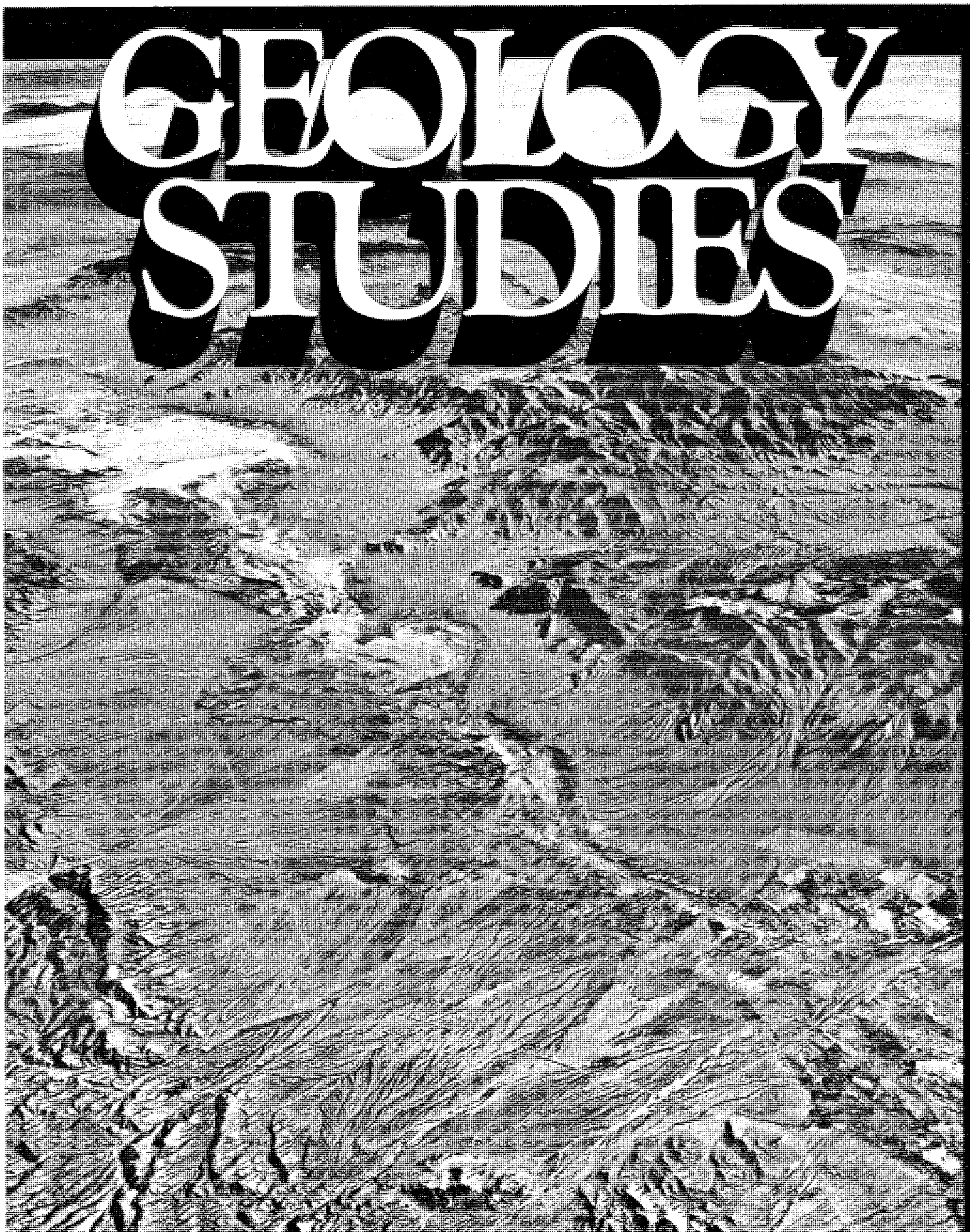
BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES



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Brigham Young University Geology Studies

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Papers presented at the 31st annual meeting, Rocky Mountain Section, Geological Society of America, April 28–29, 1978, at Brigham Young University, Provo, Utah, reviewing stratigraphic and paleontologic research in the Great Basin and honoring Dr. Harold J. Bissell.

CONTENTS

THE GLORY OF GOD IS INTELLIGENCE

Cover: *The Great Basin seen from a high-altitude reconnaissance plane. Photo courtesy U.S. Geological Survey.*

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EDITOR'S PREFACE

For the 1978 Rocky Mountain Section of the Geological Society of America meeting in Provo, Utah, a symposium was organized to mark the retirement of Professor Harold J. Bissell (program below). During the course of the symposium, held on April 29, several hundred present and past students, colleagues, and friends participated. Papers given at the symposium were invited from colleagues and former students. The theme of the symposium was a review of stratigraphic and paleontologic research in the Great Basin.

Of the nine papers presented in Provo, six are printed in this commemorative volume, dedicated to Harold J. Bissell, an enthusiastic teacher and student of Great Basin geology.

DLC

SYMPOSIUM
GREAT BASIN STRATIGRAPHY AND PALEONTOLOGY
29 April, 1978

David L. Clark and Lehi F. Hintze: Introduction to Symposium

Michael J. Brady and Richard B. Koepnick: A Middle Cambrian Platform-to-Basin Transition, House Range, West Central Utah

Richard A. Robison: Evolution of Some Trilobite Guide Fossils from the Middle Cambrian

J. Keith Rigby: Paleozoic Sponge Faunas of the Great Basin and Adjacent Areas

C. Kent Chamberlain: Trace-Fossil Ichnofacies in the Lower and Middle Paleozoic of Central Nevada

M. A. Murphy, J. B. Dunham, W. B. N. Berry, and J. C. Matti: Late Llandovery Unconformity in Central Nevada

Raymond C. Gutschick and Joaquin Rodriguez: Biostratigraphy of the Pilot Shale (Devonian-Mississippian) and Contemporaneous Strata in Utah, Nevada, and Montana

John A. Larson: Redeposited Carbonates of the Upper Oquirrh Formation, Utah

David L. Clark: Permian-Triassic Boundary: Great Basin Conodont Perspective

(Abstracts of papers published in vol. 10, no. 5, Geological Society of America Abstracts with Programs, March 1978)

Biostratigraphy of the Pilot Shale (Devonian-Mississipian) and Contemporaneous Strata in Utah, Nevada, and Montana

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ABSTRACT.–In the western United States, Late Devonian and Early Mississippian strata marginal to the cratonic platform exhibit rapid vertical changes in response to the Antler orogeny; however, the litho- and biofacies have great north-south extent along depositional strike. This report concentrates on the biostratigraphy of the Pilot Shale of western Utah and its relation to the Leatham Formation of northern Utah and the Sappington Member of the Three Forks Formation of western Montana.

In the Confusion Range of western Utah, the lower member of the Pilot Shale contains turbidite and debris flow units, convoluted siltstones, sedimentary breccias, dark organic shales, sheet channel siltstones with groove casts, and the neritic trace fossil assemblage *Rusophycus, Cruziana, Chondrites, Skolithos,* and *Planolites.* A regional erosional unconformity separates the lower and middle members.

The middle member of the Pilot Shale has the following sequence: (1) Basal sandstone and dark euxinic shales, layered cherts, and calcareous concretions with radiolarians, (2) disconformable lag sandstone and dark shale with inarticulate brachiopods and conchostracans, (3) a high density, high diversity oncolite-shell bank dominated by brachiopods (*Syringothyris* assemblage zone), gastropods, bivalves, cephalopods, trilobites, fenestellid bryozoans, echinoderm debris, and *Cosmorhaphe* traces. Some oncolites with fossil shell cores show in situ upward digitate stromatolite growth.

The upper member is a regressive unit of silty shales, siltstone, and sandstone beds with large-scale channel scour-fill deposits. *Cosmorhaphe, Scalarituba,* and other small burrow-fill traces occur, but shelled invertebrates are scarce. The Joana Limestone has a basal sandstone which is unconformable on the upper member of the Pilot Shale.

INTRODUCTION

This paper focuses attention on the geologic history of the Pilot Shale (Late Devonian–Early Mississippian) of western Utah and is based on field observations and interpretations of its litho- and biofacies. The regional distribution of the Pilot and related correlative rocks is presented and stresses the remarkable extent of litho- and biosomes along depositional strike of the geosyncline. Examples include a black, fissile, fossiliferous shale bed less than .25 m in thickness which occurs in the same stratigraphic position from southeast Nevada to western Montana, a distance of more than 1200 km; and a very fossiliferous oncolite-shell bank which extends laterally for over 1000 km.

The location and extent of the Pilot Shale is depicted in figure 1, together with three other basins of contemporaneous deposition. The distribution of the Pilot, Leatham, Sappington, and Exshaw-Bakken basins are shown in relation to the framework of deposition between the cratonic platform on the east and the Antler orogenic highlands to the west.

The study emphasizes the fossils recorded in the Pilot Shale: Foraminifera, radiolarians, *Tasmanites,* sponges and sponge spicules, horn corals, brachiopods (abundant and diverse), bryozoans, snails, bivalves, cephalopods (nautiloid and goniatites), conchostracans, trilobites, conodonts, and fish fragments, abundant trace fossils (burrows and trails), and algae(?). They occur in nodular limestones, siltstones, black shales, black bedded cherts, lag sandstones, and calcareous concretions.

The Pilot Shale was named and described by Spencer (1917) from exposures at Pilot Knob near Ely, Nevada. There are many subsequent references to the formation, but the following are among the most pertinent to this report: Langenheim (1960), Johnson and Reso (1966), Hose (1966), Clark and Ethington (1967), Gutschick and Moreman (1967), Sandberg and Poole (1970, 1977), Sandberg and Ziegler (1973), Poole (1974), Sandberg (1976), Gutschick and Rodriguez (1977), and Poole and Sandberg (1977).

The following are general references to rock units correlative of the Pilot Shale: Leatham Formation–Holland (1952), Sandberg and Gutschick (1969, 1978), Sandberg and Poole (1977); Sappington Member–Gutschick, McLane, and Rodriguez (1976), Sandberg and Poole (1977); Exshaw-Bakken Formation–Macqueen and Sandberg (1970), Pelzer (1966), and Christopher (1961).

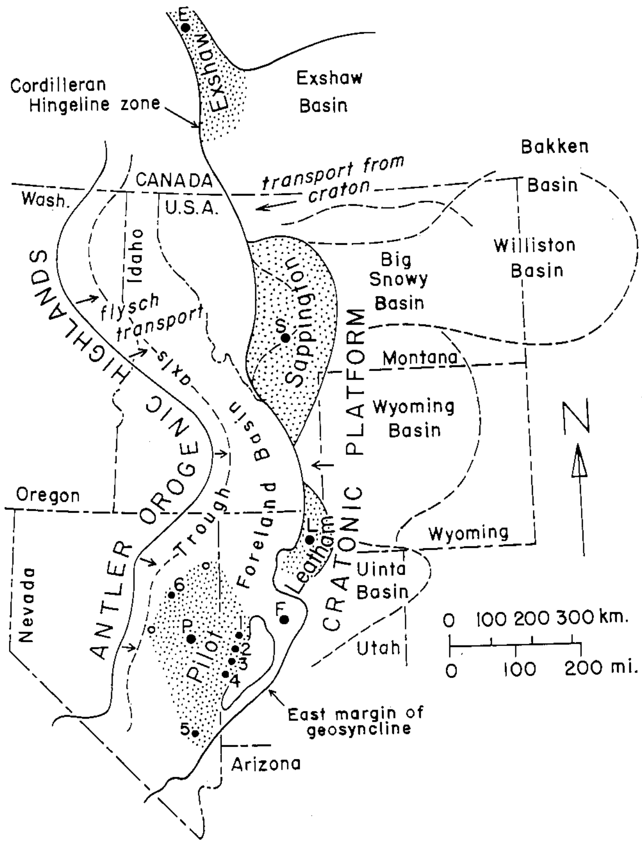


FIGURE 1.–Distribution of latest Devonian sedimentary basins (Pilot, Leatham, Sappington, and Exshaw-Bakken) in relation to their structural and depositional framework (partly restored) based on Poole (1974), and Sando (1976). Type localities shown: L-Leatham at Leatham Hollow; P-Pilot at Ely; F-Fitchville, E. Tintic Mts.; S-Sappington near Milligan Canyon; and E-Exshaw, Jura Creek. Pilot Shale localities: 1. Lower Pilot west of Coyote Knolls; 2. Confusion Range; 3. Burbank Hills; 4. N. Needle Range; 5. Bactrian Mountain; 6. Southern Ruby Range.

Geologic Setting and Problems

Anyone contemplating or involved in stratigraphic studies in the western Rocky Mountains and Great Basin must be aware of the geologic complexities graphically summarized in figure 2. Palinspastic reconstruction is complicated because of successive Antler, Sonoma, Sevier, and Laramide orogenic thrusting (crustal shortening and gravitational gliding attenuation). Transverse lateral movements, e.g., the Wells Fault, have offset strata and mountain ranges 50 to 150 or more km (Ketner 1977, Poole and Sandberg 1977). Intrusions, such as the Idaho and Boulder batholiths, have reconstituted country rock sediments; and volcanic outpourings, such as those at Yellowstone Park and those underlying the Snake River Plain, have extensively covered older rocks. Postorogenic erosion, as in the Sevier uplift and the Holocene denudation have removed or covered much stratigraphic evidence. Downwarped basins, as in the case of the Oquirrh Basin, have displaced older rocks out of reach to the field geologist. The Great Salt Lake is yet another obstacle as strata are concealed under it. Also, studies of Paleozoic rocks in the Basin and Range Province must be confined only to the ranges where exposures are available, except for subsurface data. Finally, the plate tectonics model adds another perspective by placing the Late Devonian basins within the tropics (Irving 1977).

Acknowledgments

Fieldwork for this report originated from extensive work on the Sappington Member in Montana throughout the 1950s and 60s which expanded to the Leatham Formation in 1963 and Exshaw Formation in 1965. Observations began on the Pilot Shale in 1966 at Bactrian Mountain, southeast Nevada, and in the Confusion Range, western Utah, and has continued to the present. The contributions of many student field assistants during this time is especially appreciated.

Special thanks is extended to Charles A. Sandberg, U.S. Geological Survey, for field association and cooperation during the period from 1962 to the present. We are grateful to him for his field observations, knowledge concerning these rocks, and the fruits of a comprehensive conodont program. F. G. Poole is another colleague who has helped in and out of the field. Our report draws heavily on the resources of these two men.

Helpful direction came early in the fieldwork from Richard K. Hose, U.S. Geological Survey; Anthony Reso, Tenneco Oil Company; and Walter Sadlick—all of whose generous guidance proved valuable. Financial assistance for this study was granted by the National Science Foundation through faculty and undergraduate research grants GE-363, GE-2612, G-16222, GP-1197, and GP-4513, for which we express our gratitude.

General Stratigraphic Relations

The Pilot Shale of western Utah and eastern Nevada, Leatham Formation of northern Utah, Sappington Member of the Three Forks Formation of western Montana are transitional clastic sequences which formed in response to the Antler orogenic activity to the west. They separate Late Devonian carbonate rocks below from Early Mississippian limestones above and mark the transition between systems. This relationship, together with the paleontological information on which the chronology has been established, is summarized in figure 3. In the case of the Pilot Shale of western Utah, the Guilmette carbonates–clastic Pilot shale and siltstone–Joana Limestone sequence is expressed by corresponding hogback ridge-valley-hogback ridge topography (fig. 4).

