of medium- to thick-bedded, very fine-grained sandstones and thin-bedded shales and mudstones. Sandstones are very fine-grained to fine-grained, silty, well sorted. Complete Bouma sequences, but Tb-Te most common. Tc division usually thickest interval in sequence. Sandstone beds have sharp bases and gradational tops. Depth of burrowing limited in some thick beds. Sole marks include oriented load casts, groove casts, and tool marks. Flutes usually poorly developed.

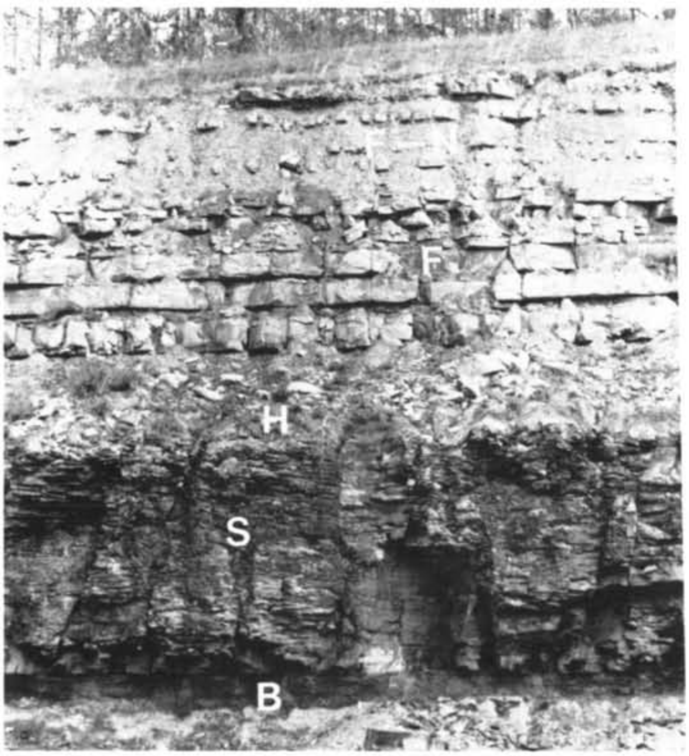


Figure 46. Bedford Shale (B), Sunbury Shale (S), Henley Bed (H), Farmers Member (F), and Farmers-Nancy transitional beds (F-N) at Ramey section (Day 1, Stop 5).

Farmers-Nancy transitional beds: Thin-bedded, very fine-grained, glauconite-streaked sandstones alternating with thick intervals of structureless, glauconitic, bioturbated, faintly laminated shales and mudstones. Tops and bottoms of sandstone beds gradational. Sandstone beds structureless or display Td-Te divisions.

Nancy Member (lower part): Dark-greenish-gray to bluish-gray, glauconitic, highly bioturbated shale. Fine-grained, poorly sorted, structureless, ripple-marked sandstone bed occurs approximately 8 meters above the base. Bed pinches out to the east. Sole of bed contains excellent traces, twisted load casts, tool marks, groove casts, and poorly developed flutes.

Description:

Borden Formation

Farmers Member

Henley Bed

Mudstone, greenish-gray to dark-greenish-gray, clayey; thin siltstones in upper part of unit; pyritic; excellent conodont fauna.

Farmers Member

Bed 1: Sandstone, light-olive-gray to light-gray, very fine-grained, silty; heavily iron-stained in lower 8 centimeters; base sharp, top undulatory; Tb-Te; traces include vertical burrows, *Zoophycos*, horizontal nonbranching burrows, and *Palaeophycus*; sole has load casts, tool marks, poorly developed flutes, and groove casts.

Bed 2: Mudstone, greenish-gray; basal contact sharp.

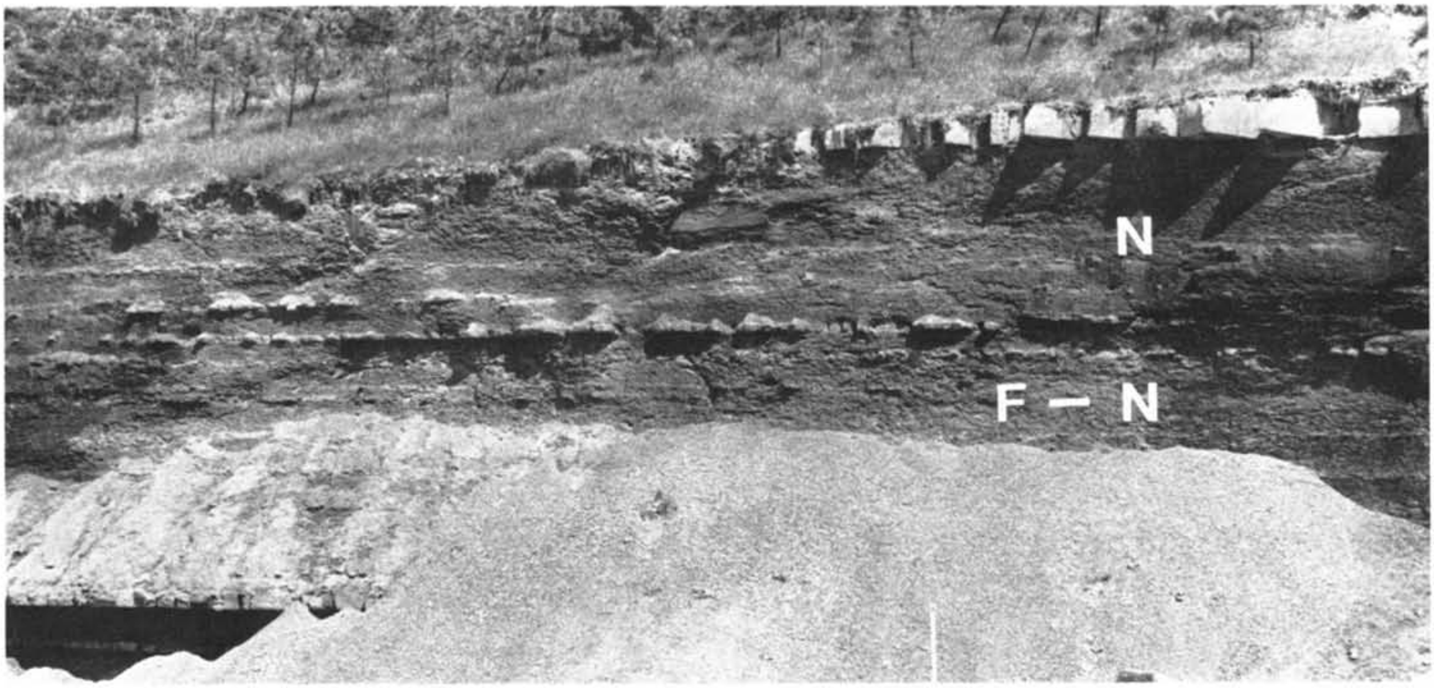


Figure 47. Farmers-Nancy transitional beds (F-N) and Nancy Member (N) at Ramey section (Day 1, Stop 5). Note thick, turbiditic sandstone bed in Nancy Member at top of photograph. Sole of bed shows excellent traces and sole marks.

Bed 3: Sandstone, light-gray to medium-gray, silty; Tb-Te; base sharp, top undulatory; traces include abundant *Zoophycos*, and vertical and horizontal burrows; sole marks include tool marks, load casts, and oriented groove casts.

Bed 4: Mudstone, greenish-gray; basal contact sharp.

Bed 5: Sandstone, light-gray, very fine-grained, silty; heavily iron-stained; base and top undulatory; *Zoophycos*; sole not exposed.

Bed 6: Mudstone, greenish-gray; basal contact sharp.

Bed 7: Sandstone, light-gray to medium-gray, very fine-grained; basal 20 centimeters iron-stained; Tb-Te; base and top sharp; sole marks include load casts, tool marks, groove casts, and poorly developed flutes; traces include *Chondrites*, *Palaeophycus*, *Helminthopsis*, *Zoophycos*, and *Protopaleodictyon*.

Bed 8: Mudstone, greenish-gray; basal contact sharp.

Bed 9: Sandstone, light-gray to medium-light-gray, very fine-grained, silty; Td-Te; base sharp, top undulatory; sole marks include small load casts and tool marks.

Bed 10: Shale, dark-greenish-gray to greenish-gray, silty; basal contact sharp.

Bed 11: Sandstone, light-gray to medium-light-gray, very fine-grained, well sorted, silty; lower 5 centimeters iron-stained; Tb-Te; base and top sharp; traces include *Zoophycos*, *Palaeophycus*, and horizontal branching and non-branching burrows; sole marks include load casts and tool marks.

Bed 12: Shale, dark-greenish-gray; basal contact sharp.

Bed 13: Siltstone, reddish-brown,

Table 9.—X-ray Diffraction Mineral Percentages of Selected Samples from the Borden Formation at Ramey Section, Interstate 64, Mile 132.5.

MEMBER	BED NO.	LITHOLOGY	QUARTZ	FELDSPAR	DOLOMITE	SIDERITE	PYRITE	KAOLINITE	ILLITE	CHLORITE
NANCY	Bottom 46	mdst	58	2			1	6	24	9
	45	ss	75	2		5		4	10	4
	Top 44	mdst	61	2				6	25	6
	Bottom 44	mdst	62	2				7	24	5
TRANS.	43	ss	76	3	1	2		6	10	2
	28	mdst	52	2		1		5	34	6
FARMERS	27	ss	67	2				9	16	6
	14	mdst	56	2		2		6	25	9
	13	ss	78	2		2		7	8	3
	8	mdst	54	3		2		8	26	7
	5	ss	76	2				6	13	3
	4	mdst	45	3		2		6	38	6
	Bottom 1	ss	77	4	3			5	9	2
HENLEY	Top	mdst	59	1	4			4	28	4

sideritic.

Bed 14: Shale, greenish-gray, laminated.

Bed 15: Sandstone, light-gray to medium-light-gray, very fine-grained, silty; Tb-Te; base sharp, top undulatory; traces include *Zoophycos*, *Planolites*, vertical burrows, andhorizontalbranching and non-branching burrows; sole marks include oriented groove casts, tool marks, and load casts.

Bed 16: Shale, dark-greenish-gray, silty.

Bed 17: Sandstone, light-gray to medium-light-gray, very fine-grained, silty; Tb-Te; base sharp, top undulatory; traces include *Zoophycos*, *Palaeophycus*, and vertical burrows; sole marks include load casts.

Bed 18: Shale, greenish-gray; contains 3-centimeter-thick ironstone layer; basal contact sharp.

Bed 19: Sandstone, light-gray to medium-light-gray, very fine-grained; Tb-Te; base and top sharp; abundant *Zoophycos*; sole marks include load casts, groove casts, and tool marks.