The Pilot Shale is divided into three informal members: lower, middle, and upper which are characteristically developed in the Confusion Range (fig. 5). However, pre-Joana Limestone erosion has restricted the distribution of the upper two members. The lower member consists of light- to dark-colored, fine-textured clastics which appear to be conformable with the underlying rocks. A distinctive lower black shale unit separated by unconformities at the bottom and top makes up the lower part of the middle member. Within its upper part, this member carries a thin dark shale with conchostracans and is overlain by a fossiliferous oncolite limestone unit. Significant sandstone beds occur above the unconformities, reflecting Antler orogenic pulsations. The upper member is composed of fine-textured clastics similar to those of the lower member and is truncated by pre-Joana erosion.

The Leatham Formation of northern Utah (fig. 6) and the Sappington Member of western Montana are remarkably similar to the middle member of the Pilot Shale of western Utah, and the two units undoubtedly represent sediments deposited within the same depositional basin. The Leatham is given formational status; however, the Sappington is regarded as the upper member of the Three Forks Formation (hereafter it will be referred to only as the Sappington Member). The upper parts of the Leatham and Sappington may represent a portion of the

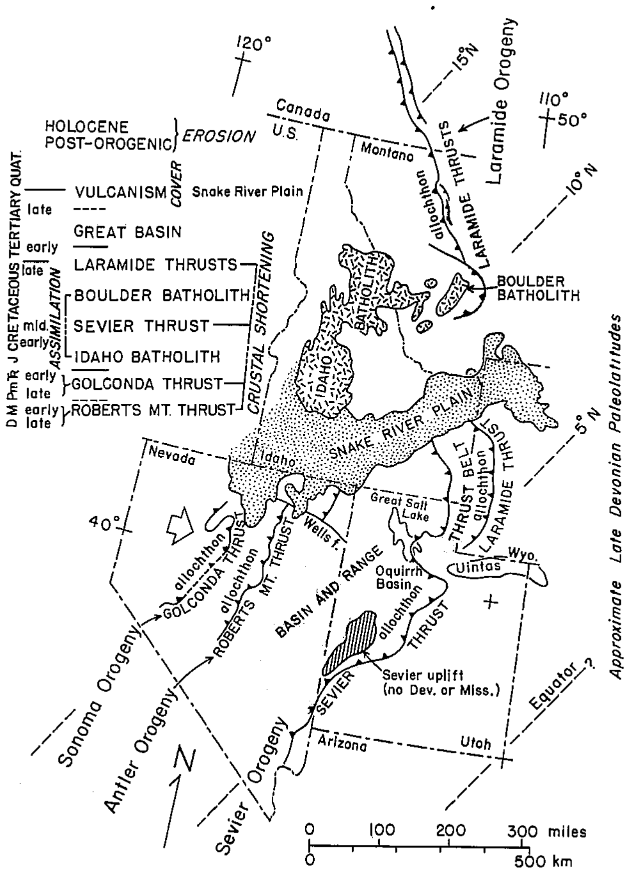


FIGURE 2.—Relationship of Late Devonian sedimentary basins, shown by compact stippling, to contemporary (Antler orogeny) and subsequent diastrophism and erosion. Based on geologic map of the United States (compiled by King and Beikman 1971, 1974), Sandberg and Poole (1977), and Irving (1977).

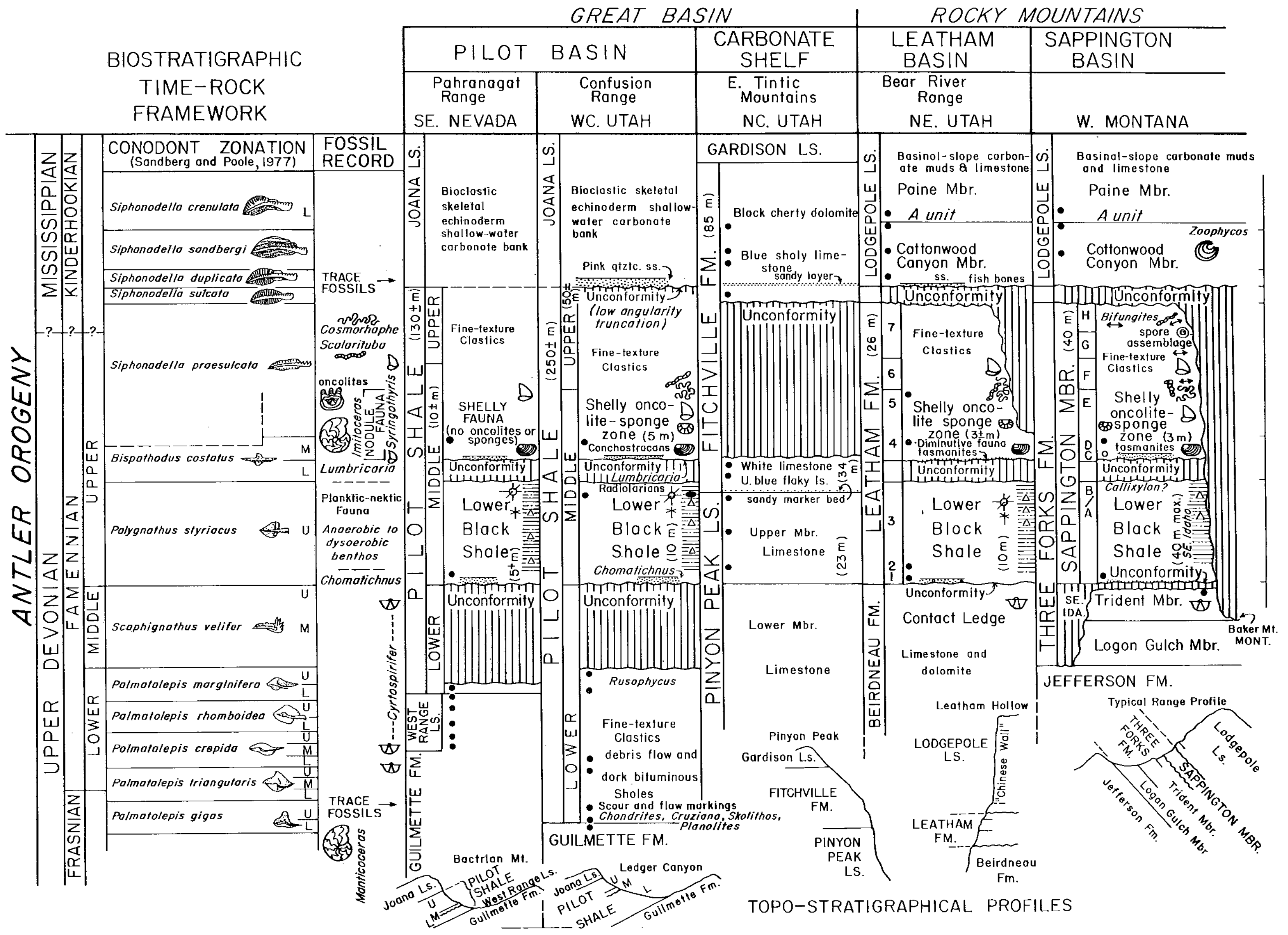


FIGURE 3.—Biostratigraphic chart to relate time and rocks to stratigraphic sections, locations, paleontologic zonation and fossil distribution, and correlations. Black circles represent conodont collections which identify specific zones. Conodont data from Sandberg and Poole (1977). Time units along the ordinate are not of equal magnitude.

upper member of the Pilot Shale. To the east of the Pilot basin, shallow-water carbonate rocks contemporary with the Pilot Shale are present in the Pinyon Peak and Fitchville limestones.

Localities

Pilot Shale localities examined in the Confusion Range are shown in figure 7 and those in the Burbank Hills in figure 8. The Bactrian Mountain section location is provided by Johnson and Reso (1966). Other Pilot Shale localities are found in Sandberg and Poole (1977).

Leatham Formation localities are furnished by Holland (1952), Sandberg and Poole (1977), and Rodriguez and Gutschick (1978). Sappington Member localities are shown in Gutschick, McLane, and Rodriguez (1976), and Sandberg and Poole (1977).

FIGURE 4.–Pilot Shale valley along Ledger Canyon, Confusion Range. The section dips about 30° to the left (west). The road marks the approximate position of the base of the Pilot, and the top is at the base of the Joana Limestone hogback scarp to the left. The Guilmette Formation forms the dip slope of the hogback on the right.

PILOT SHALE

Lower Member

The lower member of the Pilot Shale consists of a sequence of fine-grained clastic sediments. In the Confusion Range, where the member is more than 250 m thick (fig. 5), it is composed primarily of light-weathering, colored shale and siltstones, often high in silt-size dolomite grains and dark carbonaceous shale. The member includes debris flow units with penecontemporaneous soft-sediment folding, sheet-flow channel layers with sole flow-markings and trace fossils–burrows and trackways. Its topographic expression is recessive so that it often forms the bottom and flank of a strike valley. An illuminating graphical summary of the time-rock relations of the lower member of the Pilot Shale based on conodont zonation is available in Sandberg and Poole (1977, fig. 7).

A complete, fortuitous, gulch exposure of the lower member of the Pilot Shale in contact with the underlying Guilmette Formation occurs west of Coyote Knolls (figs. 9, 10; Hose 1963, 1966). Here, a basal Pilot transitional, thin-bedded (<10 cm) siltstone and silty shale sequence contains sheet-flow and scour channel beds which have sole markings and abundant trace fossils (fig. 11G). The trace fossils are burrows and trackways of *Chondrites, Planolites, Skolithos,* and *Cruziana* which

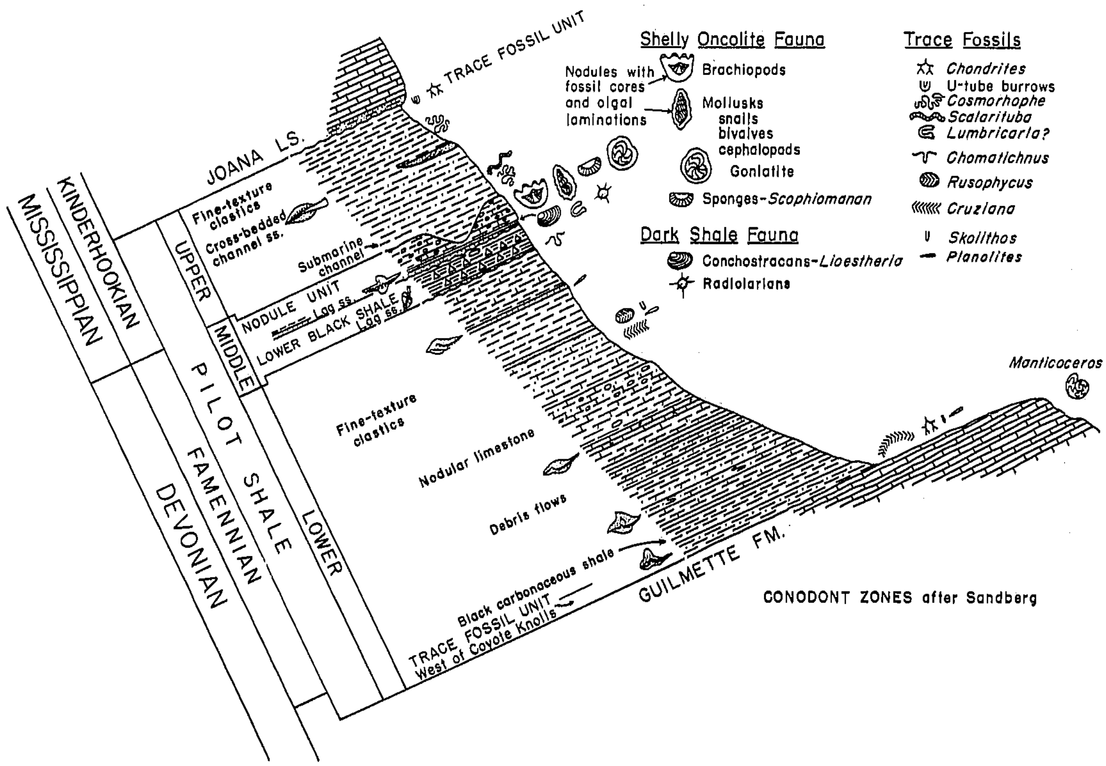


FIGURE 5.–Biostratigraphy of the Pilot Shale section in the Confusion Range, western Utah. Compare with chart (fig. 3).

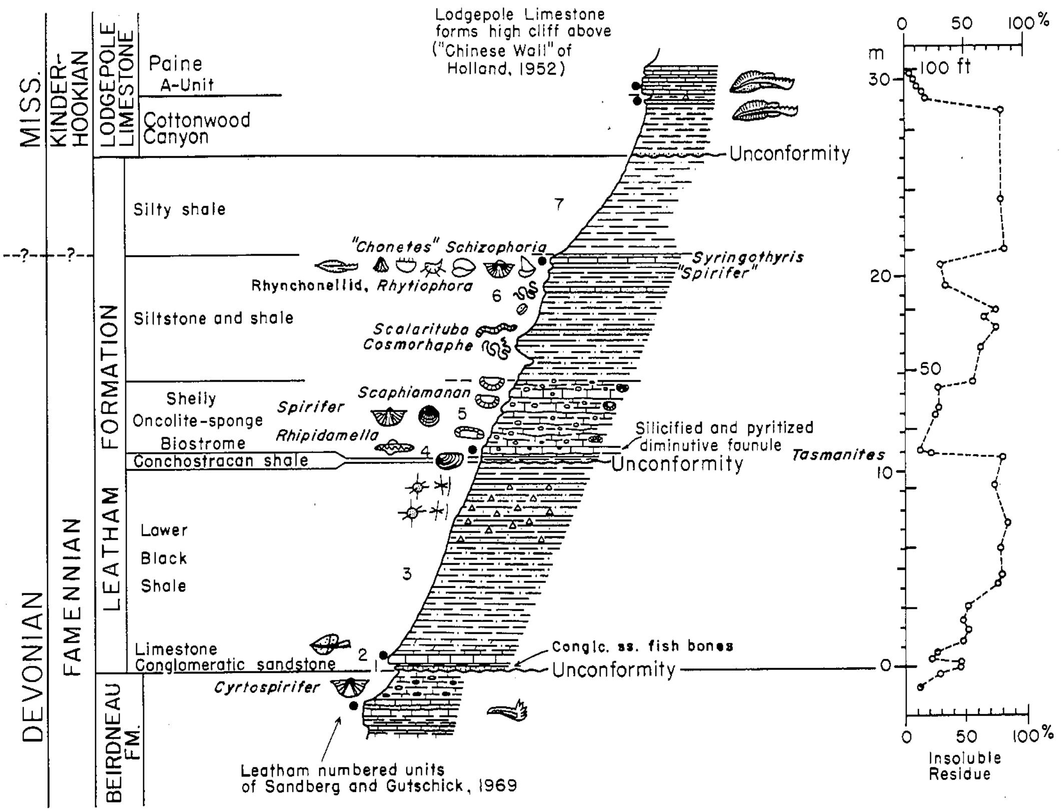


FIGURE 6.–Type section of the Leatham Formation at Leatham Hollow, Bear River Range, northern Utah. Compare with chart (fig. 3).

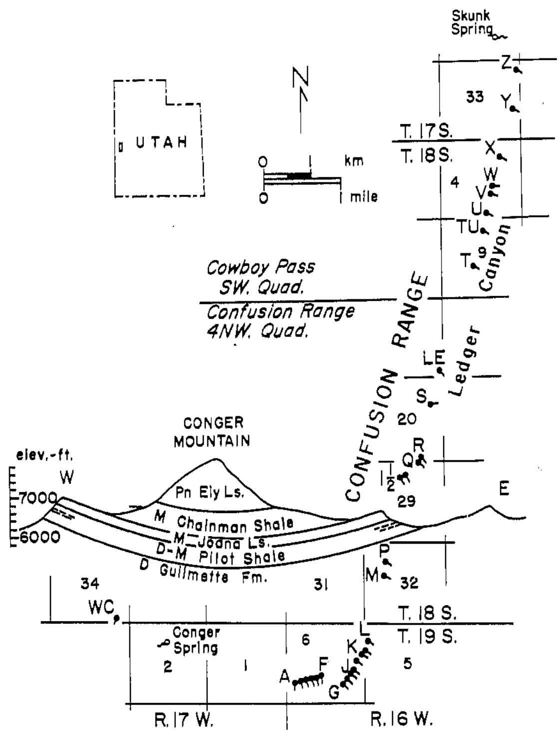


FIGURE 7.–Pilot Shale section localities in the Confusion Range, western Utah, showing W-E topostratigraphic profile. Based on geologic maps by Hose (1963, 1966), Hose and Repenning (1963), and Hintze (1974). These do not represent all Pilot sections exposed in the Confusion Range.

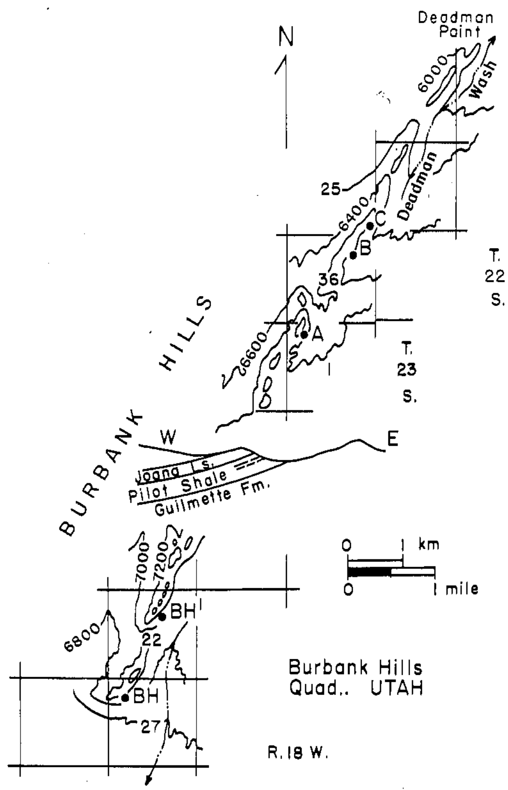


FIGURE 8.–Some Pilot Shale localities along Deadman's Wash strike valley in the Burbank Hills, western Utah, showing W-E topostratigraphic profile.

occur in convex relief on the bottom of the channel-fill beds (Gutschick and Rodriguez 1977). Herringbone trackways up to 1 cm wide and 20 cm long crisscross the channel floor, and their paths show the influence of channel flow currents. Sole mark fluting suggests a southwesterly direction of flow.

In the same section siltstone units in the lower Pilot are folded and contorted, the result of syndepositional debris flow shearing or sliding along the sloping bottom (fig. 10). Fossils in the lower Pilot, other than traces, are scarce. *Spirorbis* tubes have been found in the channel siltstones, and occasional thin layers of bioclastic debris are found higher in the lower Pilot section. The latter contains numerous echinoderm fragments and productid and spiriferid brachiopods, including *Cyrtospirifer.*

Other sections of the lower Pilot can be found along the strike valleys of Ledger Canyon (fig. 4, 7), e.g., Little Mile and a Half Canyon (1½) and section K. Body fossils were not found along Ledger Canyon in this part of the section. However, trace fossils are common in the siltstone layers that form ledges and bench exposures along valley slopes. A *Rusophycus-Cruziana* trace assemblage was discovered on the bottom of thin (2–10 cm) channel-fill siltstone slabs in convex relief (Gutschick and Rodriguez 1977).

An important widespread unconformity separates the lower and middle Pilot members. Every place where the lower black shale of the middle Pilot and equivalent strata has been observed from southeastern Nevada to western Montana and Alberta, the shale rests unconformably on the underlying rocks. This has clearly been demonstrated by Sandberg and Poole (1977, fig. 7) for the Pilot basin.

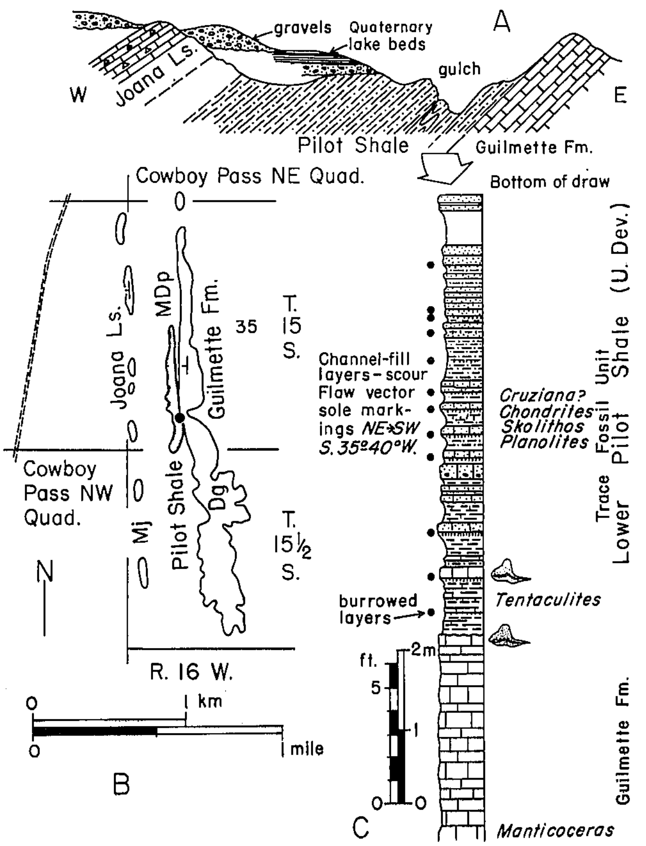


FIGURE 9.–Lower Pilot Shale locality west of Coyote Knolls, Cowboy Pass NE Quad., Millard County, Utah (after Hose 1963). A.–Field sketch of geologic relations. B.–Geologic map of the area. Coyote Knolls is about 5 km due east. C.–Upper Guilmette-Lower Pilot stratigraphic section showing transitional contact and lowest Pilot trace-fossil unit.

Middle Member

The middle member of the Pilot Shale is a succession of the following units in ascending order: lower black shale with basal sandstone, thin lag-sandstone bed, thin, dark conchostracan shale, and a very fossiliferous oncolite biostrome or equivalent calcareous siltstone unit (figs. 3, 5). It is the stratigraphic equivalent of the Leatham and Sappington and represents extensive, remarkably persistent strike deposition along the geosyncline across western United States into Canada.

Lower Black Shale

The lower black shale lithofacies has broad areal distribution (fig. 12). It is considerably more restricted in the Pilot basin where it has been recognized in a narrow belt from the Bactrian Mountain area to the Confusion Range and in one other isolated section, south Ruby Range. The shale unit is well developed in the Leatham Formation (fig. 6), Sappington Member, and Exshaw Formation as revealed by detailed sections (fig. 13).

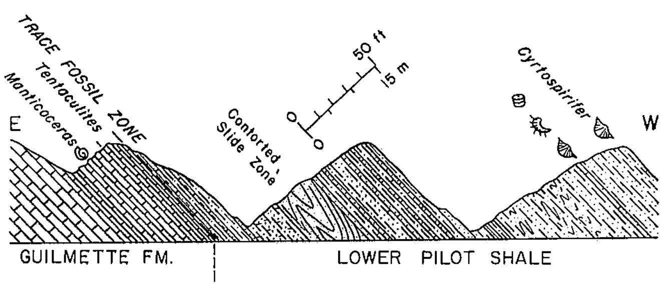
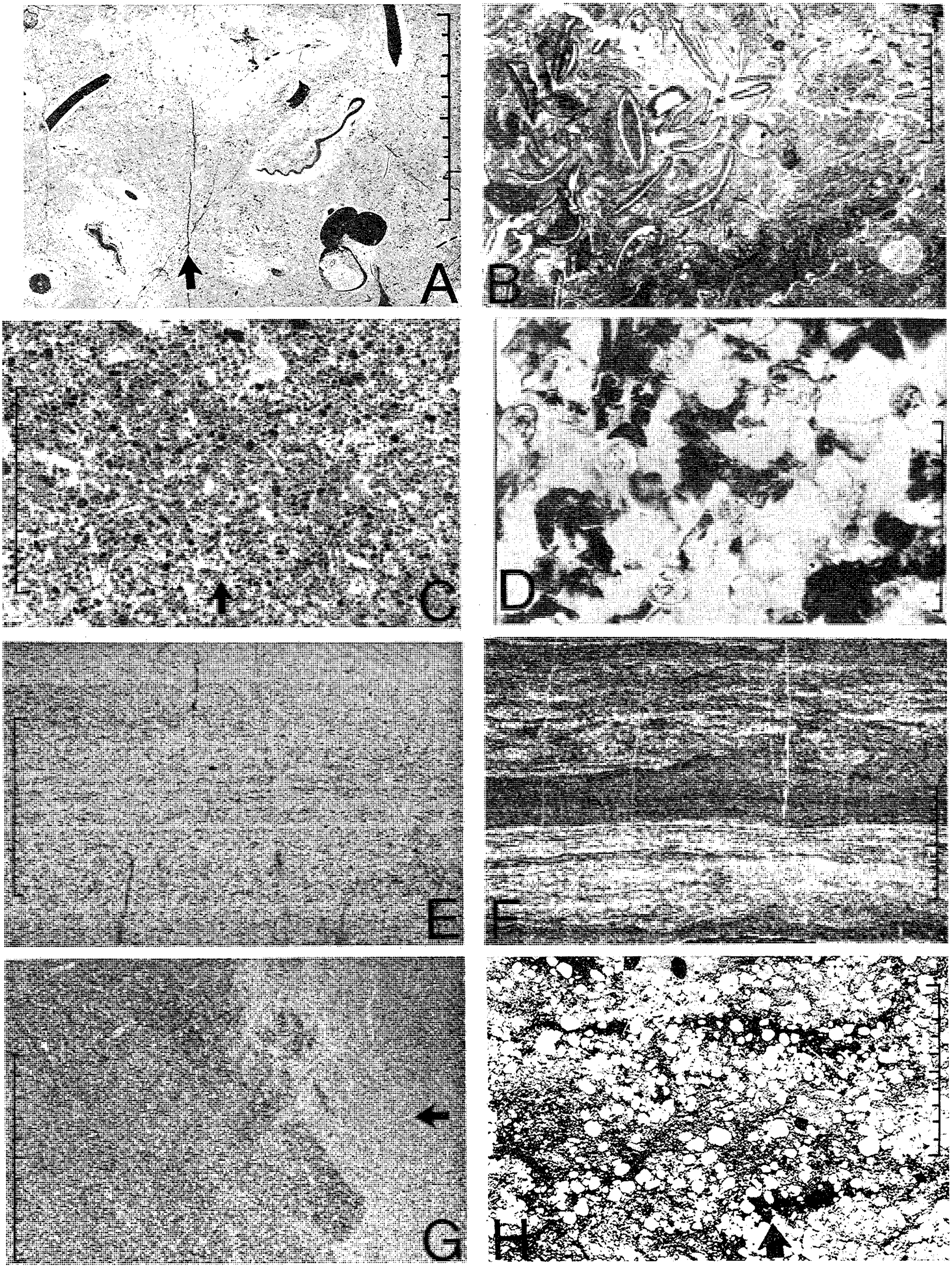


FIGURE 10.–Detailed field sketch of well-exposed lower Pilot Shale section in gulch west of Coyote Knolls.

FIGURE 11.–Photomicrographs of some Pilot-Leatham biofacies. Arrows point up stratigraphically. Scale shown is 1 cm divided into mm. A.–Middle Pilot basal limestone bed of oncolite zone (fig. 16). Note the light-colored, thin, algal-coated layers surrounding fossil fragments, including a trilobite segment. B.–Fossil shell coquinoid basal limestone bed of the oncolite zone, Leatham Formation, unit 4, at Leatham Hollow (LH25). This is part of the pyritized, diminutive faunule zone. C.–Middle Pilot lag sandstone which overlies the lower black shale, section A, Confusion Range (CF10). Rock is composed of poorly sorted, rounded, water-worn grains associated with fish bones, conodonts, and *Lumbricaria* sole markings. D.–Lag-sandstone *Tasmanites* layer (8 cm thick) which occurs between lower black shale (unit A) and conchostracan shale (unit C), Sappington Member, Frazier Lake section, Bridger Range, Montana. *Tasmanites* are uncompressed and filled with clear quartz and tiny framboidal pyrite crystals (speckled *Tasmanites* interiors in photo). Scale shows 1 mm divided into 0.1 mm. E.–Black, bedded chert in the lower black shale showing even, undisturbed laminations (CWC-1) from sections west of Conger Spring, Confusion Range. F.–Silicified silty shale and chert in lower black shale, Leatham Formation, Leatham Hollow section. Undisturbed and disturbed laminae with very small-scale scour and current bedding are visible (LH28). G.–Siltstone from the trace-fossil unit at the base of the Pilot Shale section, west of Coyote Knolls (fig. 9). Sample comes from a channel-fill layer with flow fluting and trace fossils (PL8CKT). H.–Basal sandstone of the Leatham Formation, Leatham Hollow (LH7B). Rock consists of well-rounded, poorly sorted quartz grains, chert granules, limestone pebbles, water-worn fish bones, and conodonts.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The lower black shale unit is a dark, organic-rich, silty, cherty shale which is slope forming. The chert and/or silicified shale occurs in layers with planar bedding and sharp contact with enclosing rocks. Chert layers are often evenly laminated and may contain small radiolarians, sponge spicules (some thin layers are spiculites), conodonts, and occasionally fossil wood (*Callixylon*?); otherwise benthic fossils have not been found in the chert or shale. In some sections the chert layers are very abundant as is the case south of Bactrian Mountain and in the Confusion Range. The amount of silt varies, and some parts of this unit are composed of siltstone. Pyrite is also a common constituent of the rock unit.