Bed 20: Shale, greenish-gray, faintly laminated; basal contact sharp.

Bed 21: Ironstone bed, reddish-brown.

Bed 22: Sandstone, light-gray to medium-light-gray, very fine-grained; iron-stained; contains a wedge of calcareous sandstone that pinches out to the east and contains abundant fossil detritus consisting of pelmatozoan detritus, brachiopods, and bryozoans; Td-Te; base and top sharp; traces include *Bifungites*, *Helminthopsis*, *Zoophycos*, and vertical and horizontal burrows; sole marks include oriented groove casts, load casts, and poorly developed flutes and tool marks.

Bed 23: Mudstone, medium-gray; basal contact sharp.

Bed 24: Ironstone bed, reddish-brown, blocky fracture.

Bed 25: Sandstone, light-gray to medium-light-gray, very fine-grained, well sorted, silty; base and top undulatory; Tb-Te; traces include *Zoophycos*, *Palaeophycus*, and vertical burrows; sole marks include load casts, tool marks, and groove casts.

Bed 26: Shale, mottled greenish-gray to brownish-gray; 3-centimeter-thick sideritic layer at top of bed.

Bed 27: Sandstone, light-olive-gray to light-gray, very fine-grained, silty; Tb-Te; base sharp, top undulatory; traces include *Palaeophycus*, abundant *Zoophycos*, and vertical and horizontal burrows; sole marks include groove casts and load casts.

Farmers-Nancy transitional beds

Bed 28: Shale, medium-bluish-gray to medium-dark-gray, clayey, glauconitic, faintly laminated; contains a 6-centimeter-thick discontinuous siltstone bed 19 centimeters below the top; bioturbated.

Bed 29: Siltstone, olive-gray to light-gray, sandy, glauconitic; Tb-Te; base and top undulatory; traces include *Zoophycos*, *Palaeophycus*, and *Cylindrichnus*; sole poorly exposed.

Bed 30: Shale, light-bluish-gray to medium-bluish-gray, glauconitic; faintly laminated; bioturbated.

Bed 31: Siltstone, coarse-grained, light-olive-gray to medium-gray, glauconitic; highly bioturbated; structureless; base and top undulatory; traces include abundant *Zoophycos*, vertical tapering burrows, and horizontal burrows; sole marks include load casts, oriented tool marks, and groove casts.

Bed 32: Mudstone, greenish-gray; glauconitic; bioturbated; basal contact sharp.

Bed 33: Sandstone, light-gray to light-olive-gray, very fine-grained, well sorted, silty; heavily iron-stained; highly bioturbated; base sharp, top undulatory; structureless; fossiliferous with molds of pelmatozoan detritus and brachiopods; traces include *Zoophycos*, vertical tapering burrows, and horizontal branching burrows; sole marks include load casts, flutes, groove casts, and tool marks.

Bed 34: Shale, medium-bluish-gray, mottled, silty.

Bed 35: Siltstone, reddish-brown, calcareous, glauconitic, burrowed; vertical and horizontal burrows.

Bed 36: Shale, light-olive-gray, laminated.

Bed 37: Sandstone, light-gray to medium-light-gray, very fine-grained, well sorted, silty; Td-Te; base sharp, top undulatory; traces include *Zoophycos* and vertical burrows that extend throughout entire thickness of bed; sole marks include oriented groove casts, tool marks, and load casts.

Bed 38: Shale, greenish-gray to medium-bluish-gray, silty, glauconitic; faintly laminated; small ironstone concretions occur throughout; 7-centimeter-thick siltstone bed occurs 21 centimeters above base of bed; base sharp; traces include vertical and horizontal burrows.

Bed 39: Sandstone, very fine-grained, silty, moderately to well sorted; structureless; fossiliferous with molds of brachiopods and pelmatozoan detritus; base and top sharp; traces include *Zoophycos*, *Lophoctenium*, vertical tapering burrows that extend throughout entire thickness of bed, and horizontal branching and overlapping burrows; sole marks include load casts, tool marks, and groove casts.

Bed 40: Shale, medium-bluish-gray to greenish-gray, silty; faintly laminated; contains small ironstone concretions throughout; a 3-centimeter-thick ironstone layer occurs at top of bed; a 6-centimeter-thick discontinuous concretion layer occurs 9 centimeters from top of bed; basal contact sharp; traces include *Zoophycos* and vertical and horizontal burrows.

Bed 41: Ironstone with siltstone interior; pillowy-shaped bed; fossiliferous with brachiopods and pelecypods; bioturbated.

Bed 42: Shale, greenish-gray, clayey.

Bed 43: Sandstone, light-gray to light-olive-gray, silty; Td-Te; base and top sharp; traces include *Zoophycos*, *Helminthopsis*, vertical tapering burrows which extend throughout entire thickness of bed, horizontal branching burrows, overlapping horizontal burrows, and ?*Biformites*; sole marks include load casts, oriented tool marks, and groove casts.

Nancy Member (lower part)

Bed 44: Shale, dark-greenish-gray to medium-bluish-gray, glauconitic, laminated; numerous discontinuous ironstone concretion beds and concretionary siltstone layers occur throughout bed; a 9-centimeter-thick siltstone bed occurs 1.94 meters above the base and an 8-centimeter-thick siltstone bed occurs 2.56 meters above base of bed; bed thickens to the east and merges with the overlying shale as bed 45 pinches out; basal contact sharp; traces include *Zoophycos* and vertical and horizontal burrows.

Bed 45: Sandstone, light-brownish-gray to light-olive-gray, very fine-grained, poorly to moderately sorted, micaceous, contains heavy minerals; structureless; basal 20 centimeters calcareous with molds of pelmatozoan detritus, brachiopods, and bryozoans; upper 8 centimeters heavily burrowed; top of bed contains symmetrical ripple marks with a wave length of 11 centimeters and an amplitude of 5 millimeters; bed pinches out to the east; base and top undulatory; traces include *Zoophycos, Palaeophycus*, excellent *Helminthopsis, Bifungites, Cylindrichnus*, horizontal burrows, and large, "stubby," vertical burrows; sole marks include twisted load casts, tool marks, groove casts, and flutes.

Bed 46: Shale, medium-bluish-gray to light-bluish-gray, silty, laminated; base sharp, top poorly exposed; contains small ironstone concretions throughout; glauconite-streaked; traces include *Zoophycos, Scalarituba, Helminthoida*, and vertical and horizontal burrows.

Body Fossils:

Henley Bed
- None?

Farmers Member
- brachiopods
- bryozoans
- pelmatozoan detritus

Farmers-Nancy transitional beds
- brachiopods
- bryozoans
- pelecypods
- pelmatozoan detritus

Nancy Member
- brachiopods
- bryozoans
- pelmatozoan detritus

Trace Fossils:

Henley Bed
- None?

Farmers Member
- *Bifungites*
- **Chondrites*
- *Helminthoida*
- *Helminthopsis*
- horizontal branching and non-branching burrows
- *Lophoctenium*
- **Palaeophycus*
- *Planolites*
- *Protopaleodictyon*
- *Scalarituba* (*Scalarituba*-view)
- *type-1 *Zoophycos*
- *type-2 *Zoophycos*

Farmers-Nancy transitional beds
- *Biformites*
- **Cylindrichnus*
- *Helminthoida*
- *Helminthopsis*

horizontal branching and non-branching burrows
Lophoctenium
Palaeophycus
Scalarituba (*Scalarituba*-view)
type-1 *Zoophycos*
*type-2 *Zoophycos*

Nancy Member
Bifungites
Cylindrichnus
**Helminthoida*
Helminthopsis
Palaeophycus
Scalarituba (*Scalarituba*-view)
Zoophycos (mainly type-2)

Interpretation:

Henley Bed: Basin-floor deposits.
Farmers Member: Distal turbidites in Farmers Member: basin-floor deposits.
Farmers-Nancy transitional beds: Distal turbidites in prodeltaic deposits.
Nancy Member: Prodeltaic deposits.

29.2 132.1 On the right, upper part of the Huron Member, Three Lick Bed, and Cleveland Member of the Ohio Shale (Devonian); Bedford Shale, Sunbury Shale, Henley Bed, and basal part of the Farmers Member exposed on slope above first bench.
29.3 132.0 On the left, Ohio Shale (Devonian) is exposed for next 1.0 mile.
30.3 131.0 Milepost.
30.8 130.5 On the left, Ohio Shale completely exposed; Crab Orchard shales and dolomites (Silurian) exposed at the base along west end of cut.
30.9 130.4 Overpass, County Road 1722.
31.3 130.0 Next 6.7 miles poor exposures as topography is developed on the weak, non-resistant mudstones and shales of the Crab Orchard Formation (Silurian) and high-level fluvial deposits (Pleistocene-Holocene).
32.3 129.0 Bath-Rowan County Line. Licking River.
32.7 128.6 Overpass, Ky. Highway 211.
33.3 128.0 On the left, Crab Orchard shales (Silurian).
34.3 127.0 Milepost.
35.3 126.0 Milepost.
36.3 125.0 Milepost.

*abundant

36.5 124.8 Overpass.
37.3 124.0 Milepost.
38.0 123.3 Exit 123, U.S. Highway 60, Salt Lick-Owingsville. *Exit.* Turn left on U.S. Highway 60 and then re-enter Interstate 64, east; on the right, limestones and shales of the Bull Fork Formation and Preachersville Member of the Drakes Formation (Upper Ordovician).

RETRACE FIELD TRIP ROUTE TO CARTER CAVES STATE RESORT PARK.

Second Day of Field Trip

The route for the second day of the field trip will traverse portions of Grahn, Tygarts Valley, Wesleyville, and Head of Grassy quadrangles. The buses will depart from the parking lot of the Carter Caves State Resort Park Lodge at 8:00 a.m.

Road log will begin at intersection of main entrance road to Carter Caves State Resort Park and Ky. Highway 182.

Summary

The second day of the excursion will examine the Farmers Member, Cowbell Member, and Nada Member to the north-northeast (the relatively shallower part of the sedimentary basin that is associated with a prograding delta complex). Comparisons will be made with sequences and environments seen on Day 1. Of particular interest are: (1) variations between proximal turbidites and distal turbidites, (2) shallow-water *Cruziana* ichnofacies in the Cowbell and Nada Members, and (3) the less carbonate facies of the Nada Member.

Unfortunately, the distribution of roads and outcrops farther to the northeast does not allow as good a sequential look at the Borden succession as on Day 1.