The lower black shale is unconformable on older rocks wherever observed; consequently, the basal portion is variable. A coarse basal sandstone which ranges considerably in texture and thickness is usually present. Some limy beds are present in this lower part as in the Leatham Hollow section. Large concretions, up to 1 m diameter, may be present such as those which occur in the lower part of the Exshaw and the south Ruby Mountains sections and upper part of the Pilot black shale unit in the Confusion Range. In some sections they may contain conodonts and radiolarians. A thin K-bentonite clay layer occurs in the Exshaw black shale, representing a weathered volcanic ash-fall layer; no other such layer has been seen by us or reported in the shale unit in the western United States.

The base of the middle Pilot Shale and Leatham Formation commonly contain sandstones which thicken into significant sand bodies (fig. 14). The sandstones have the attributes of coarseness, rounded grains, some hematite stain, silicified quartzitic texture, and planar cross-stratification, and they contain extraneous conglomeratic reworked materials, water-worn fish bones and plates, conodonts, dark, shiny phosphatic pellets and pebbles, and burrows. These sand bodies are similar to ones described by Ryan and Langenheim (1973). A quartzitic sandstone bed in the Burbank Hills section A (fig. 8) revealed a mound burrow with associated ejecta when the rock was cut normal to the bedding (Gutschick and Rodriguez 1977). This trace burrow, *Chomatichnus*, is shown in figure 15.

Lag Sandstone–Conchostracan Shale

There are three thin (.5 m total), faunally distinct units which occur between the lower black shale and the overlying oncolite biostrome: basal lag sandstone, middle black conchostracan shale, and upper greenish-gray shale with mollusks (figs. 16, 17). The lag sandstone is disconformable on the lower black shale marking a sharp change brought about by Antler orogenic unrest. The sandstone is similar to the one at the base of the lower black shale except the latter is much thicker. Fish bones, conodonts, *Tasmanites* (fig. 11D), and phosphate pellets are common. Poor sorting of grains is characteristic, and bed thickness varies up to 20 cm. *Lumbricaria* traces (fig. 18) are common on the bottom of this layer in the Confusion Range and probably elsewhere since the unit can be recognized from southeastern Nevada to western Montana (figs. 3, 13).

The black fissile conchostracan shale unit, up to 20 cm. thick, is gradational on top of the sandstone. This thin, dark shale biofacies is very widespread along the geosynclinal margin (fig. 19). Single valves of the conchostracan *Cyzicus* (*Lioestheria*) sp. (fig. 20) often cover the rich organic laminae in profusion, and occasionally articulated double-valve shells are common. These late Devonian crustaceans are among the earliest in the fossil record and are thought to represent either freshwater (Tasch 1977) or brackish-water environments of shallow depth. A graphic summary (fig. 21) shows the faunal association of the conchostracans which we have observed in the Pilot, Leatham, and Sappington strata. There are exclusively marine forms, e.g., brittle starfish, goniatites, *Lingula* and *Orbiculoidea*, and trilobites to suggest at least brackish-water marine conditions for this biofacies. The fossils, dark rock color, and organic carbon content suggest a dysaerobic environment due to poor water circulation and possibly a plant flotant (algal) cover (Zangerl and Richardson 1963, p. 12).

The black shale grades upward into greenish-gray shale (unit D of the Sappington) which contains the bivalve *Grammysia*, snails, brachiopods, and pelmatozoan stem segments. The white calcite shells, rarely with pearly luster, are most often leached so preservation is in the form of molds; the shells are distorted by compaction. Unit D has wide distribution in western Montana although it is only 10–15 cm thick; otherwise its presence in the Pilot and Leatham is questionable. This triplet

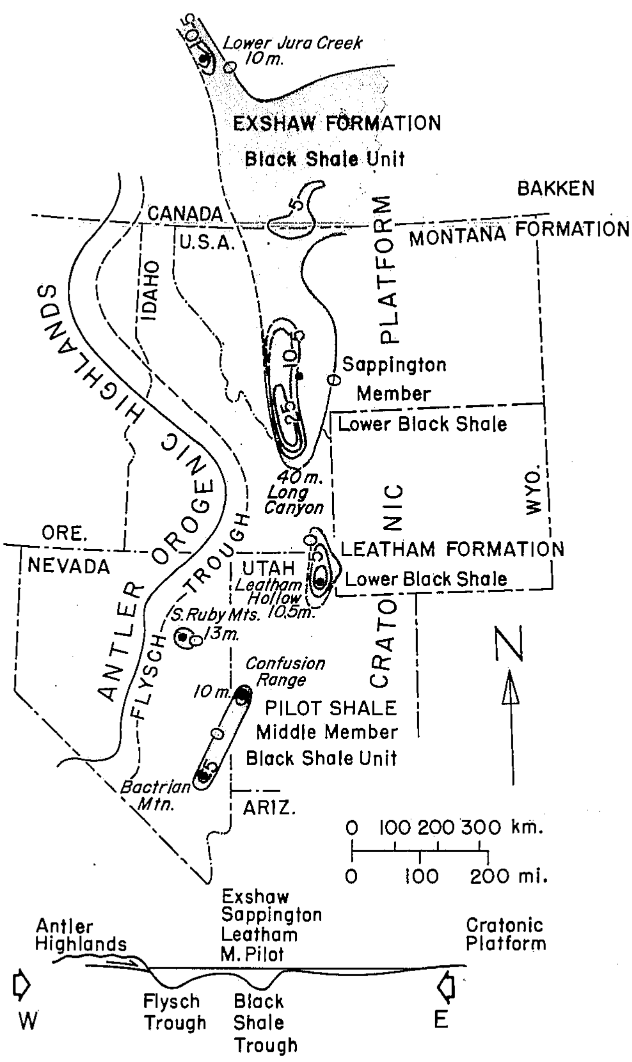


FIGURE 12.—Distribution of lower black shale unit of middle member of the Pilot Shale, Leatham Formation, Sappington Member, and Exshaw Formation along the Cordilleran geosyncline (thickness in meters). A diagrammatic reconstruction of the depositional framework is shown in cross-section below.

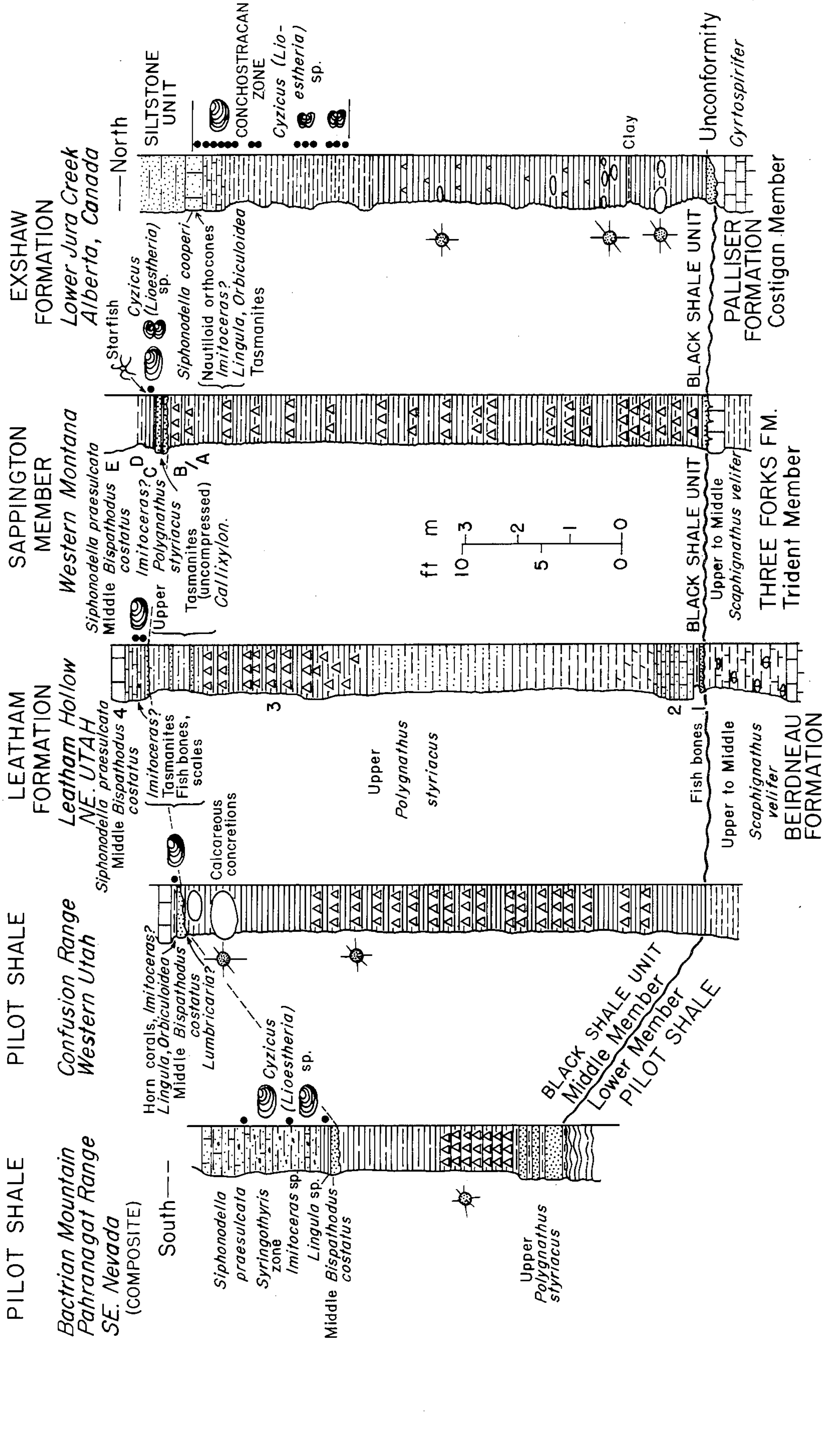


FIGURE 13.–N-S cross-section showing detailed correlation of lower black shale for various stratigraphic units based on measured and collected sections representing deposition along strike in the Cordilleran geosyncline from western Alberta, Canada, to southeastern Nevada.

of thin units is shown in environmental context in association with the substrate and overlying oncolite bank (fig. 17). Rocks and fossils suggest a vertical change for this transgressive sequence from anaerobic to dysaerobic to aerobic conditions.

Oncolite-Shell-Sponge Bank Unit and Equivalent Rocks

Surprisingly, one of the most persistent biofacies in this Late Devonian sequence is that of an oncolite-shell-sponge bank (fig. 17) which extends from western Utah to western Montana (fig. 22). This unit is well developed in the middle Pilot of the Confusion Range (maximum thickness 5 m), southern Burbank Hills, and northern Needle Range (fig. 23). Equivalent fossiliferous beds have been found in southeastern Nevada (Johnson and Reso 1966) but not in association with oncolites. The oncolite bank is present in the Leatham Formation of northern Utah and well represented in the Sappington throughout western Montana (fig. 24) (Gutschick 1966).

The bank consists of layers of limestone and calcareous shale with a mixture of silt and scattered nodular oncolites. The oncolites range in size up to 10 cm maximum (average 3-6 cm), range in shape and numbers, usually have a fossil core, form crinkled laminae around the nucleus, and often develop radial digitate stromatolite growth in the outer part. The abundance of nodules and fossils and their vertical accumulation in the limestone layers outline a linear pattern parallel to the geosyncline margin and a low lenticular shape normal to it (fig. 17). These are reasons for calling this a bank.

The fossil biota comprises agglutinate foraminifera (Gutschick 1962), fenestellid (Malone and Perry 1965) and ramose bryozoans, calcareous sponges (Gutschick and Perry 1959), a diverse brachiopod fauna (Rodriguez and Gutschick 1967), bivalves, snails, nautiloid and goniatite cephalopods, pelmatozoans including crinoids (Laudon 1973), holothurian sclerites, ostracods, conchostracans, trilobites (Chamberlain 1969), conodonts (Sandberg and Gutschick 1978), fish fragments, and calcareous tubes (*Spirorbis, Cornulites*). The sponge *Scaphiomanon* has wide distribution in this biofacies (fig. 25). Trace fossils, such as borings and burrows (Rodriguez and Gutschick 1970) and epibionts (Rodriguez and Gutschick 1975), have also been recorded and studied.

Oncolites from the Pilot, Leatham, and Sappington parts of the bank are shown in figure 26. Algal body fossils have not been observed except for the form *Renalcis* (Patrick Gleason pers. comm. 9/1/72) which may not be of algal origin. Filamentous tubes of blue-green algae, e.g., *Girvanella,* or possibly the reticulate thallous pattern of the red coralline algae, have not been preserved. Wavy accretionary laminations are roughly concentric around fossil nuclei making up the core of the nodules and epibiontic encrusting organisms can be found between layers (Rodriguez and Gutschick 1975). Fingerlike stromatolitic laminae are seen in the outer portion of nodules and have been found in situ in upward growth position (fig. 26F, I). The oncolites apparently do not exhibit a sediment-

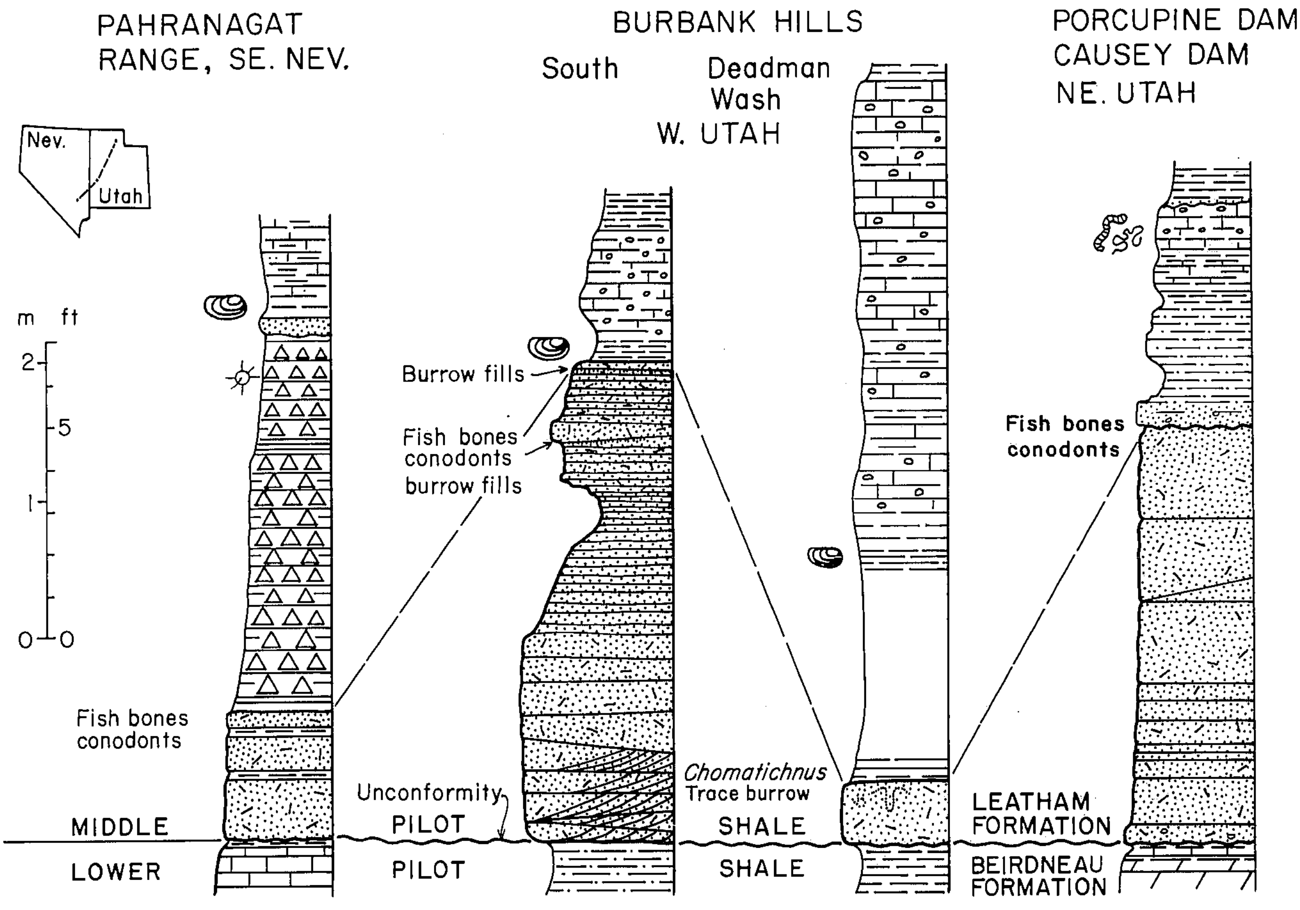


FIGURE 14.—Sections showing the basal sandstone of the lower black shale, middle member of the Pilot Shale and Leatham Formation.

trapping, layered characteristic of the mucilaginous blue-green algae.

The following distinct types of stromatolitic structure have been observed within oncolites throughout the distribution of the bank:

1. Accretionary concentric laminae about a nucleus, often whole or fragmentary shell cores, to form the oncolite which has the shape of the enclosing shell (figs. 26A, C, E, K). Mobility by rolling about on the bank is suggested by this form.
2. Oncolites with shell nuclei on which small stromatolite structures radiate outward to form the nodule. This form is more adapted to stationary development with growth occurring both laterally and upwards (fig. 26G).
3. Combinations of the above are common with concentric growth initially around the nucleus and digitate stromatolite radiation in the latter stage of oncolite development (figs. 26B and H).
4. Oncolites which exhibit considerable burrowing or boring activity by deposit-feeding organisms or shelter-seekers. This can take place within the shelled nucleus before algal encrustment (fig. 26C), during, or after oncolite growth—but before lithification (fig. 26J). Boring organisms prevail when the substrate is hard.

Oncolites may roll about in any stage either during or after their development but before burial. The shape of the shell nucleus, however, apparently influences movement. Those with small or rounded, easily dislodged shapes may exhibit a tendency toward concentric laminar structure (fig. 26C, E) while those with heavy, more irregular forms may tend toward stability and digitate growth (fig. 26F, G, I). Nodules with a history in which immobility dominates exhibit upward digitate growth clearly revealing this late stability (figs. 26F, I). Small tubercles representing the last convex laminae may be found on the surface of such nodules.

Brachiopods–Middle Pilot, Leatham, and Sappington Faunas

Leatham and middle Pilot brachiopod faunas of late Famennian age from Utah have been relatively unstudied. Ogden (1951), Holland (1952), and Hose (1966) published faunal lists but did not describe or illustrate the taxa. Comparatively more has been completed in equivalent strata of the adjacent areas. Johnson and Reso (1966) have published a paleontological study of a brachiopod faunule from the middle Pilot Shale in

FIGURE 15.—Trace burrow mound structure *Chomatichnus* sp. in cross-section from the sandstone bed at the base of the lower black shale unit, middle member of the Pilot Shale, section A, Burbank Hills, Millard County, Utah (Gutschick and Rodriguez 1977). Drawing is a sketch of the white sand burrow-fill and ejecta shown in the photo to the right; matrix sand is the darker color. Note the small burrow structure to the left of the main burrow (UND1277).

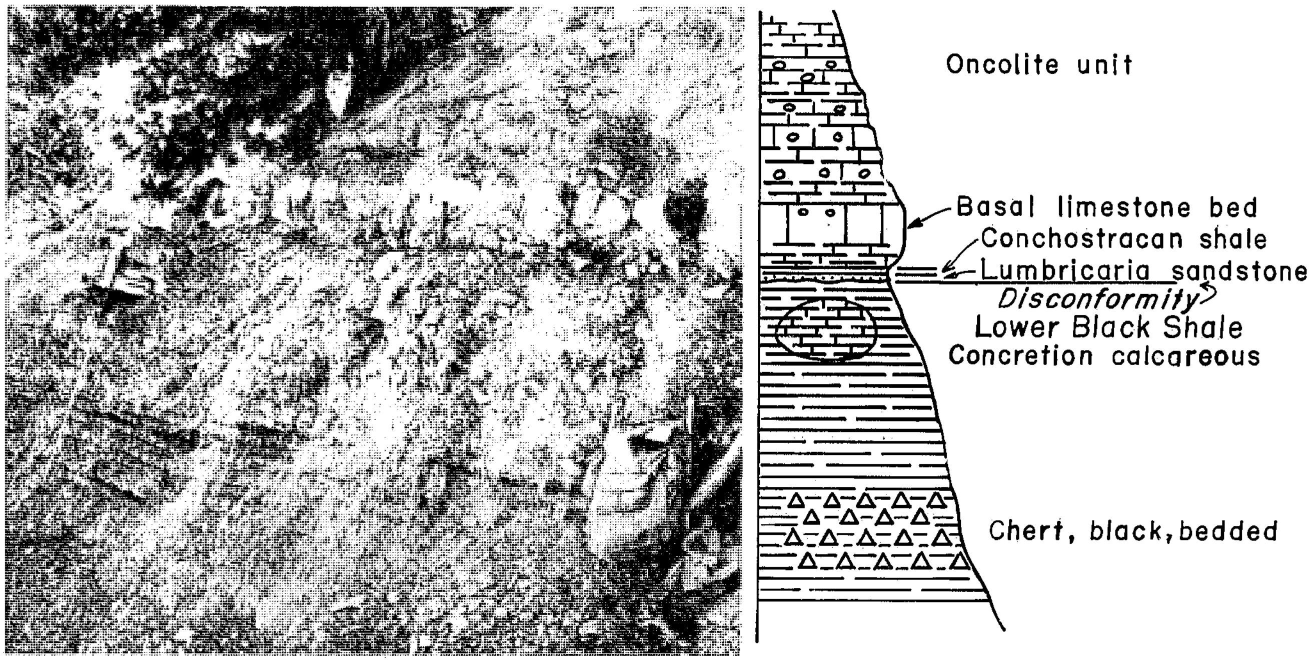


FIGURE 16.–Middle member of the Pilot Shale, section K, Confusion Range, Utah (7/12/70). Hammer near middle of photo marks the top of the lower black shale. Jacob staff on left is 1.5 m long.

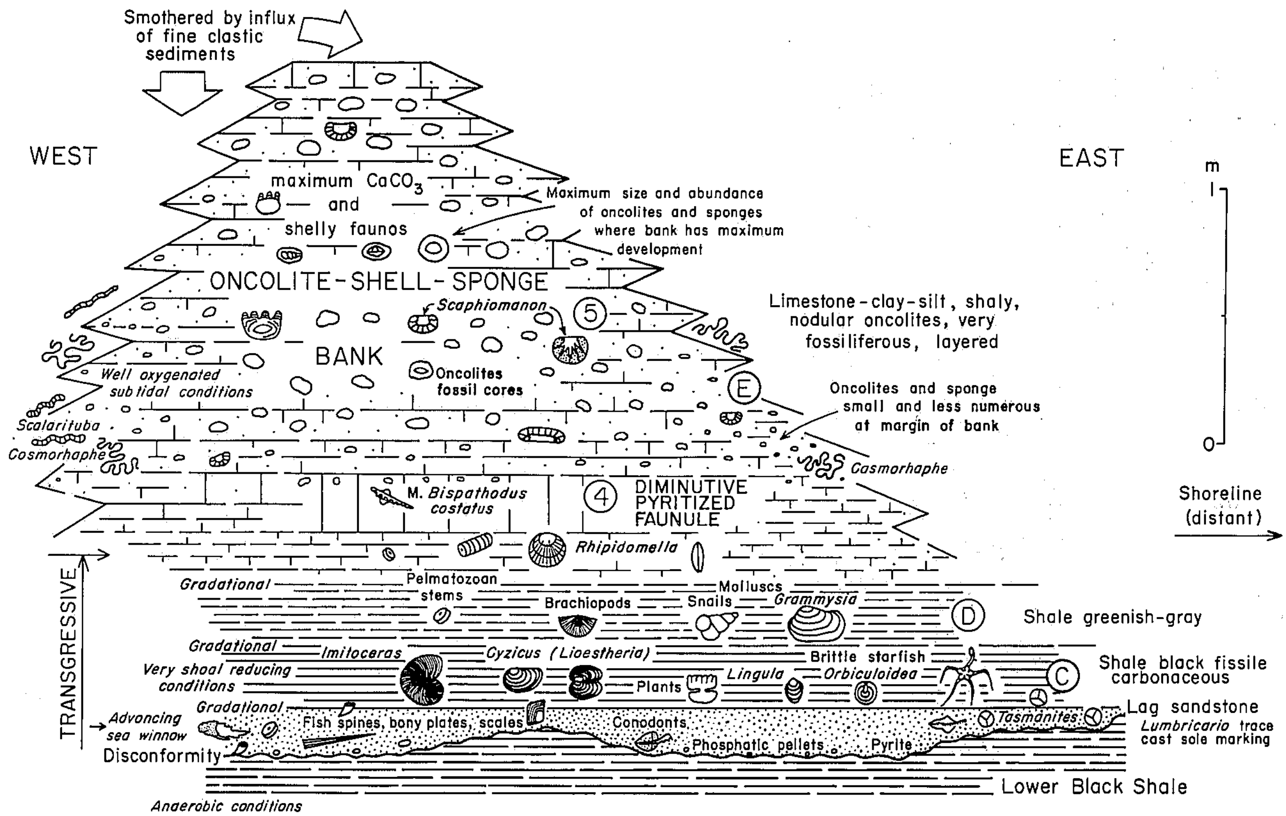


FIGURE 17.–Composite detailed reconstruction of a W-E section of the upper part of the middle Pilot Shale and equivalent units in the Leatham Formation and Sappington Member. A transgressive succession of rock units and fossil environments (anaerobic to dysaerobic to aerobic) are shown in passing from the unconformity on the lower black shale to the full development of the oncolite-shell-sponge bank.

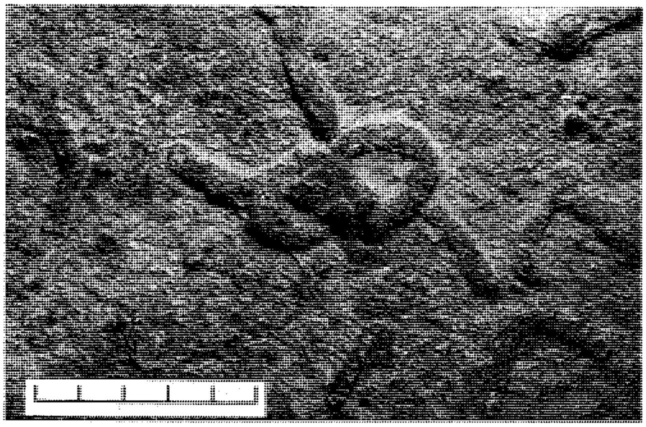


FIGURE 18.—The trace fossil *Lumbricaria* on the bottom of the lag-sandstone bed in the middle member of the Pilot Shale, section D-E, Confusion Range, Utah (UND1267). Scale in cm.

the Pahranagat Range of eastern Nevada; and Rodriguez and Gutschick (1967, 1975, 1978) have reported on Sappington brachiopods and aspects of the paleoecology of the Sappington (Montana), Leatham, and Pilot that have involved brachiopods. The latter studies are continuing.

The biostratigraphic distribution of the Leatham, middle Pilot, and Sappington brachiopod faunas is best described with reference to the conodont zonation framework (fig. 3) established by Sandberg and Poole (1977). These faunas overlie the *Cyrtospirifer* brachiopod zone—generally coincident with the *Scaphignathus velifer* conodont zone—of the Trident Member of the Three Forks Formation in Montana and the Beirdneau Formation and lower Pilot Shale of Utah. The dark shale and bedded cherts of the offshore Upper *Polygnathus styriacus* zone (Sandberg 1976), which constitute the lowermost beds of the Leatham, middle Pilot, and Sappington units, are generally devoid of benthic, shelled invertebrates. Above this, the lower dark shaly beds (unit C of the Sappington Member) carry the inarticulates *Lingula* and *Orbiculoidea*; these brachiopods, along with abundant and widespread conchostracans (figs. 17, 19, 21), suggest nearshore brackish, perhaps lagoonal, conditions. *Lingula* and *Orbiculoidea* continue to occur in the overlying strata but are not a dominant element of the higher faunas.

The brachiopods of the oncolite (algal bank) biostrome and overlying silty rocks constitute the *Syringothyris* assemblage zone. This sequence encompasses the beds overlying the inarticulate-bearing shales through the Middle *Bispathodus costatus* zone into the *Siphonodella praesulcata* zone. At Leatham Hollow, the basal 0.6 m of the algal nodule unit consists of a dark, coquinoid limestone (fig. 11B) containing a diminutive fauna which has been silicified and, in part, pyritized. It is composed primarily of brachiopods (fig. 27) but also includes tiny ectoprocts, orthoconic nautiloids, nepionic goniatites, gastropods, bivalves, *Cornulites* and *Spirorbis* tubes, pelmatozoans, holothurian sclerites, and conodonts. Many fossils are algal coated, and small oncolites are also present. The biota, which includes the Middle *Bispathodus costatus* conodont fauna, is similar to that of the overlying oncolite beds. Silicification appears to have "frozen" the skeletal size-frequency distribution which is strongly positive-skewed. The small size of the shells is interpreted as representing juveniles rather than any environmental stress which might have stunted the growth. Immaturity is indicated by the absence of growth rings on the tiny brachiopod shells and the presence of attachment rings on the productoids. The possibility that the young shells were sorted during transport is ruled out since the shells are articulated, unabraded, and retain delicate structure. Similarly, there is no evidence of shell malformation or dwarfing such as would be required if the shell size were related to environmental stresses like oxygen deficiency. Rather, it appears that a carryover of the environmental regime present during deposition of the underlying dark conchostracan muds continued into these beds for short but frequent periods of dysaerobic and possibly brackish-water conditions. In the resulting situation, despite successive attempts to colonize the bottom through settlement by invertebrate larvae from nearby well-oxygenated environments, few individuals reached maturity.