MILEAGE

DESCRIPTION

0.00 Junction of entrance road to Carter Caves State Resort Park and Ky. Highway 182. Turn left (north) on Ky. Highway 182 to Carter City.
0.1 On right, Cowbell Member of Borden Formation overlain by lower member of Newman Limestone.
0.3 On left, Carter Caves Sandstone. The Carter Caves Sandstone consists of rather pure quartzose and conglomeratic sandstone that, according to Englund and Windolph (1971), was deposited largely

as a marine offshore bar. It averages about 40 feet in thickness, ranges between 2 and 8 miles in width, and is aligned north-northeast to northeast for 30 miles. Contrary to a previous age assignment of Pennsylvanian, Sheppard and Dobrovolny (1962) established a Late Mississippian age for this sandstone on the basis of a marine invertebrate fauna of Late Mississippian age in an overlying shale-and-limestone sequence.

0.7 On the right, Breathitt Formation (Pennsylvanian).

1.5 On the right, Breathitt Formation.

1.9 On the right, Carter Caves Sandstone.

3.9 On the right, strongly crossbedded Newman Limestone.

4.2 On the right, Cowbell and Nada Members of Borden Formation overlain by Newman Limestone.

4.4 On the right, Cowbell Member.

4.5 Junction of Ky. Highways 182 and 2; turn right (north) on Ky. Highway 2 to Carter City.

4.7 On the left, Cowbell Member has excellent sedimentary structures.

4.9 On the left, McGlone Fork.

5.0 On the left, Cowbell Member.

5.6 On the left, Cowbell Member.

6.0 On the left, junction with Ky. Highway 396.

6.1 On the left, hill capped with Newman Limestone; Cowbell on slope below.

6.3 On the left, Cowbell Member.

6.6 On the left, Cowbell Member.

7.4 Carter City.

7.8 Juncton of Ky. Highways 2 and 474; turn left (west) on Ky. Highway 474. Ky. Highway 474 follows the former Chesapeake-Ohio railroad that ended just below Carter City. The railroad was flooded out in the early 1940's. Passengers from southern Ohio came by railroad in the late 1800's and early 1900's to Carter City for picnicking, barn dances, and spelunking.

8.2 On the right, Cowbell Member.

9.3 On the right, Cowbell Member.

9.7 Village of Poplar.

9.8 On the right, Cowbell Member.

9.9 On the left, the Standard Slag Company Carter Plant; approximately 120 feet of Newman Limestone are exposed in quarry on top of hill.

11.8 On the right, below road, is Smith Creek Post Office, which locals claim is the smallest active post office in the United States.

11.9 On the left, begins section of Cowbell Member for 0.6 mile.

12.5 Junction of Ky. Highways 474 and 1149; turn right (north) on Ky. Highway 1149; this is the top of the Trace Creek section.

13.8 STOP 1—TRACE CREEK SECTION (Fig. 48).

Location:

Section begins on Ky. Highway 1149 1.3 miles northwest of junction of Ky. Highways 474 and 1149 (Lewis County) and extends southeast to junction of Ky. Highways 474 and 1149 (Carter County). Carter coordinate location 8-X-76, 120 feet FSL, 1,900 feet FEL. Wesleyville quadrangle. Lewis County, Kentucky.

Stratigraphy:

Cowbell Member (Units 1-5), Nada Member.

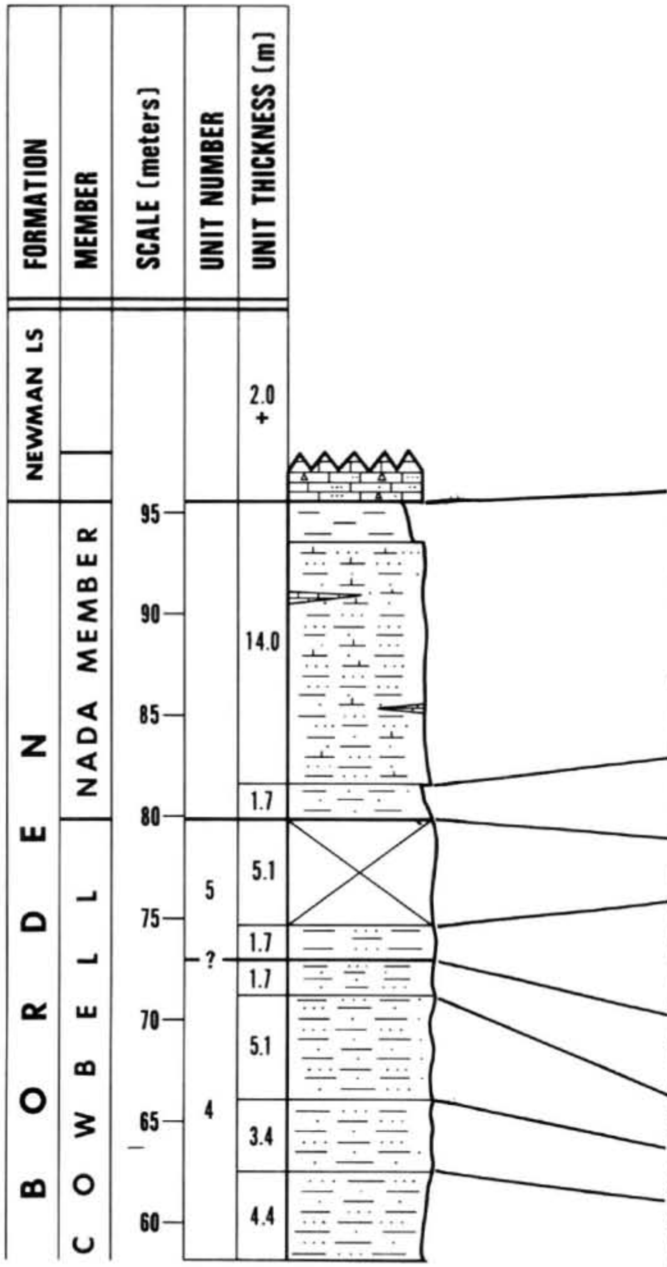
Petrology and Physical Sedimentary Structures.

Cowbell Member, Unit 1: Base is gradational with Nancy Member. Consists primarily of yellowish-gray to bluish-gray, massive, sandy, micaceous siltstone. Numerous shaly siltstones, silty shales, and very fine-grained sandstones. Sedimentary structures, which are best seen in upper part of unit, include small-scale scour-and-fill features, ripple marks, parallel laminations, and wavy laminations.

Cowbell Member, Unit 2: Base gradational with Unit 1. Consists of primarily highly bioturbated silty shale with some shaly and sandy siltstone beds. Siltstone beds commonly display parallel and wavy laminations.

Cowbell Member, Unit 3: Base is highly gradational with Unit 2. Massive siltstones with discontinuous, glauconite-streaked, shaly interbeds. Well-developed sedimentary structures include scour-and-fill features, parallel laminations, and cross laminations.

Cowbell Member, Unit 4: Base highly gradational with Unit 3. Alternating



Siltstone, shale, and limestone; shale, dark-reddish-brown to greenish-gray, silty, bioturbated with *Zoophycos*, *Scalarituba*, and *Helminthoida*; a prominent 2-meter-thick reddish-brown and greenish-gray shale interval occurs at top. Siltstone, greenish-gray, shaly, glauconite-streaked, ripple-marked, calcareous, fossiliferous with pelmatozoan detritus, rugose corals, brachiopods, bryozoans, and goniatites; parallel laminations; trace fossils include *Monocraterion*, *Cylindrichnus*, *Phycodes*-like, *Teichichnus*, *Phycosiphon*, *Scalarituba*, *Helminthoida*, and *Zoophycos*. Limestone, light-olive-gray to greenish-gray, coarsely crystalline, silty, glauconite-streaked; occurs in discontinuous lenses, particularly in upper part; a highly fossiliferous carbonate lense occurs approximately 6 meters below top and contains green shale clasts, brachiopods, bryozoans, pelmatozoan detritus, pelecypods, *Zoophycos*, and other unidentifiable traces.

Shale, reddish-brown and greenish-gray mottled, silty; contains thin, fossiliferous, yellowish-gray siltstone interbeds; lower contact with Cowbell Member gradational through approximately 2 meters.

Covered interval.

Siltstone, yellowish-gray, sandy, micaceous, massive; parallel and wavy laminations; alternating dark and light laminae; shale interbeds common; weathered, limonitic, fossiliferous concretions; large, well-rounded, burrowed, silty concretions up to 30 centimeters in diameter; traces include *Cylindrichnus*, *Zoophycos*, and very abundant unidentifiable vertical burrows.

Silty shale and shaly siltstone, yellowish-gray to light-olive-gray, sandy; faint parallel laminations; fossiliferous with brachiopods and pelmatozoan detritus; vertical burrows rare; poorly exposed.

Silty shale and shaly siltstone, light-olive-gray to dark-yellowish-orange; poorly exposed interval.

Shaly siltstone and silty shale, light-olive-gray, micaceous, bioturbated; brachiopods common, traces include *Zoophycos*, *Scalarituba*, and *Helminthoida*.

Silty shale and shaly siltstone, yellowish-gray, highly bioturbated; parallel laminations; interval covered with float; brachiopods common; traces include *Zoophycos*, *Helminthoida*, and *Scalarituba*; limonitic concretions near top very fossiliferous with brachiopods and goniatites; prominent siltstone bed (5 to 20 centimeters thick) at top very fossiliferous with crinoid detritus, gastropods, rugose corals, nautiloids, and trilobite fragments.

Figure 48. Stratigraphic section at Trace Creek along Ky. Highway 1149. Exposure extends northwestward from intersection of Ky. Highway 474 and 1149 for a distance of approximately 1.3 miles. Carter coordinate location 8-X-76, 120 feet FSL, 1,900 feet FEL, Wesleyville quadrangle, Lewis County, Kentucky. See Figure 32 for explanation of symbols.