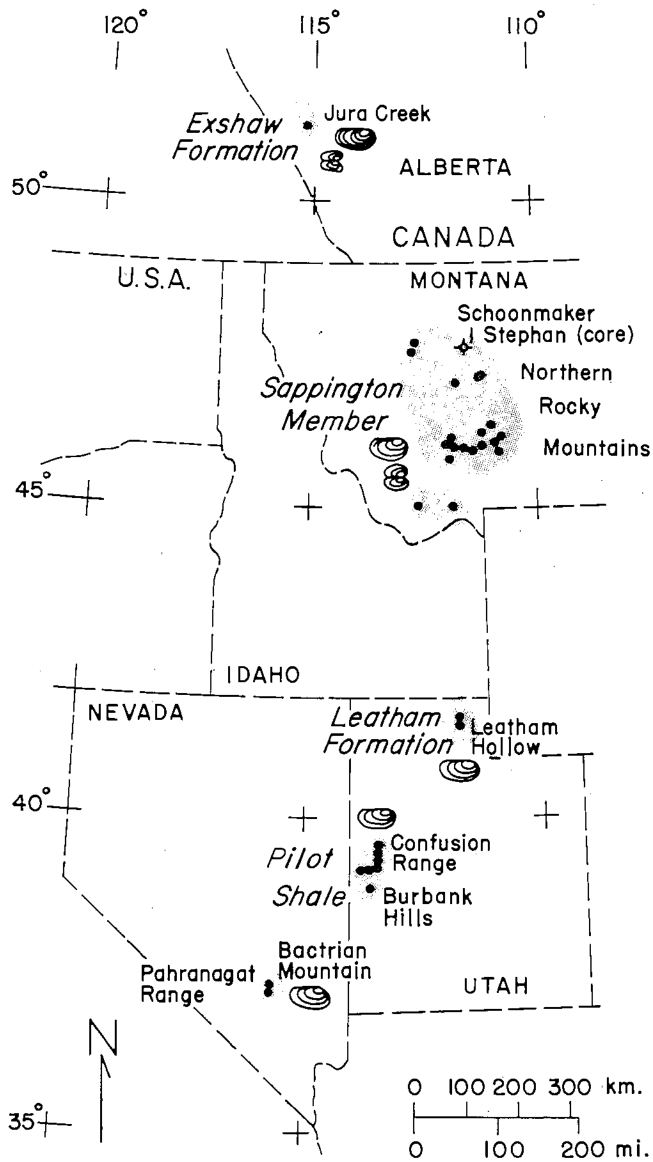


FIGURE 19.—Distribution of the conchostracan dark shale zone in the middle member of the Pilot Shale, Leatham, Sappington, and Exshaw biofacies. Compare with figure 13.

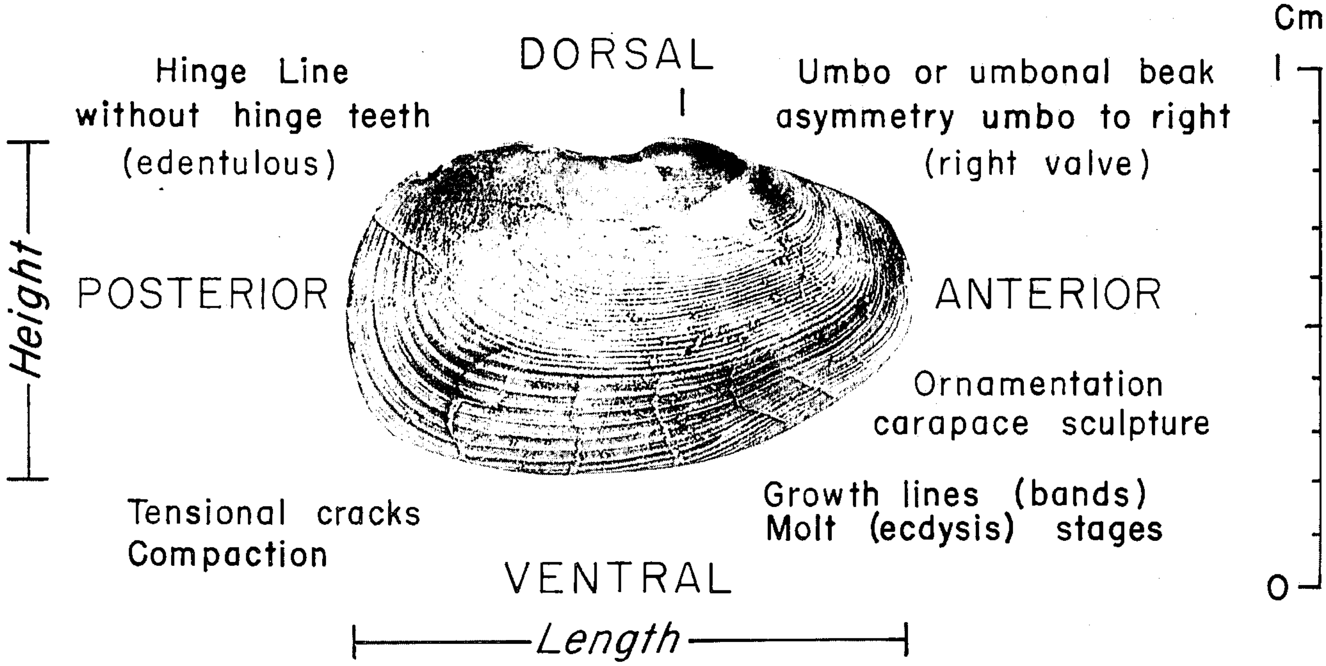


FIGURE 20.–Right valve of the conchostracan *Cyzicus* (*Lioestheria*) sp. from the *Syringothyris* zone at Bactrian Mountain, Nevada. This form is characteristic of the conchostracan shale biofacies.

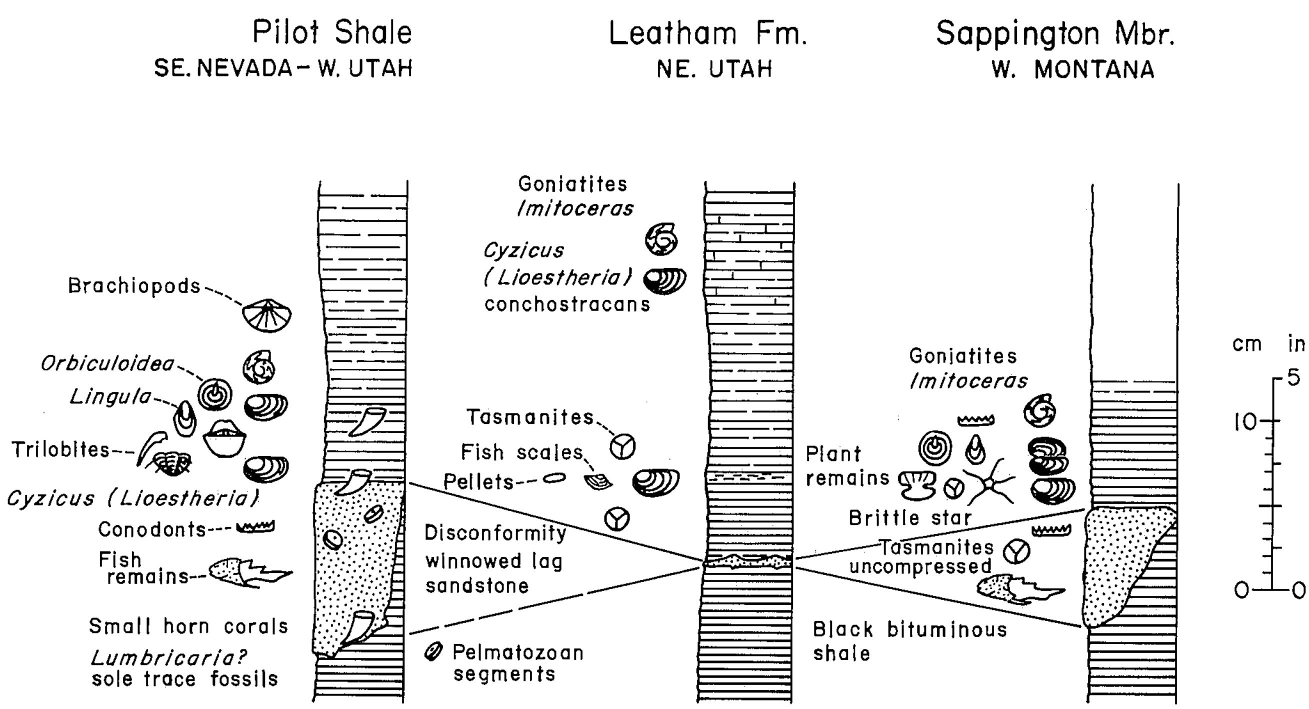


FIGURE 21.–Details of fossil associations in the lag sandstone and conchostracan shale, middle member of the Pilot Shale, Leatham Formation, and Sappington Member from southeastern Nevada to western Utah to western Montana.

The Leatham Formation is represented by a single dark-gray, fossil-fragmental limestone unit (0.7 m thick) in the Broad Canyon section, Stansbury Island (Sandberg and Gutschick 1978). This isolated occurrence is approximately halfway between the Leatham type area in the Bear River Range and the Pilot Shale of the Confusion Range. *Rhipidomella missouriensis* is the most common brachiopod in the limestone bed associated with "*Spirifer*," *Composita, Crurithyris, Philhedra,* the tetracoral *Michelinia,* and conodonts of the Middle (?) *Bispathodus costatus* zone. The limestone does not have oncolites at this locality.

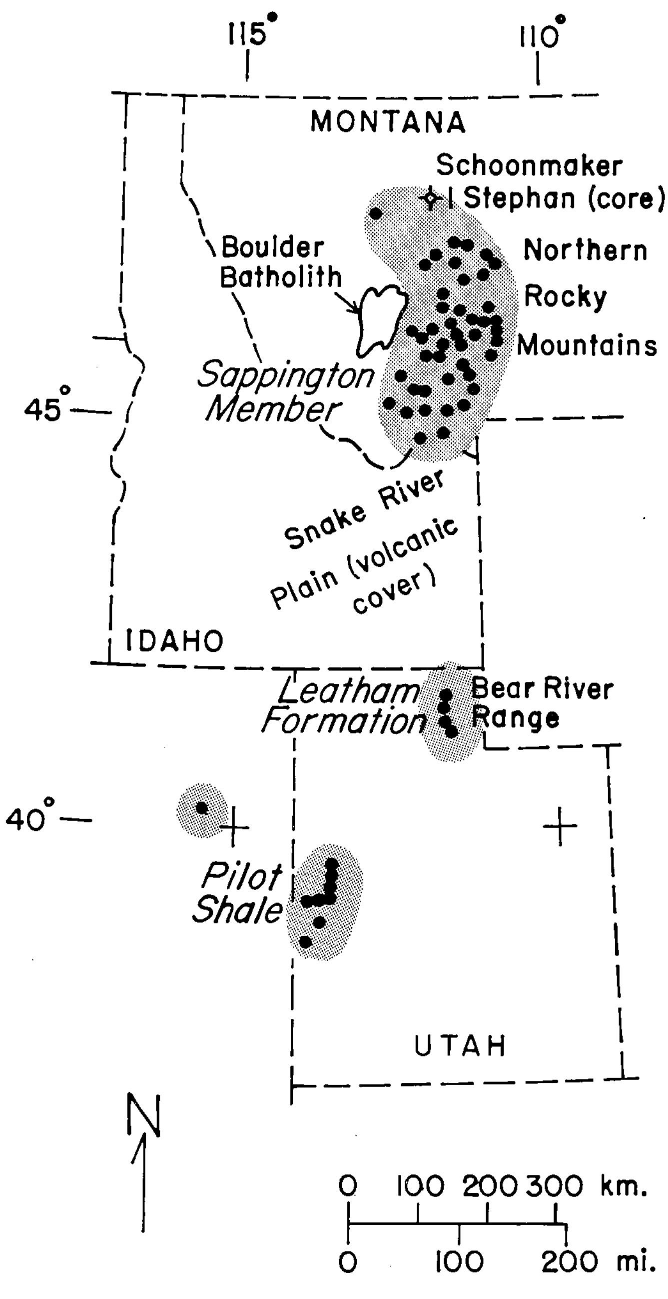


FIGURE 22.–Map showing the extent of the oncolite bank in the middle member of the Pilot Shale, Leatham Formation (units 4 and 5), and Sappington Member (unit E).

Higher beds within the oncolite biostrome unit carry the full *Syringothyris* assemblage zone. In all, 14 superfamilies have been recorded by us from these rocks (fig. 28). However, no one rock unit contains all of them. Although there is variation in composition and dominance of the faunas between the areas of outcrop, the Leatham, middle Pilot, and Sappington have seven brachiopod genera in common (fig. 29). These are *Rhipidomella, Schuchertella, Retichonetes, Rhytiophora* (fig. 30), *Syringothyris* (fig. 31), "*Spirifer,*" and *Crurithyris.* The genus *Tylothyris* is a possible eighth member of this group, but only a single flattened specimen, questionably of this genus, has been collected from middle Pilot rocks. The Sappington is most diverse with all superfamilies except the Reticulariacea represented; the Leatham contains 12, and the middle Pilot, 10. The Spiriferacea are best represented with *Syringothyris,* "*Spirifer,*" and *Crurithyris* present in all three units.

The most striking and significant difference in the faunas appears to lie in the apparent absence of craniaceans and strophalosiaceans in the middle Pilot. These two superfamilies, each represented by numerous specimens of the craniaceans *Acanthocrania* and *Philhedra* and the strophalosiaceans *Heteralosia* and *Leptalosia* in both Sappington and Leatham strata, have not been recorded from western Utah and eastern Nevada. On the other hand, the middle Pilot does contain a large productoid tentatively assigned to *Orbinaria* (fig. 32), which is not found in the Sappington, and a *Reticularia*? (fig. 33), which is not found in either the Leatham or the Sappington. This may reflect somewhat lower energy levels in whatever periodic water movement might have occurred as the craniaceans and one of the strophalosiaceans lived firmly cemented to other shells.

At the generic level (fig. 29) the Sappington, as expected, is most diverse, with some 20 genera, and the Leatham and middle Pilot have 17 and 14 respectively. Sixteen genera are common to the Sappington and Leatham; 10 to the Sappington and middle Pilot, and 10 to the Leatham and Pilot. The seven genera cited above are common to all three units. Inter-

FIGURE 23.–Middle Pilot oncolite unit, section B, Confusion Range (8/16/67). Hammer in lower left side of photo provides a scale.

estingly, there is significant variation in equitability as well as numbers of genera. The Productacea, for example, are represented by large numbers of *Rhytiophora* in Sappington and Leatham faunas, whereas the large *Orbinaria* is dominant in the middle Pilot in the Confusion Range. Similarly, *Rhipidomella,* the craniaceans and strophalosiaceans, and the spiriferaceans are abundant in Montana and the Bear River Range, but, aside from *Syringothyris,* these forms are much less common in the Confusion Range. There, the middle Pilot carries numerous chonetids and reticulariaceans, especially in siltstone beds near the top of the unit.

The occurrence of the enteletacean *Schizophoria* is of particular interest. Composing at least half of the individual brachiopods collected at Spring Hollow, it is very scarce at other Leatham exposures, and only a single specimen has been found in the middle Pilot (Rodriguez and Gutschick 1978). We have interpreted this form as a new species, *S. williamsi* (in press) and believe that it may have evolved from *S. australis* of the Percha and Ouray formations, thus suggesting at least a brief marine connection to the south and east. The species abundance in this shallow-water setting must be explained in the light of *Schizophoria*'s customary pre-Famennian occurrence in beds deposited in offshore environments. Offshore species may temporarily dominate nonfluctuating, quiet-water, nearshore, muddy environments (Bretsky 1968), and could be what we are seeing here. Alternatively, the occurrence of large numbers of individuals of a species might suggest that the species was opportunistic. However, although *S. williamsi* meets many of the criteria for identification of opportunists established by Levinton (1970), it does not appear to be eurytopic as is characteristic of opportunists.

Nonbrachiopod Oncolite Fauna

As in the case of the brachiopods, the other fossils which make up the fauna of the oncolite bank have not been described for the Pilot Shale. Brief faunal lists have been given by Ogden (1951), Johnson and Reso (1966), and Hose (1966) but collectively they are incomplete. Some of the characteristic forms which occur as nuclei of oncolites are shown in figure 34. Fossils also occur in matrix rock exclusive of algal coatings or oncolite formation.

Upper Member

In many respects the upper member of the Pilot Shale resembles the lower member in the dominance of fine clastic sediments and paucity of invertebrate fossils. In most areas the base of the member is gradational above the oncolite bank beds; however in a few places, channels have been cut into oncolite bank strata below (Little One and One-half Mile Canyon section) and down through them onto the lower black shale (LE section, fig. 7). Where the contact is gradational, the basal beds are either dark organic silty shales or calcareous siltstones and silty shales with an abundance of the vermicular traces *Cosmorhaphe* and *Scalarituba.*

The main body of rock in the member is dominated by slope-forming silty shale and subdued step-forming siltstone beds. Occasional cross-bedded channel sandstone lenses with burrow traces and conodonts occur in the Confusion Range. Invertebrate fossils are more common in the Bactrian Mountain section than they are in the Confusion Range. In southeast Nevada brachiopods (*Lingula,* spiriferids, and productoids), fenestellid bryozoans, trilobites, shrimplike arthropods, sponge

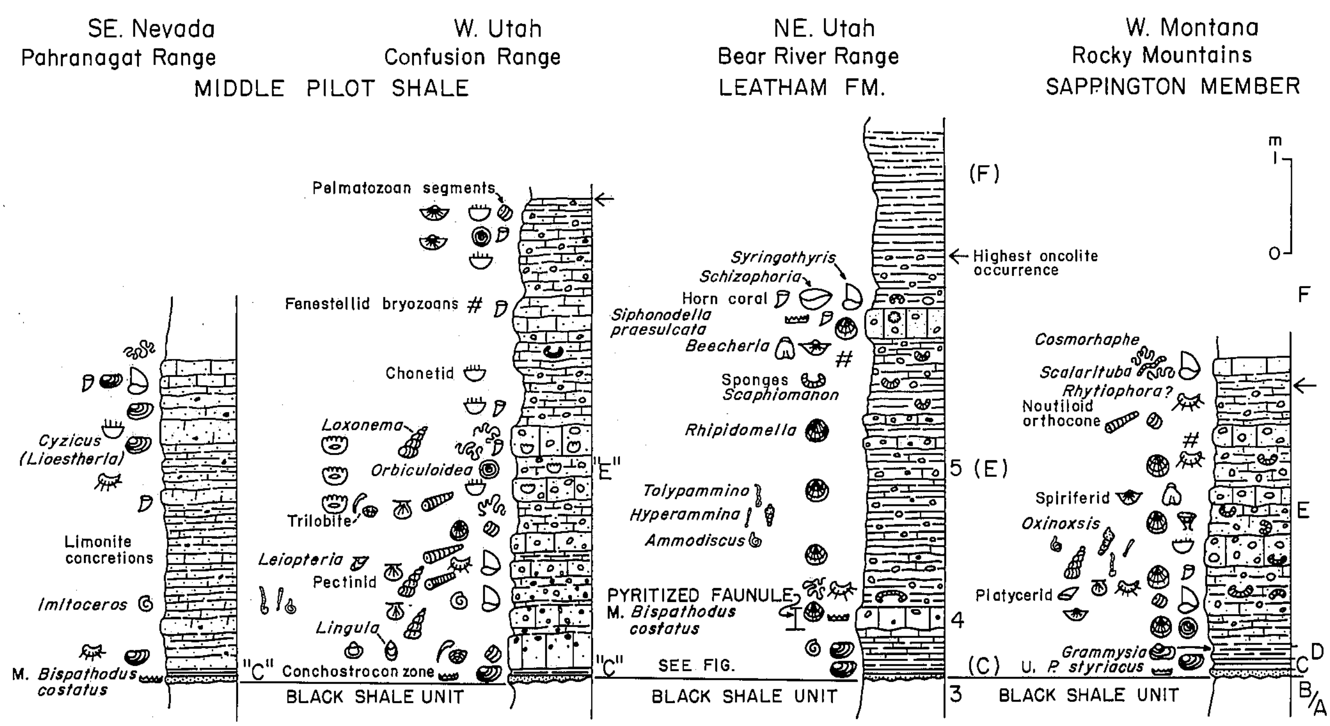


FIGURE 24.–Representative section of oncolite bank unit and equivalent strata in the middle member of the Pilot Shale, Leatham Formation, and Sappington Member from southeastern Nevada to western Montana.

spicules and spiculites, and *Cosmorhaphe* traces occur in the thick upper member sequence. Otherwise the faunas are scarce and preservation is poor.

The top of the Pilot Shale shows evidence of truncation in the Confusion Range. The upper member appears to be missing in the western part of the basin, except for the south Ruby Range section, probably because of Antler uplift and pre-Joana limestone erosion.

Syringothyris occurs at the top of unit 6 in the Leatham Formation and unit F in the Sappington, suggesting their correlation with the middle member of the Pilot Shale. Some question exists concerning the relation of unit 7 of the Leatham Formation and units G and H of the Sappington Member with the Pilot Shale. In the absence of fossils with which to establish their age, they are tentatively correlated with the lower part of the upper member of the Pilot Shale.

Basal Joana Sandstone

Differential uplift caused by the Antler orogeny during Early Mississippian time resulted in erosional truncation of the top of the Pilot Shale, which was followed by deposition of a pink, quartzitic sandstone unit which is unconformable on the Pilot Shale. Trace fossils are abundant in these sandstone beds and include *Chondrites, Pilichnia, Lanicoidichna,* U-shaped burrow tubes, and other forms (Gutschick and Rodriguez 1977). The sandstone beds grade rapidly upward into carbonate beds of the Joana Limestone (fig. 5).

DEPOSITIONAL HISTORY OF THE PILOT SHALE AND SOME CORRELATIVE STRATA

The succession of marine faunas and floras play an important role in deciphering the depositional cycle of the Pilot Shale in relation to the Antler orogeny. Conodont faunas are invaluable for establishing the chronology and, together with body fossils and trace fossils in the clastic units, are useful for environmental interpretation. Repeated upwarp and erosion punctuate the sequence with unconformities and overlying lag-sandstone units. Dark organic source-bed rocks reflect restricted anaerobic basinal conditions. Very thin stratigraphic units in the middle member of the Pilot Shale have remarkably wide geographic distribution and represent synchronous, or at most, very slightly diachronous deposits.

The Pilot Shale is the consequence of the major Antler orogenic activity along the western margin of the Late Devonian continent (Johnson 1971, Poole 1974). The sedimentary response to the pulses of tectonism is reflected in the predominantly clastic Pilot sequence which is bracketed between Guilmette–West Range carbonate rocks below and the overlying Joana Limestone (fig. 3). A graphic summary of the time-rock units and their environmental interpretation is provided in figure 35.

Initial Antler deformation in the form of compressional flexure folding produced a slowly subsiding, elongate, foreland Pilot basin to the east (fig. 1) between a marginal rising land area to the west and the cratonic platform east of the basin. At the end of Frasnian time and during the early Famennian, fine clastic sediments from the western source area slowly spread over the irregular basin floor. Subsidence exceeded sediment influx in the western part of the basin, and periods of starved sedimentation conditions, coupled with restricted circulation, deposited sediments below oxygen minimum levels. Meanwhile, carbonates continued to be deposited to the southeast. At about this same time to the northeast in Utah, the Stansbury uplift was locally shedding coarse conglomerate and sandstone (Rigby 1969). The eastern part of the basin in the area of the Confusion Range became a depocenter during accumulation of the lower Pilot. Groove casts along the undersides of sheet channel siltstones also indicate a Stansbury sediment source to the northeast.

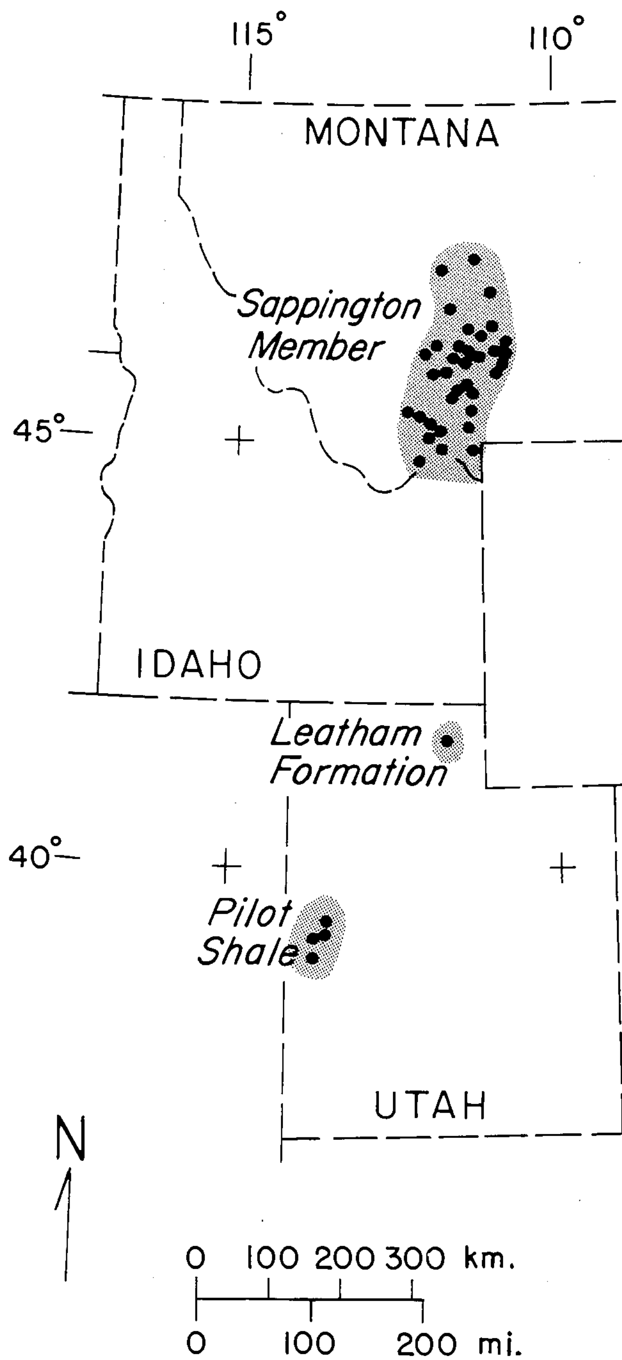


FIGURE 25.—Map showing the known distribution of the sponge *Scaphiomanon* in the middle member of the Pilot Shale, Leatham Formation, and Sappington Member within rocks of the oncolite bank unit.

On the basis of the type of sediments, sedimentary structures, and paleontology, a neritic zone environment is suggested for the lower Pilot Shale. The sequence contains turbidite and debris flow units, convoluted layers, sedimentary breccias, dark organic units, and sheet channel layers with groove casts, all within a fine clastic succession. The faunas are dominated by trace fossils and nektoplanktic conodonts. Shelly fossils are rare except for a few thin echinoderm-brachiopod debris flow layers.

Lower Pilot deposition closed with differential Antler epeirogenic uplift of the basin, resulting in extensive erosion. This tectonism may represent the onset of development of the Roberts Mountains Thrust. Middle Famennian deposits are missing in the study area; however, carbonates of this age are present in the shallow-water Pinyon Peak Limestone and Beirdneau Formation to the east and northeast.

Middle Pilot sediments were deposited on a pronounced unconformity, and this same erosional surface is present at the base of the Leatham, Sappington, and Exshaw sequences (figs. 3, 13, and 14). After elevation and erosion of the lower Pilot basin sediments, another surge of the Antler orogeny caused downwarp of the Pilot basin, thereby enabling deposition of the extensive lower black shale of the middle Pilot. Problems in