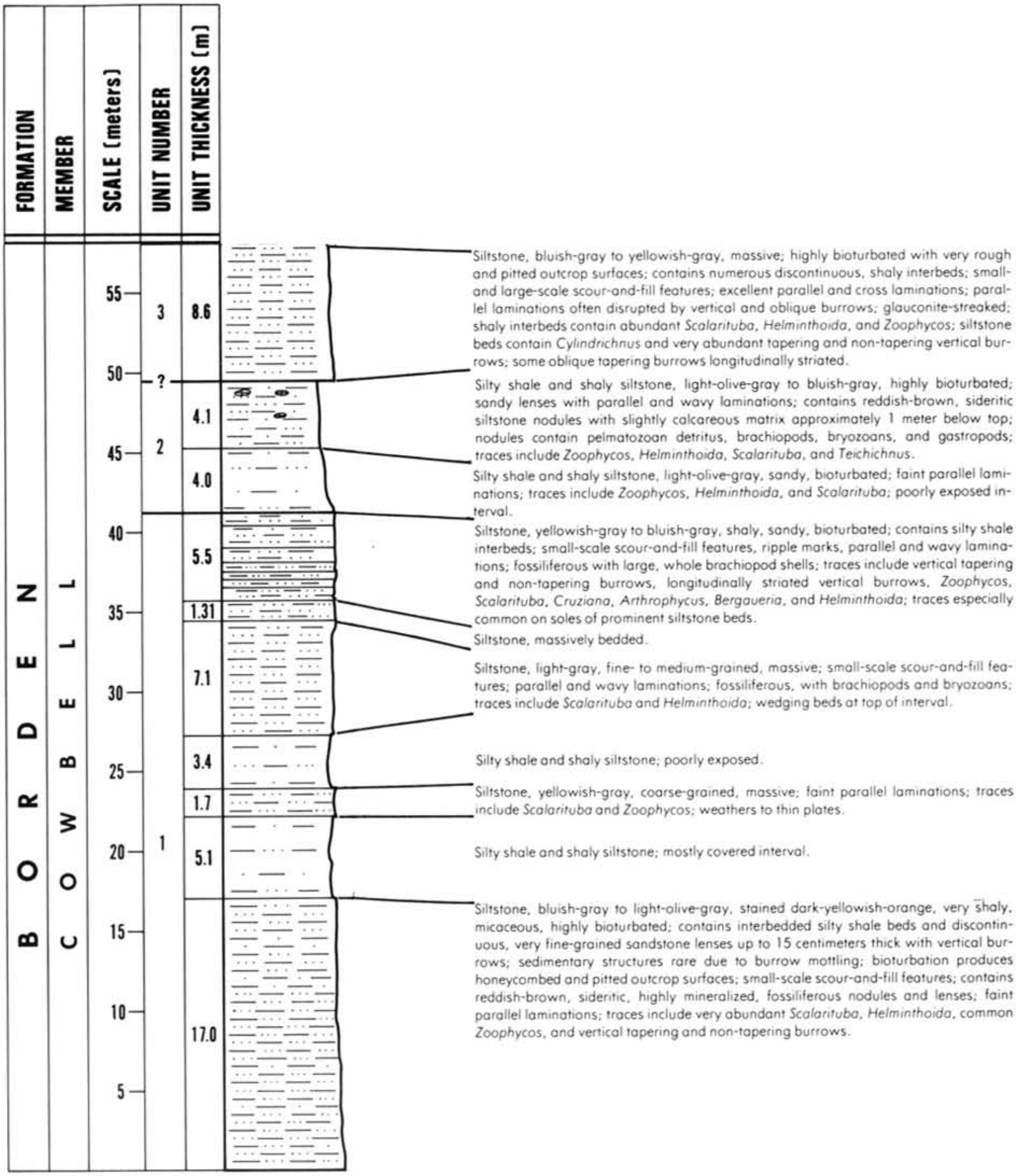


Figure 48. Continued

silty shale and shaly siltstone. Some siltstone beds display parallel laminations. Portion of unit poorly exposed.

Cowbell Member, Unit 5: Base highly gradational with Unit 4. Unit poorly exposed. Massive siltstones with minor silty shale interbeds. Parallel and wavy laminations with alternating dark and light laminae.

Nada Member: Basal contact with Cowbell Member gradational through approximately 2 meters. Alternating variable lithologies consist of red and green, structureless mudstones; glauconite-streaked, ripple-marked siltstones; and scattered, glauconite-streaked carbonate lenses. Some siltstone beds display parallel laminations. Mud and shale clasts common.

Body Fossils:

Cowbell Member, Unit 1
- *brachiopods
- *bryozoans
- pelmatozoan detritus

Cowbell Member, Unit 2
- brachiopods
- bryozoans
- gastropods
- pelmatozoan detritus

Cowbell Member, Unit 3
- brachiopods
- bryozoans

Cowbell Member, Unit 4
- *brachiopods
- *bryozoans
- gastropods
- goniatites
- nautiloids
- *pelmatozoan detritus
- rugose corals
- trilobite fragments

Cowbell Member, Unit 5
- brachiopods
- bryozoans
- pelmatozoan detritus

*abundant

Nada Member
- *brachiopods
- *bryozoans
- goniatites
- pelecypods
- *pelmatozoan detritus
- rugose corals

Trace Fossils:

Cowbell Member, Unit 1
- **Arthrophycus*
- **Bergaueria*
- **Cruziana*
- **Helminthoida*
- **Scalarituba* (*Scalarituba*-view)
- unidentifiable vertical tapering and non-tapering burrows
- **Zoophycos* (mainly type-2)

Cowbell Member, Unit 2
- **Helminthoida*
- **Scalarituba* (*Scalarituba*-view)
- **Teichichnus*
- *Zoophycos* (mainly type-2)

Cowbell Member, Unit 3
- *Cylindrichnus*
- **Helminthoida*
- **Scalarituba* (*Scalarituba*-view)
- *unidentifiable vertical tapering and non-tapering burrows
- **Zoophycos* (mainly type-2)

Cowbell Member, Unit 4
- **Helminthoida*
- **Scalarituba* (*Scalarituba*-view)
- *Zoophycos* (mainly type-2)

Cowbell Member, Unit 5
- *Cylindrichnus*
- *unidentifiable vertical burrows
- *Zoophycos* (mainly type-2)

Nada Member
- *Cylindrichnus*
- **Helminthoida*
- **Monocraterion*
- *Phycodes*-like
- *Phycosiphon*
- **Scalarituba* (*Scalarituba*-view)
- *Teichichnus*
- **Zoophycos* (mainly type-2)

*abundant

Interpretation:

Cowbell Member, Unit 1: Delta front (distal bar facies).
Cowbell Member, Unit 2: Interdeltaic bay.
Cowbell Member, Unit 3: Delta front (distal bar facies).
Cowbell Member, Unit 4: Interdeltaic bay.
Cowbell Member, Unit 5: Delta front (distal bar facies)
Nada Member: Delta platform (interdeltaic bay and more restricted skeletal carbonate bank facies).

Turn around and retrace route to junction of Ky. Highways 474 and 1149; mileage begins at junction. Turn right (west) on Ky. Highway 474.

12.5 On the left, Newman Limestone.
12.6 On the left, Carter Caves Sandstone.
12.7 Jenny Wiley trail crossing.
13.2 Junction of Ky. Highways 474 and 396; bear right on 474. Newman Limestone exposed on both sides of highway.
13.3 On the left, contact between Nada Member (Borden Formation) and Newman Limestone.
13.4 On the right, Cowbell Member.
14.6 On the right, Farmers Member of Borden Formation
15.1 On the right, Farmers Member.
16.9 On the left, Farmers Member.
17.0 Junction of Ky. Highways 474 and 59; turn right (north) on Ky. Highway 59. Farmers Member straight ahead at junction.
17.2 On the left, Farmers Member.
17.3 On the left and right, Farmers Member.
17.5 On the left, Farmers Member.
17.7 Top of Stone Hill section (Farmers Member).
17.9 STOP 2—STONE HILL SECTION (Fig. 49).

Location:
Ky. Highway 59, approximately 1.2 miles southeast of Camp Dix, Kentucky. Carter coordinate location 10-X-75, 2,200 feet FNL, 800 feet FWL. Head of Grassy quadrangle. Lewis County, Kentucky.

Stratigraphy:
Henley Bed, Farmers Member (approximately lower half).

Petrology and Physical Sedimentary Structures:
Henley Bed: Interbedded, structureless, red and green mudstones at base grading upward into greenish-gray mudstones and shales. Intercalations of burrowed, shaly siltstones and very fine-grained sandstones throughout.

Farmers Member: Important differences can be noted in the lithologic character, bedding thickness, internal sedimentary structures, sole marks, overall thickness, and trace fossil association in the Farmers at this stop compared to Stops 4 and 5 on Day 1 of the excursion. Significant differences here include: (1) relatively higher sand/shale ratio; (2) overall increase in stratigraphic thickness of member; (3) lenticular bedding; (4) very thin, pelagic mudstone-shale interbeds; (5) rare, complete Bouma sequences with very thick Ta (structureless) division; (6) decrease in bedding regularity and increase in wedging of beds; (7) increase in frequency of erosional or scoured bases; (8) increase in scouring indicated by poorly developed or absence of sole marks; (9) sole marks, when present, lack any preferred directional properties; (10) channel-like features; (11) increase in number and size of mud clasts; and (12) relatively low abundance and diversity of trace fossils (Figs. 50-53).

Description:
Borden Formation
Farmers Member
Henley Bed
Bed 1: Shale, red and green interbedded at base becoming greenish-gray at top; shaly siltstone at top burrowed; *Zoophycos*; poorly exposed; base not exposed.

Farmers Member (lower part)
Bed 2: Sandstone, greenish-gray, fine-grained; *Zoophycos*; vertical burrows which do not extend entirely through bed; base sharp; top undulatory; sole scoured with

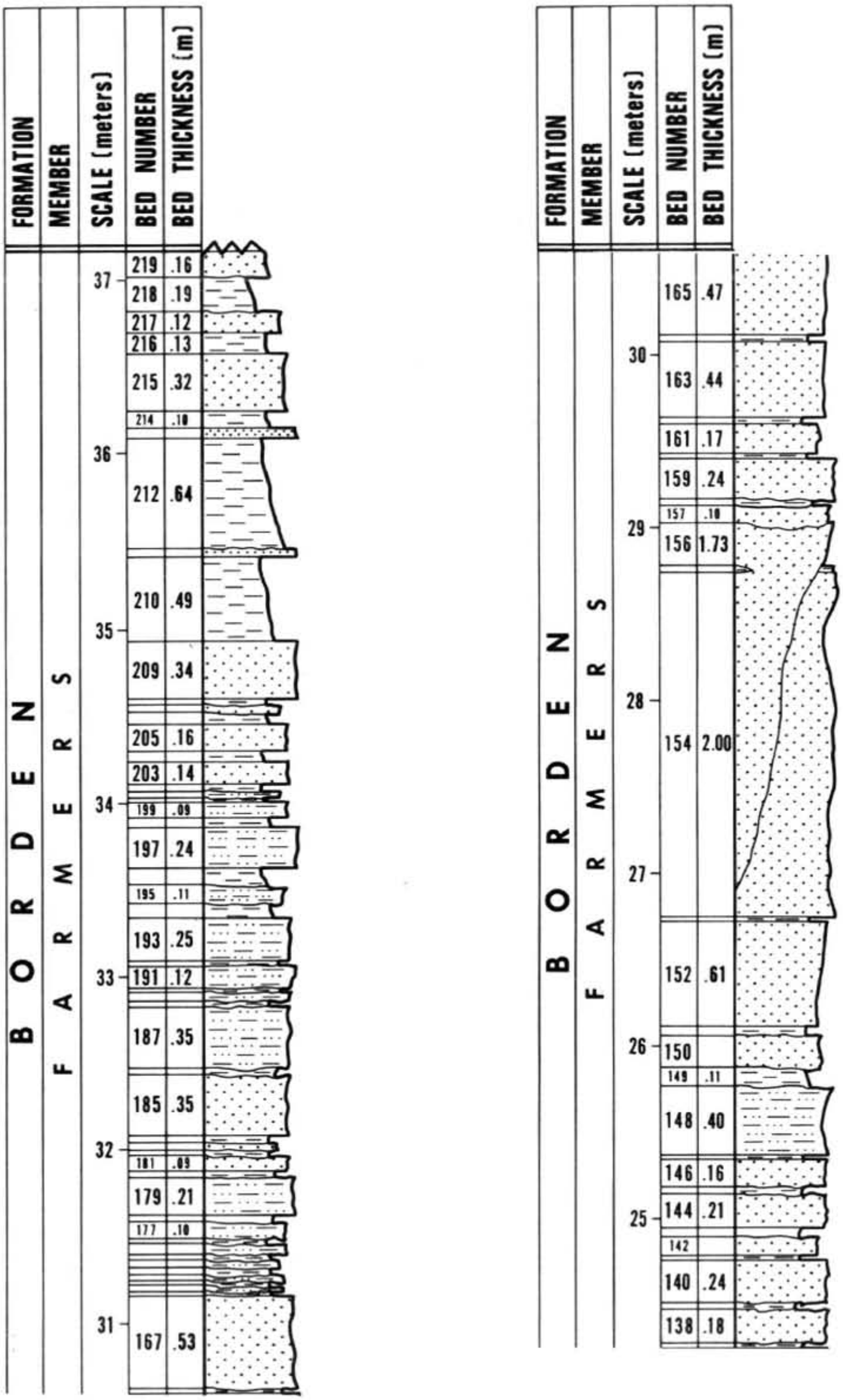


Figure 49. Stratigraphic section at Stone Hill on Ky. Highway 59, approximately 1.2 miles southeast of Camp Dix, Kentucky. Carter coordinate location 10-X-75, 2,200 feet FNL, 800 feet FWL, Head of Grassy quadrangle, Lewis County, Kentucky. See Figure 32 for explanation of symbols.

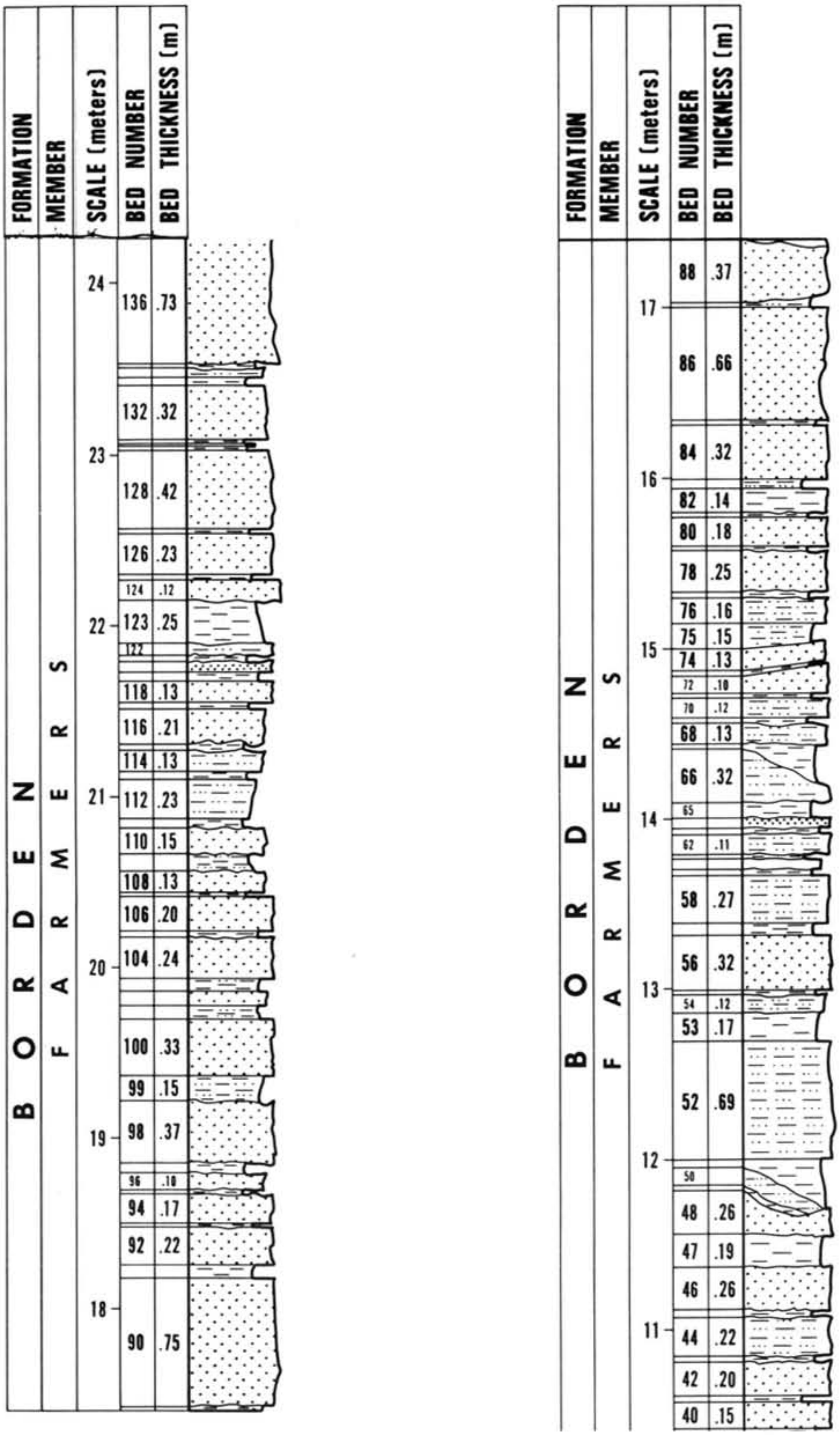


Figure 49. Continued

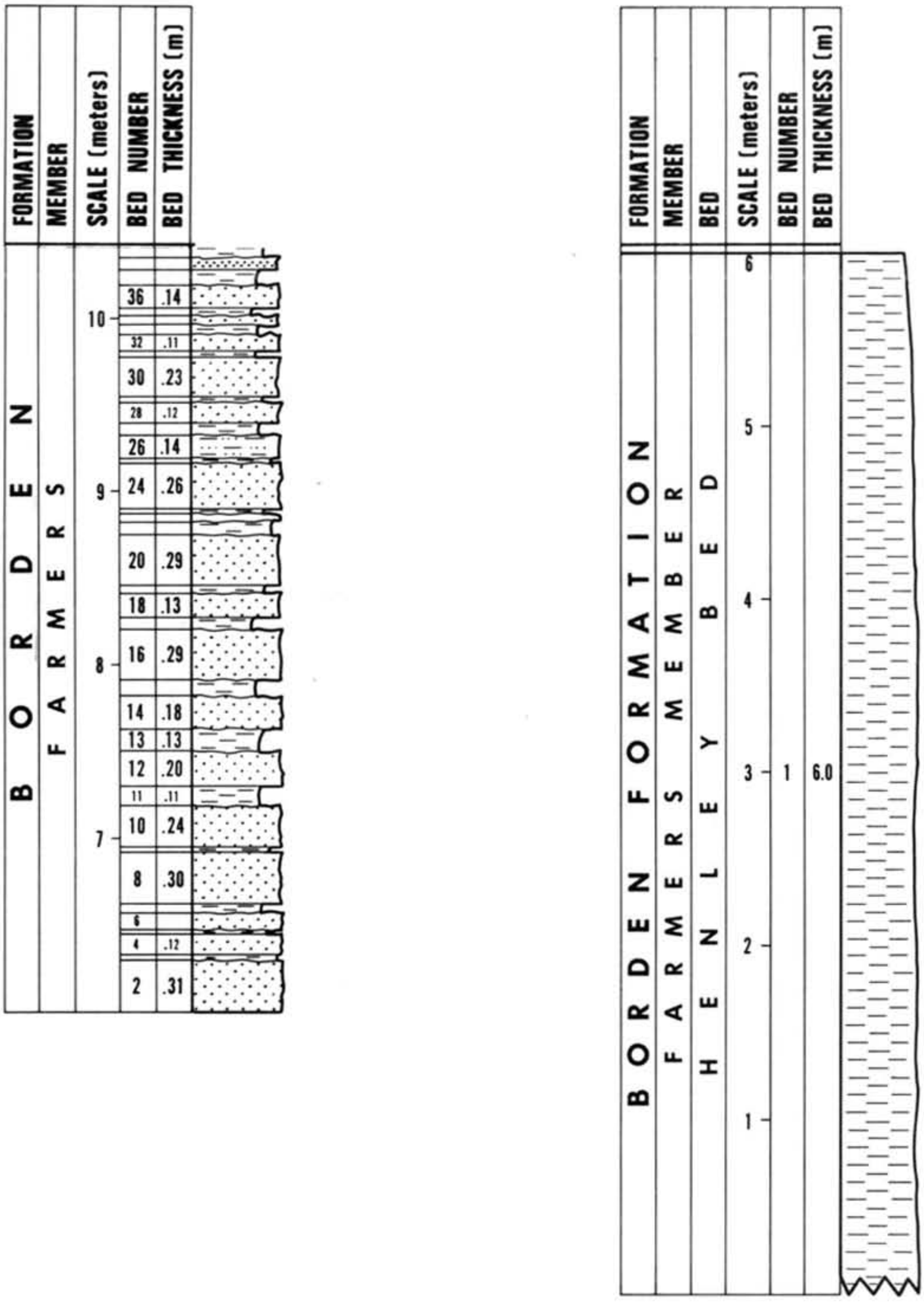


Figure 49. Continued

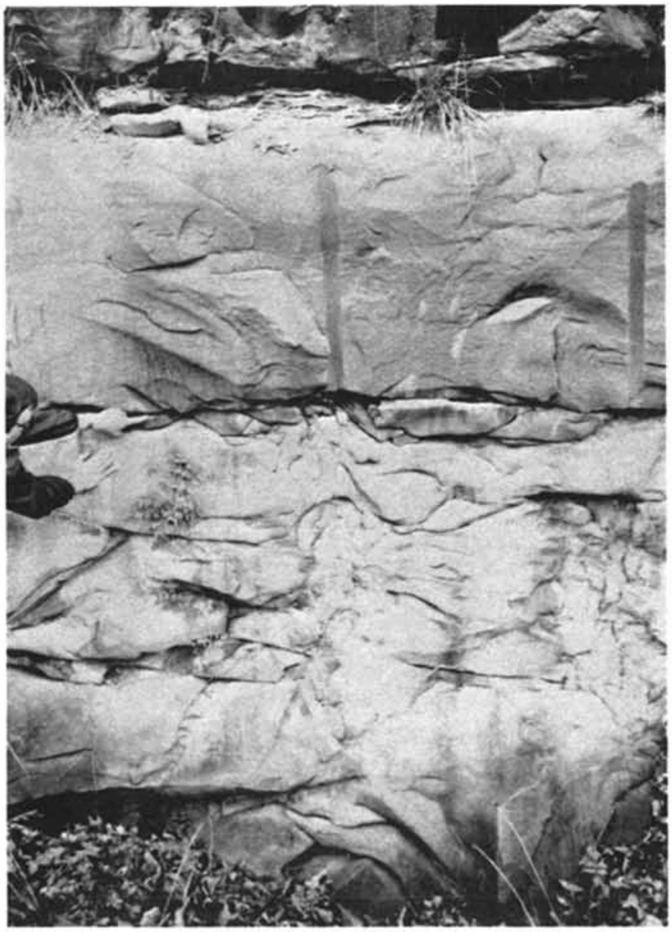


Figure 50. Amalgamated beds in more proximal turbidite facies of Farmers Member. Note lack of interturbidite beds. Highway 24 near Red Buck Hollow, Wesleyville quadrangle.

horizontal traces, small load casts, and groove casts.

Bed 3: Mudstone.

Bed 4: Sandstone, very fine-grained, silty; *Zoophycos*; faint parallel laminations; base and top sharp; sole has small load casts.

Bed 5: Mudstone.

Bed 6: Sandstone, very fine-grained, silty; fines upward; *Zoophycos* bed; vertical burrows; base and top undulatory.

Bed 7: Mudstone, greenish-gray; iron-stained; silty; bioturbated.

Bed 8: Sandstone, grayish-orange, very fine-grained; vertical burrows that do not extend entirely through bed; mostely Tc-Te; base and top sharp; sole scoured with horizontal branching burrows, few tool marks, and small load casts.

Bed 9: Mudstone.

Bed 10: Sandstone, grayish-orange, very fine-grained, silty; Ta (structureless); *Zoophycos* in upper 18 centimeters; base scoured, top undulatory; sole lacks markings.

Bed 11: Mudstone, mottled, bioturbated.

Bed 12: Sandstone, yellowish-orange, very fine-grained, silty; *Zoophycos* type-1 with very coarse spreiten; mostly Ta (structureless); base sharp, top undulatory; sole has dwelling burrows, horizontal burrows, *?Neonereites*, and small tool marks.

Bed 13: Mudstone, grayish-orange, silty.

Bed 14: Sandstone, very fine-grained, silty; Ta (structureless); *Zoophycos* type-2 at top has coarse spreiten; base and top undulatory; sole scoured with small and large horizontal branching burrows and small tool marks.

Bed 15: Shale, very silty; limonitic concretions at top.

Bed 16: Sandstone, brownish-orange, very silty; parallel laminations with bioturbated Te in upper 2 centimeters; *Zoophycos* rare at top; base and top undulatory.

Bed 17: Mudstone, mottled, burrowed.

Bed 18: Sandstone, grayish-orange, fine-grained, silty; vertical burrows; Ta (structureless), with Td-Te in upper 4 centimeters; top highly biotur-

Figure 51. Sole of turbidite bed 161 at Stone Hill section (Day 2, Stop 2) has large scoured load casts in more proximal facies of Farmers Member. Note sharp base of turbidite bed and very thin interturbidite bed.

bated; *Zoophycos* bed; base sharp, top undulatory; sole scoured with few small groove casts, loads, tools, and cylindrical burrows.

Bed 19: Shale, greenish-gray, mottled brownish-orange; *Zoophycos* bed.

Bed 20: Sandstone, yellowish-gray, very fine-grained, silty; Ta (structureless), with Td-Te in upper 3 centimeters; *Zoophycos* at top; liezegang banding; base sharp, top undulatory; sole scoured with small load casts, cylindrical burrows, and small horizontal burrows.

Bed 21: Shale, greenish-gray, burrow mottled; faint laminations.

Bed 22: Sandstone, grayish-orange, very silty; vertical burrows; parallel laminations throughout; *Zoophycos* bed.

Bed 23: Mudstone, grayish-orange.

Bed 24: Sandstone, grayish-orange, very fine-grained, silty; parallel laminations throughout; Te in upper 4 centimeters; *Zoophycos* at top; short vertical burrows; base sharp, top undulatory; sole scoured with large horizontal branching burrows, small groove casts, load casts, and tool marks.

Bed 25: Mudstone, greenish-gray, silty.

Bed 26: Siltstone, yellowish-gray; *Zoophycos* bed; top and base undulatory.

Figure 52. Channel-like feature in more proximal turbidite facies of Farmers Member at Stone Hill section (Day 2, Stop 2). Very thin interbeds of mudstones separate individual sandstone turbidite beds.

Bed 27: Shale, greenish-gray, burrow mottled.

Bed 28: Sandstone, yellowish-gray, very fine-grained, silty; *Zoophycos* throughout; parallel laminations (Tb), wavy laminations (Tc), and Te in upper 2 centimeters; vertical burrows; base sharp, top undulatory; sole scoured with horizontal branching and non-branching burrows, cylindrical burrows, small load casts, groove casts, and tool marks.

Bed 29: Mudstone.

Bed 30: Sandstone, yellowish-gray, fine-grained, silty; mostly Ta (structureless); vertical burrows, base and top sharp; sole scoured with abundant cylindrical burrows, large horizontal branching burrows, few small load casts, tool marks, and groove casts.

Bed 31: Mudstone, greenish-gray.

Bed 32: Sandstone, gray, very fine-grained, silty; faint parallel laminations; *Zoophycos* type-1 bed; Te, 1-centimeter-thick; base sharp, top undulatory; sole scoured with horizontal branching and non-branching burrows, cylindrical burrows, fecal pellets, and groove casts.

Bed 33: Shale, greenish-gray, burrow mottled.

Bed 34: Sandstone, light-greenish-

Figure 53. Turbidite bed 179 of Farmers Member at Stone Hill section (Day 2, Stop 2) has large shale clast. Uppermost turbidite bed has scoured sole and beds wedge in lower part of photograph.

gray, very fine-grained, very silty; *Zoophycos* bed; top and base undulatory.

Bed 35: Shale, greenish-gray, silty; bioturbated.

Bed 36: Sandstone, grayish-orange, fine-grained, silty; *Zoophycos* in upper 2 centimeters; faint parallel laminations; liezegang banding; sole scoured with cylindrical burrows, large horizontal branching and non-branching burrows, small load casts, and groove casts.

Bed 37: Mudstone, greenish-gray, bioturbated.

Bed 38: Sandstone, greenish-gray to yellowish-gray, very fine-grained, silty; parallel laminations; vertical burrows; *Zoophycos* common; base sharp, top undulatory; sole lacks markings.

Bed 39: Shale, greenish-gray

Bed 40: Sandstone, yellowish-gray, fine-grained, silty; Ta (structureless) well developed; *Zoophycos* common at top; base and top sharp; sole scoured with cylindrical burrows, large horizontal non-branching burrows, and large load casts.

Bed 41: Mudstone, reddish-brown, silty, limonitic.

Bed 42: Sandstone, yellowish-gray, fine-grained; faint parallel laminations (Tb), wavy laminations (Tc), and 4 centimeters of Te at top; *Zoophycos* at top; vertical burrows common; base sharp, top undulatory; sole scoured with load casts.

Bed 43: Mudstone, greenish-gray, limonitic.

Bed 44: Siltstone, yellowish-gray; limonitic at base with liezegang banding in lower 5 centimeters; *Zoophycos* bed; base and top undulatory.

Bed 45: Mudstone, greenish-gray.

Bed 46: Sandstone, yellowish-gray, very fine-grained, silty; faint parallel laminations in basal 2 centimeters; Te, 6-centimeters-thick; liezegang banding; base and top undulatory; sole scoured with small horizontal branching burrows, cylindrical burrows, small tool marks, and groove casts.

Bed 47: Shale, yellowish-orange; limonitic concretions.

Bed 48: Sandstone, gray with reddish-brown stains, very fine-grained, silty; *Zoophycos* common at top; Ta (structureless) at base overlain by faint parallel laminations; Te in upper 2 centimeters; base sharp, top undulatory; sole scoured with small horizontal branching and non-branching burrows, cylindrical burrows, small tool marks, and groove casts; bed thins, then thickens (42 cm) to east.

Bed 49: Shale, bluish-gray, silty; parallel laminations.

Bed 50: Siltstone, yellowish-gray; parallel laminations; *Zoophycos* bed; sole scoured with cylindrical burrows and horizontal branching burrows; bed thickens to the west.

Bed 51: Shale, yellowish-gray with limonite stains at top; bed thickens to the east as beds 48-50 pinch out.

Bed 52: Siltstone, yellowish-gray; *Zoophycos* at top; limonite concretions at base; base and top sharp.

Bed 53: Shale, light-olive-gray, silty; faint parallel laminations; *Zoophycos* bed.

Bed 54: Siltstone, yellowish-gray; faint parallel laminations; *Zoophycos* bed.

Bed 55: Mudstone.

Bed 56: Sandstone, light-olive-gray, very fine-grained, silty; mostly Ta (structureless); base undulatory, top sharp; sole scoured with horizontal branching and non-branching burrows, load casts, and small tool marks.

Bed 57: Shale, yellowish-gray, silty.

Bed 58: Siltstone, reddish-brown; Tc in basal 7 centimeters; liezegang banding at base; base and top sharp.

Bed 59: Shale, greenish-gray, silty, bioturbated.

Bed 60: Siltstone, yellowish-gray, highly bioturbated; *Zoophycos* bed.

Bed 61: Shale, greenish-gray.

Bed 62: Siltstone, yellowish-gray; *Zoophycos* abundant at top; base and top undulatory; sole scoured with small horizontal meandering traces, load casts, and small tool marks.

Bed 63: Shale, yellowish-gray.

Bed 64: Siltstone, yellowish-gray; parallel laminations; *Zoo-*

phycos bed; base and top undulatory.

Bed 65: Shale, yellowish-brown, bioturbated.

Bed 66: Siltstone, yellowish-gray to grayish-orange; *Zoophycos* common in upper 5 centimeters; base and top undulatory; sole scoured with excellent horizontal branching and non-branching burrows, small load casts, and tool marks; bed thins to the east.

Bed 67: Shale, yellowish-brown, badly weathered.

Bed 68: Siltstone, yellowish-gray; *Zoophycos* bed; base and top undulatory.

Bed 69: Shale, dark-olive-gray.

Bed 70: Siltstone, dark-gray; parallel laminations.

Bed 71: Shale, dark-olive-gray to yellowish-brown.

Bed 72: Siltstone, yellowish-gray; climbing ripples (Tc) in basal 12 centimeters and parallel laminations (Td) in upper 6 centimeters; *Zoophycos* at top; vertical burrows; mud clasts; base and top sharp; bed thickens to the east.

Bed 73: Mudstone, light-olive-gray, badly weathered.

Bed 74: Sandstone, dark-yellowish-orange to light-gray, very fine-grained, silty; Tb in basal 5 centimeters; 8 centimeters of Td-Te in upper 8 centimeters; *Zoophycos* at top; base sharp, top undulatory; sole scoured with small tool marks.

Bed 75: Shaly siltstone and silty shale, yellowish-gray, interbedded; highly bioturbated.

Bed 76: Siltstone, limonite-stained, bioturbated; minor amount of shale produces concretionary bedding.

Bed 77: Shale, light-olive-gray, micaceous; dark mineral grains (?phosphate).

Bed 78: Siltstone, yellowish-gray; faint parallel and wavy laminations; *Zoophycos* at top; ellipsoidal siltstone concretions; liezegang banding.

Bed 79: Shale, yellowish-brown, silty.

Bed 80: Sandstone, yellowish-gray, very fine-grained, silty, micaceous; parallel laminations (Tb) in lower 12 centimeters and wavy laminations (Tc) in upper 6 centimeters; base and top sharp; sole scoured with flutes.

Bed 81: Mudstone, yellowish-brown.

Bed 82: Siltstone, yellowish-gray; wavy laminations; liezegang banding; base undulatory, top sharp; sole scoured with flutes.

Bed 83: Shale, shaly siltstone, yellowish-gray to bluish-gray.

Bed 84: Sandstone, yellowish-gray, very fine-grained, silty; Tb-Te; base and top sharp; concretions; sole scoured with large horizontal branching burrows, cylindrical burrows, small groove casts, tool marks, and load casts.

Bed 85: Mudstone, bluish-gray.

Bed 86: Sandstone, bluish-gray, very fine-grained; silty; Tb-Te; parting lineations in Tc division; small concretions; base sharp, top undulatory; sole scoured with load casts.

Bed 87: Siltstone, yellowish-gray, shaly.

Bed 88: Sandstone, light-bluish-gray, very fine-grained, silty; Td-Te; base and top undulatory; sole scoured with load casts; bed thins to the east.

Bed 89: Mudstone.

Bed 90: Sandstone, light-bluish-gray, very fine-grained; Tc, 5-centimeters-thick; Td, 69-centimeters-thick; Te, 1-centimeter-thick; concretions; base undulatory, top sharp; sole scoured with load casts.

Bed 91: Shale and siltstone, bluish-gray to yellowish-gray; siltstone has parallel laminations and is bioturbated; *Zoophycos*.

Bed 92: Sandstone, yellowish-gray, very fine-grained, silty; Tb, 15-centimeters-thick; Tc, 5-centimeters-thick; Td-Te, 2-centimeters-thick; vertical burrows; base sharp, top undulatory; sole scoured with cylindrical burrows, horizontal, branching, boxwork-like burrows, small groove casts, load casts, and tools.

Bed 93: Shale, bluish-gray.

Bed 94: Sandstone, light-yellowish-gray, very fine-grained, silty; faint parallel laminations; vertical burrows; base sharp, top undulatory; sole scoured with horizontal branching and non-branching burrows, cylindrical burrows, small load casts, and tools.

Bed 95: Mudstone, bluish-gray.

Bed 96: Siltstone, yellowish-gray to bluish-gray; *Zoophycos* bed; sole scoured with load casts and highly bioturbated.

Bed 97: Shale, brownish-yellow.

Bed 98: Sandstone, yellowish-gray to bluish-gray, very fine-grained, very silty; highly bioturbated; *Scalarituba* common; base and top undulatory; sole scoured with small horizontal non-branching burrows and groove casts.

Bed 99: Shale and siltstone, yellowish-gray to bluish-gray; *Zoophycos* bed.

Bed 100 Sandstone, yellowish-gray, very fine-grained to fine-grained; structureless (Ta) throughout; 1 centimeter of Te at top; base and top sharp; sole scoured with small horizontal branching and non-branching burrows, small tool marks, groove casts, and flutes.

Bed 101: Siltstone, light-yellowish-orange, shaly; bioturbated.

Bed 102: Siltstone, yellowish-gray; Td-Te; base sharp, top undulatory; *Zoophycos* bed; sole scoured with horizontal branching and non-branching burrows, small tool marks, and load casts.

Bed 103: Siltstone, dark-bluish-gray, shaly; bioturbated.

Bed 104: Sandstone, dark-yellowish-gray, very fine-grained, liezegang banding; *Zoophycos* at top; parallel laminations; base sharp, top undulatory; sole scoured with horizontal branching, non-branching, boxwork-like burrows, *Helminthopsis*, *Bifungites*, small tool marks, groove casts, and load casts.

Bed 105: Shale, light-bluish-gray, very silty.

Bed 106: Sandstone, light-yellowish-orange, very fine-grained, very silty; liezegang banding; vertical burrows; base and top sharp; sole scoured and heavily iron-stained.

Bed 107: Shale.

Bed 108: Sandstone, yellowish-gray, very fine-grained, silty; faint parallel laminations; *Zoophycos* common throughout; base sharp, top undulatory; sole scoured

Bed 109: Shale and siltstone, greenish-gray to light-olive-gray; mottled due to bioturbation; sole scoured with horizontal burrows and small tool marks.

Bed 110: Sandstone, yellowish-gray, very fine-grained, very silty; *Zoophycos* at top; base and top undulatory; sole scoured and iron-stained.

Bed 111: Shale, dark-bluish-gray to light-olive-gray, very silty.

Bed 112: Siltstone, dark-yellowish-orange; *Zoophycos* at top; randomly oriented mud clasts; base and top sharp; sole not exposed.

Bed 113: Mudstone, greenish-gray when fresh, dark-yellowish-orange when weathered.

Bed 114: Sandstone, grayish-orange, very fine-grained, very silty; *Zoophycos* bed; base sharp, top undulatory; sole scoured with small, fine groove casts, and a few small tool marks.

Bed 115: Mudstone, light-olive-gray when fresh, weathers reddish brown.

Bed 116: Sandstone, light-olive-gray to dark-yellowish-orange, very fine-grained, very silty; *Zoophycos* at top; Tb-Te; base very undulatory, top sharp; sole scoured with abundant load casts, small tool marks, and horizontal branching and non-branching burrows.

Bed 117: Mudstone, light-olive-gray when fresh, weathers reddish brown.

Bed 118: Sandstone, light-olive-gray to yellowish-gray, very fine-grained, silty; *Zoophycos* common; base and top sharp; sole highly scoured with small groove casts, tool marks, and horizontal branching and non-branching burrows.

Bed 119: Shale, light-olive-gray to bluish-gray; bioturbated.

Bed 120: Sandstone, yellowish-gray, very fine-grained, very silty; parallel laminations; *Zoophycos* bed; base sharp, top undulatory; sole scoured with a few small tool marks and horizontal non-branching burrows.

Bed 121: Mudstone, dark-olive-gray.

Bed 122: Siltstone, dark-bluish-gray, sandy; *Zoophycos* bed; parallel laminations throughout; base and top undulatory; sole scoured with load casts, and very fine groove casts.

Bed 123: Shale-mudstone, dark-olive-gray; mottled burrowing; 4.5-centimeter-thick siltstone lense 7.0 centimeters below top of bed; abundant *Zoophycos*.

Bed 124: Sandstone, dark-yellowish-orange, very fine-grained, silty; faint parallel laminations; base undulatory, top sharp; sole scoured and poorly exposed; very small load casts.

Bed 125: Mudstone, light-olive-gray.

Bed 126: Sandstone, dark-olive-gray to yellowish-gray, rusty-appearing, very fine-grained, very silty; faint parallel laminations; base undulatory, top sharp; *Zoophycos* at top; sole highly scoured.

Bed 127: Mudstone.

Bed 128: Sandstone, dark-yellowish-orange to yellowish-gray, very fine-grained, very silty; parallel laminations; *Zoophycos* common at top; randomly oriented mud clasts; base and top sharp; sole scoured with a few tool marks, load casts, and horizontal meandering burrows.

Bed 129: Mudstone.

Bed 130: Sandstone, yellowish-gray, very fine-grained, silty; liezegang banding; *Zoophycos* at top; Ta (structureless); base and top sharp;

sole scoured; iron-stained; small load casts, groove casts, and small tool marks.

Bed 131: Shale, greenish-gray to olive-gray.

Bed 132: Sandstone, dark-yellowish-orange, very fine-grained, silty; liezegang banding; abundant randomly oriented mud clasts; base and top sharp; sole scoured, iron-stained, with load casts.

Bed 133: Shale, grayish-green to dark-olive-gray, silty; silty laminae.

Bed 134: Siltstone, light-yellowish-orange; *Zoophycos* bed; burrows infilled with dark-bluish-gray shale (*Scalaritubo* and *Helminthoida*); base sharp, top undulatory.

Bed 135: Shale, dark-olive-gray, silty.

Bed 136: Sandstone, dark-yellowish-orange, very fine-grained, silty; Tb, 2-centimeters-thick; Tc, 43-centimeters-thick; Td, 25-centimeters-thick; Te, 3-centimeters-thick; *Zoophycos* at top; base undulatory; top sharp; sole scoured with load casts, small tools, groove casts, and horizontal meandering burrows.

Bed 137: Mudstone, light-olive-gray.

Bed 138: Sandstone, dark-yellowish-orange, silty; Ta, 14-centimeters thick; Td, 3-centimeters-thick; Te, 1-centimeter-thick; abundant *Zoophycos*; base and top undulatory; sole scoured with well developed load casts.

Bed 139: Mudstone, light-olive-gray.

Bed 140: Sandstone, yellowish-gray, very fine-grained, silty; *Zoophycos* rare; base undulatory, top sharp; sole deeply scoured with well-developed load casts and flutes.

Bed 141: Mudstone, light-olive-gray to dark-yellowish-orange.

Bed 142: Sandstone, dark-yellowish-orange, very fine-grained, silty; *Zoophycos* common throughout; parallel laminations throughout; sole scoured with horizontal meandering burrows.

Bed 143: Mudstone, dark-olive-gray with dark-yellowish-orange mottling.

Bed 144: Sandstone, dark-yellowish-orange, very fine-grained, silty; Tc, 2-centimeters-thick at base, overlain by parallel laminations (Td); abundant *Zoophycos* at top; sole scoured with load casts, tool marks, fine groove casts, and horizontal non-branching burrows.

Bed 145: Mudstone, bluish-gray.

Bed 146: Sandstone, light-bluish-gray to dark-yellowish-orange, very fine-grained, silty; *Zoophycos*; parallel laminations; base undulatory, top sharp; sole scoured with load casts.

Bed 147: Shale, bluish-gray, silty laminae.

Bed 148: Sandstone, olive-gray to dark-yellowish-orange, very fine-grained, silty; liezegang banding; *Zoophycos*; upper 4 centimeters heavily burrowed; Tc, 5-centimeters-thick, poorly developed; Td, 31-centimeters-thick; Te, 4-centimeters-thick; base sharp, top undulatory; sole scoured, iron-stained, small tools, poorly exposed.

Bed 149: Shale, bluish-gray to light-olive-gray; silty laminae.

Bed 150: Sandstone, very fine-grained, very silty; liezegang banding; Tc, 3-centimeters-thick at base; Td, 13-centimeters-thick; Te, 2-centimeters-thick; *Zoophycos* at top; base sharp to undulatory, top undulatory; sole scoured with small tools and well-developed load casts.

Bed 151: Shale, bluish-gray to dark-olive-gray; silty at base.

Bed 152: Sandstone, light-olive-gray, very fine-grained, silty; basal 30 centimeters burrowed; pseudo-convolute bedding (liezegang banding); 6-centimeter-thick siltstone bed at base to the west; thickness of bed varies laterally.

Bed 153: Mudstone; thickness of bed varies laterally.

Bed 154: Sandstone, yellowish-gray, silty, slightly calcareous; *Zoophycos* at top; parallel laminations throughout; base sharp, top undulatory; sole scoured, iron-stained, with well-developed flutes; bed is channeled, 2 meters thick to the east, and channeled completely out to the west.

Bed 155: Shale, light-olive-gray to yellowish-gray, silty, bioturbated.

Bed 156: Sandstone, dark-yellowish-orange, fine-grained, silty; base and top undulatory; abundant randomly-oriented, large and small mud clasts; sole heavily iron-stained; channel cuts out bed 154 to the west.

Bed 157: Sandstone, light-gray, very fine-grained, silty; faint parallel laminations; *Zoophycos* beds; base and top undulatory; sole scoured with load casts.

Bed 158: Shale, olive-gray to greenish-gray.

Bed 159: Sandstone, olive-gray to dark-yellowish-orange; parallel laminations; base and top undulatory; sole scoured with load casts and small groove casts.

Bed 160: Shale.

Bed 161: Sandstone, stained dark yellowish orange, silty; parallel laminations; randomly oriented mud clasts; sole scoured with well-developed load casts.

Bed 162: Shale, yellowish-gray.

Bed 163: Sandstone, light-olive-gray, very fine-grained, silty; *Zoophycos* at top; base and top sharp; sole scoured and lacks sole marks.

Bed 164: Shale, dark-gray, very silty.

Bed 165: Sandstone, light-olive-gray, very fine-grained, silty; faint parallel laminations (Tb); convolute bedding (Tc) in upper 2 centimeters of bed; base sharp, top undulatory; sole scoured with load casts, groove casts, and tool marks.

Bed 166: Shale, iron-stained.

Bed 167: Sandstone, light- to medium-gray, very fine-grained, very silty; parallel laminations (Tb) in basal 3 centimeters; Tc, 32-centimeters-thick; Td, 18-centimeters-thick; base and top undulatory; sole scoured with well-developed load casts and flutes.

Bed 168: Mudstone, light-olive-gray, silty.

Bed 169: Siltstone, brownish-gray to light-reddish-brown; parallel laminations; *Zoophycos* bed.

Bed 170: Mudstone, light-olive-gray.

Bed 171: Siltstone, yellowish-gray; parallel laminations; *Zoophycos* bed.

Bed 172: Mudstone, bluish-gray.

Bed 173: Siltstone, dark-yellowish-orange; parallel laminations; abundant *Zoophycos*; vertical burrows; base and top undulatory.

Bed 174: Mudstone, light-bluish-gray.

Bed 175: Siltstone, yellowish-gray;

parallel laminations; *Zoophycos* bed; sole scoured with small load casts and tool marks.

Bed 176: Mudstone, bluish-gray.

Bed 177: Siltstone, yellowish-gray; Tc, 1-centimeter-thick at base, Td-Te at top of bed; *Zoophycos* bed.

Bed 178: Shale-mudstone, bluish-gray to light-olive-gray.

Bed 179: Siltstone, dark-yellowish-orange; abundant mud clasts; *Zoophycos* bed; base sharp, top undulatory; sole scoured with load casts and very small tool marks.

Bed 180: Shale, yellowish-gray.

Bed 181: Siltstone, yellowish-gray; parallel laminations; *Zoophycos* bed; base sharp, top undulatory; sole scoured with small load casts.

Bed 182: Mudstone, bluish-gray.

Bed 183: Siltstone, dark-yellowish-orange to bluish-gray; parallel laminations; *Zoophycos* bed; sole scoured with *Helminthoida*, *Scalarituba*, horizontal meandering trails, and vertical burrows.

Bed 184: Mudstone, greenish-gray.

Bed 185: Sandstone, dark-yellowish-orange, very fine-grained; liezegang banding; *Zoophycos* at top; base sharp, top slightly undulatory; sole scoured, iron-stained, with rare load casts, small tool marks, and groove casts.

Bed 186: Mudstone, light-olive-gray, bady weathered.

Bed 187: Siltstone, dark-yellowish-orange; *Zoophycos* at top; base and top undulatory; mud clasts; sole scoured with well-developed load casts and rare flutes.

Bed 188: Mudstone, light-olive-gray.

Bed 189: Siltstone, dark-yellowish-orange; *Zoophycos* bed; sole scoured with load casts.

Bed 190: Mudstone, light-olive-gray, stained reddish-brown.

Bed 191: Siltstone, dark-yellowish-orange, glauconite-streaked; *Zoophycos* common; base and top undulatory; sole scoured with small tool marks, load casts, and horizontal non-branching burrows.

Bed 192: Shale, dark-yellowish-orange, silty, bioturbated.

Bed 193: Siltstone, yellowish-orange when fresh, weathers light olive gray; *Zoophycos* at top; base and top sharp; vertical burrows; sole not exposed.

Bed 194: Mudstone, light-olive-gray, weathered; poorly exposed.

Bed 195: Siltstone, yellowish-gray to light-olive-gray; *Zoophycos* bed; sole not exposed; poorly exposed.

Bed 196: Mudstone, bluish-gray, mottled dark-yellowish-orange; poorly exposed.

Bed 197: Siltstone, dark-yellowish-orange; *Zoophycos* at top; base and top sharp; sole not exposed; poorly exposed.

Bed 198: Mudstone, bluish-gray to dark-yellowish-orange; poorly exposed.

Bed 199: Siltstone, dark-yellowish-orange; parallel laminations; base and top sharp; sole not exposed; poorly exposed.

Bed 200: Mudstone, light-olive-gray; poorly exposed.

Bed 201: Siltstone, yellowish-gray; parallel laminations; *Zoophycos* bed; poorly exposed.

Bed 202: Shale, bluish-gray, mottled; poorly exposed.

Bed 203: Sandstone, dark-yellowish-orange, very fine-grained, very silty; parallel laminations; base sharp, top undulatory; poorly exposed.

Bed 204: Mudstone, bluish-gray to dark-yellowish-orange; badly weathered; poorly exposed.

Bed 205: Sandstone, dark-yellowish-orange, very fine-grained, very silty; parallel laminations; base and top sharp; poorly exposed.

Bed 206: Shale, dark-yellowish-orange; silty laminae; poorly exposed.

Bed 207: Sandstone, light-gray to yellowish-gray, very fine-grained, silty; parallel and wavy laminations; highly bioturbated; sole scoured with abundant horizontal non-branching burrows and meandering trails; poorly exposed.

Bed 208: Mudstone, bluish-gray.

Bed 209: Sandstone, dark-yellowish-orange to reddish-brown; heavily iron-stained; liezegang banding; base and top sharp; sole scoured with load casts, tool marks, and horizontal non-branching burrows.

Bed 210 Shale-mudstone, bluish-gray, silty, bioturbated; *Zoophycos* common.

Bed 211: Sandstone, dark-yellowish-orange, very fine-grained, very silty; *Zoophycos* common.

Bed 212: Shale, light-olive-gray, with dark-yellowish-orange stains; silty; highly bioturbated.

Bed 213: Siltstone, dark-yellowish-orange, shaly; highly bioturbated; *Helminthoida* and *Scalarituba* present.

Bed 214: Shale, light-gray to dark-yellowish-orange; weathered.

Bed 215: Sandstone, dark-yellowish-orange to reddish-brown, very fine-grained, very silty; base and top sharp; top bioturbated; sole scoured with load casts and small tool marks.

Bed 216: Mudstone, light-olive-gray; heavily iron-stained; poorly exposed.

Bed 217: Sandstone, light-olive-gray to dark-yellowish-orange, very fine-grained, silty; heavily iron-stained; base sharp, top undulatory.

Bed 218: Mudstone, dark-yellowish-orange, sandy.

Bed 219: Sandstone, dark-yellowish-orange; parallel laminations; iron-stained; sole scoured with load casts and horizontal non-branching burrows.

Body Fossils:

Henley Bed

None?

Farmers Member

brachiopods

bryozoans

pelmatozoan detritus

Trace Fossils:

Henley Bed

None?

Farmers Member

Bifungites

Helminthoida

Helminthopsis

Scalarituba

Neonereites-view

Scalarituba-view

*unidentifiable, scoured horizontal branching, non-branching, and boxwork-like burrows

unidentifiable vertical burrows

*type-1 *Zoophycos*

*type-2 *Zoophycos*

Interpretation:

Henley Bed: Basin floor.

Farmers Member: More proximal (higher flow regime) turbidites, possibly in a mid-fan complex (?).

*abundant

END OF FIELD TRIP.
RETRACE FIELD TRIP ROUTE TO
CARTER CAVES STATE RESORT PARK.

Annual Field Conference of the Geological Society of Kentucky
1980