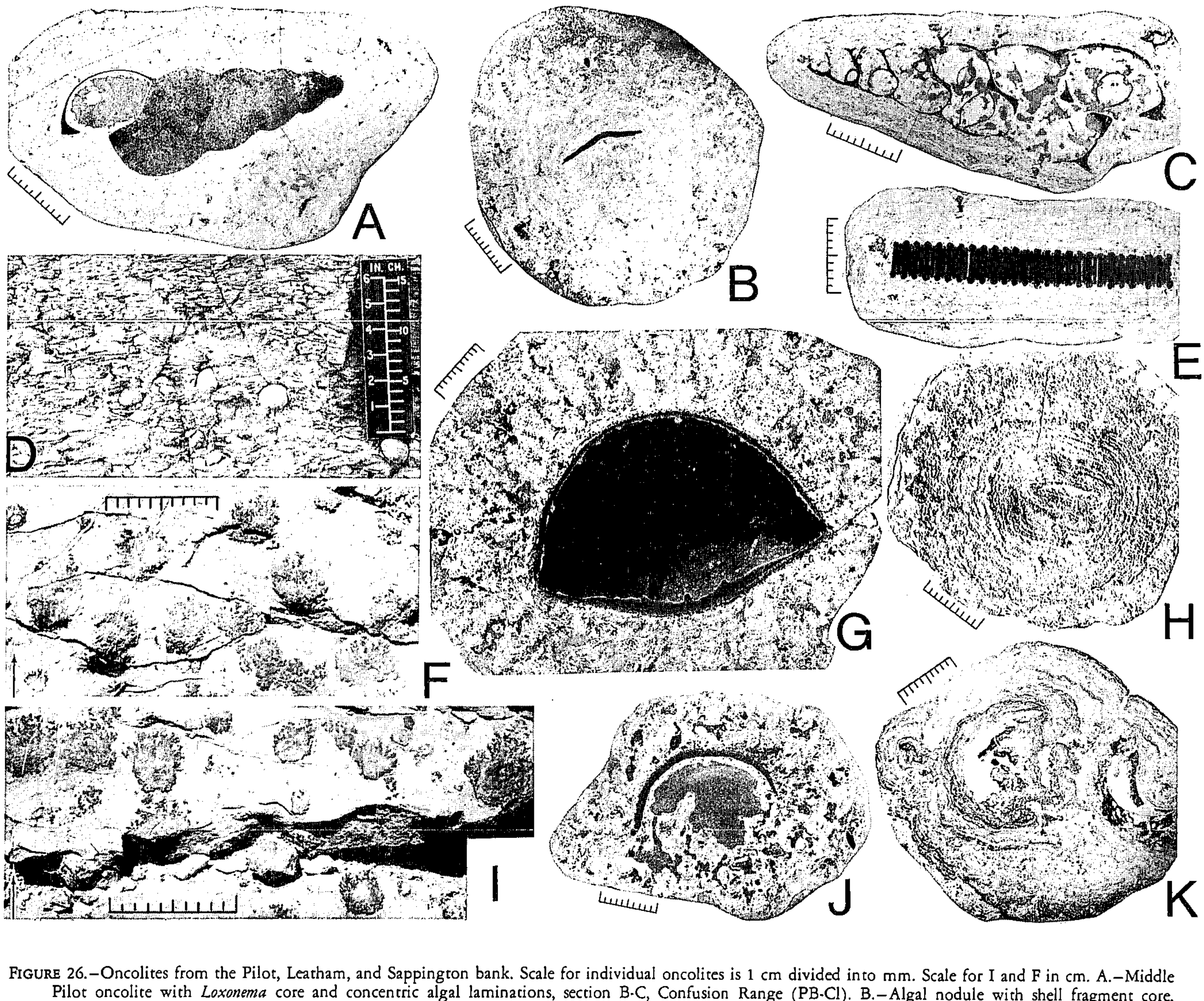


FIGURE 26.–Oncolites from the Pilot, Leatham, and Sappington bank. Scale for individual oncolites is 1 cm divided into mm. Scale for I and F in cm. A.–Middle Pilot oncolite with *Loxonema* core and concentric algal laminations, section B-C, Confusion Range (PB-Cl). B.–Algal nodule with shell fragment core, accretionary growth layers, and outer digitate stromatolite growth, Ledger Canyon, Confusion Range (PLE7). C.–*Loxonema* core in oncolite, Sappington unit E, Ashbough Canyon, Blacktail Range, Montana. The shell material is partly preserved and encloses burrowed lime mud. Concentric laminar overgrowth parallels the shape of the snail, thereby controlling oncolite form (BAB5). D.–Nodular oncolites weathering out of matrix rock, middle member of the Pilot Shale oncolite zone, Confusion Range. E.–Articulate pelmatozoan stem segment enveloped by wavy accretionary layers into a nodular peanut-shaped oncolite. F, I.–Algal nodules in situ with upward digitate growth, oncolite zone, middle member of the Pilot Shale, section TU, Confusion Range. G.–*Schizophoria* shell with clear calcite fill and radial digitate outward growth. Note minimum or lack of concentric growth on shell, Spring Hollow section of the Leatham Formation, unit 5 (SHE3). H.–Natural differential weathering etch pattern on oncolite cross-section exposed along a joint surface, Sappington, unit E, Grendah Mountain, Little Belt Mountains, Montana. Note the similarity to Pilot oncolite B. J.–Shell fragment with algal overgrowth disrupted by burrowing organism(s); dark pattern is fine lime mud filling labyrinthic burrows. Digitate stromatolite laminations are still preserved in part of the oncolite, east Monarch section, Little Belt Mountains, Montana (Msem6).

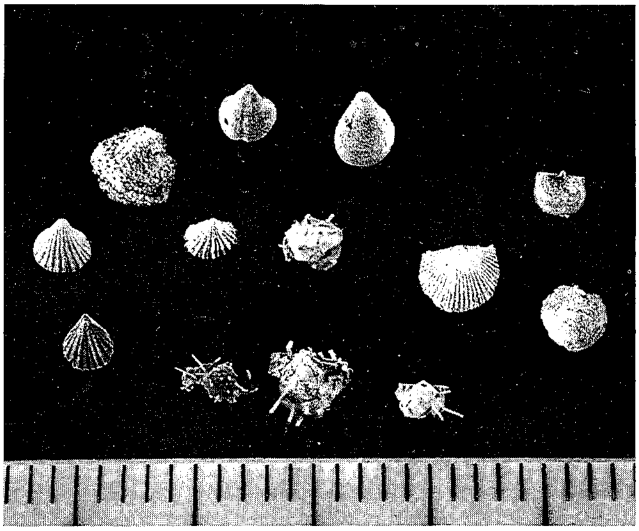


FIGURE 27.—Silicified brachiopods from the diminutive (juvenile) fauna of the lowermost oncolite beds at Leatham Hollow. Note attachment ring in spiny *Orbinaria,* lower right.

the interpretation of this depositional cycle include (1) The lower black shale of the Pilot basin is restricted to a narrow belt from the Pahranagat Range, southeastern Nevada, to the Confusion Range, western Utah; however, there is a single isolated section in the south Ruby Range in Nevada which needs explanation (figs. 12, 37); (2) there is no western Pilot basin flysch counterpart to reflect a sediment source in the Antler Highlands; and (3) an explanation is needed to account for the origin of such widespread deposition of reduced fine, dark, organic sediments, without a phosphate component, along the Cordilleran geosyncline.

Initial downwarp of the basin at the onset of middle Pilot sedimentation was accompanied by extensive deposition of clean lag sands and winnowed fossil debris, which is manifested as a thin, somewhat discontinuous, blanket layer with thicker channel and bar sedimentation units on the irregular erosional surface (figs. 13, 14). The burrow mound *Chomatichnus,* probably formed by some shrimplike organism, is associated with this basal sandstone unit (fig. 15). Accelerated subsidence of the basin deepened it enough to establish anoxic conditions below the oxygen minimum level.

The shale unit is dark colored and contains dark, layered chert beds or silicified shale, large calcareous concretions, and

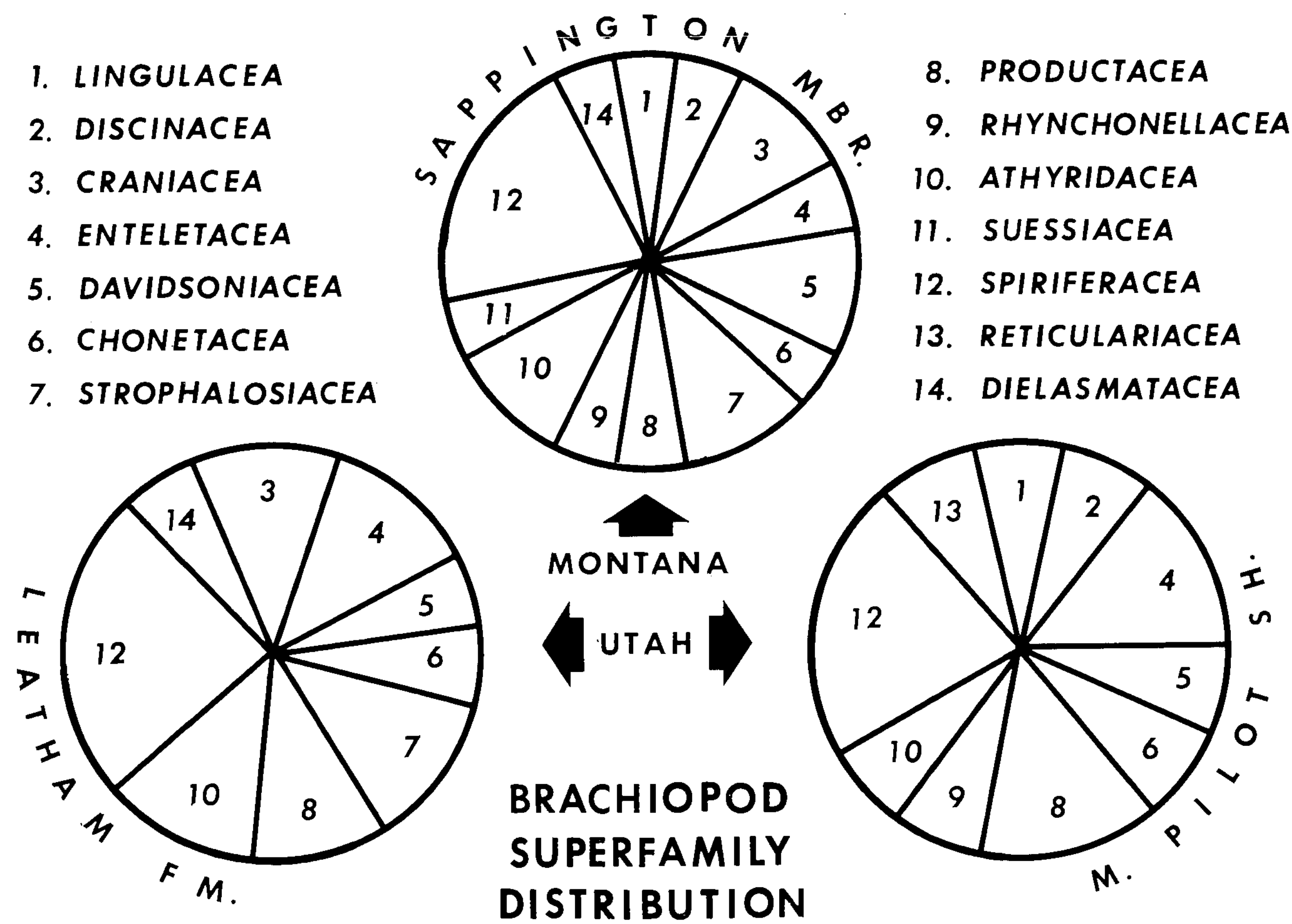
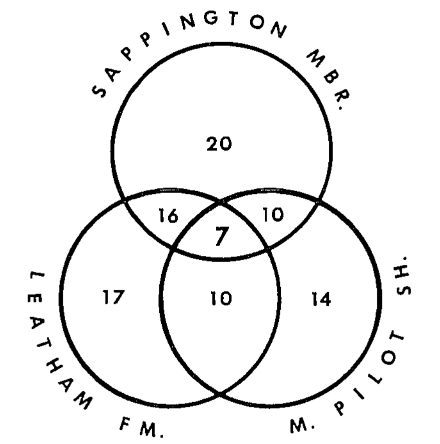


FIGURE 28.—Distribution of brachiopod superfamilies among the Leatham (Bear River Range, Utah), middle Pilot (Confusion Range, Utah), and Sappington Member, Three Forks Formation (southwestern Montana).



DIVERSITY AND OCCURRENCES IN COMMON OF BRACHIOPOD GENERA

FIGURE 29.—Diversity and occurrences in common of brachiopod genera in the Leatham, middle Pilot, and Sappington rock units. Number of genera in common are shown in the areas of overlap between the circles. Note that seven genera are common to all three units.

pyrite, reflecting conditions inhospitable to benthic shelled organisms. The only fossils recognized are planktic radiolarians and conodonts along with sponge spicules and finely comminuted organic matter. Phosphorite deposits common to this facies were apparently not deposited. In the meantime, a carbonate platform was located to the east, where shallow-water limestones of the upper member of the Pinyon Peak and basal Fitchville were being deposited.

West of the carbonate platform, the black shale was deposited in a basin deep enough to establish anaerobic conditions. If sedimentation rates indicated by Sandberg and Poole (1977) are applied (fig. 36), it cannot be regarded as a starved basin. Taking their figures for the thickness of the lithosome, the rate is calculated to be between 10 and 80 m/m.y. Perhaps a significant factor in this high rate is the contribution of silt washed in from the Antler Highlands to the west and possibly some bypassed material from the cratonic platform to the east.

Oxygen minimum levels may have been established by restriction of circulation in the late Famennian sea. It is always a temptation to relate this to barred basin conditions; however the paleogeography and bathymetry of this sea have not been established with any confidence. The problem is related to the contemporaneous widespread deposition of black shales around the craton, e.g., Besa River–Exshaw–Bakken, Sappington, Lea-

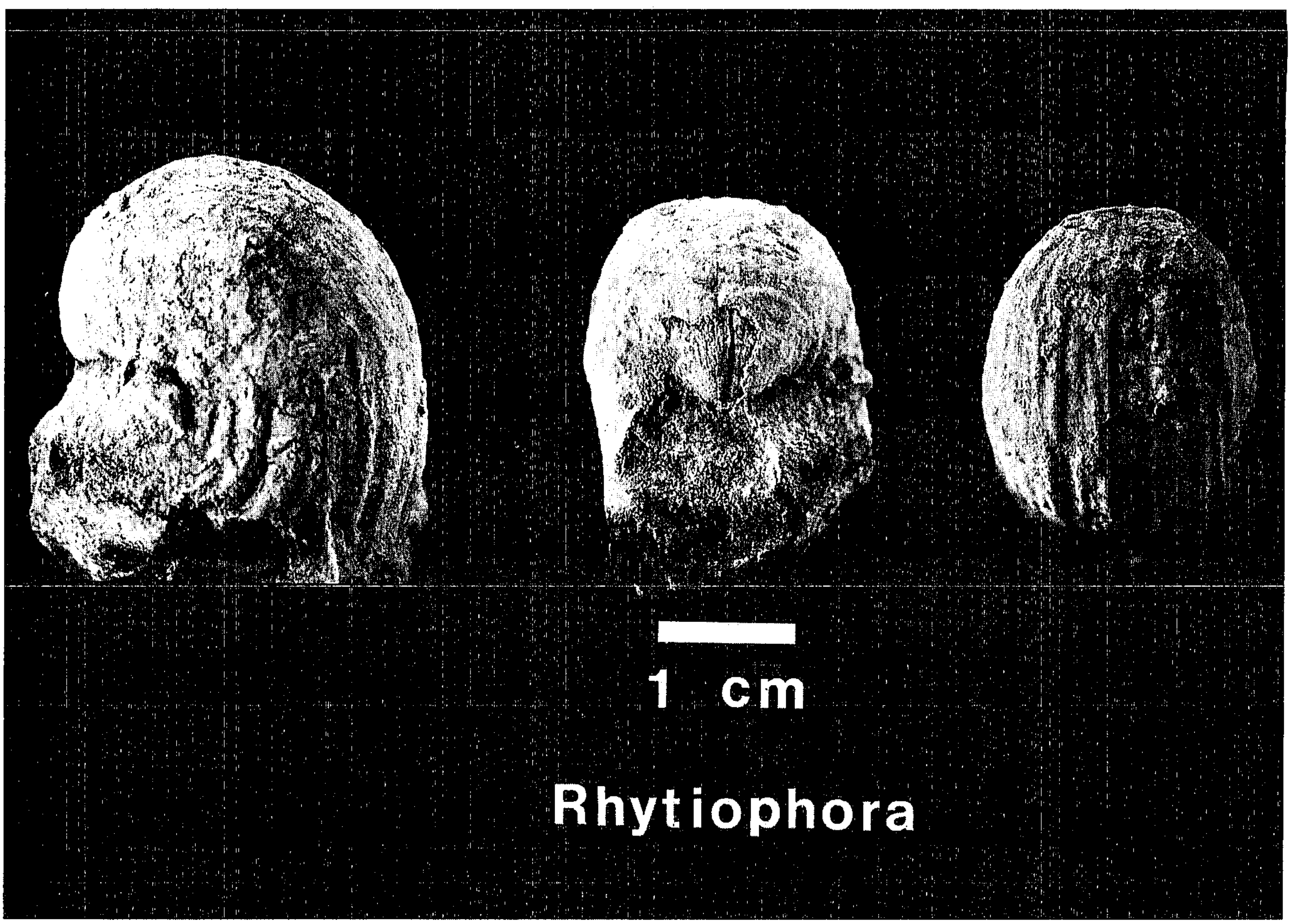


FIGURE 30.—*Rhytiophora arcuata* (Hall), a productoid brachiopod common to middle Pilot, Leatham, and Sappington strata. Lateral, posterior, and anterior views.

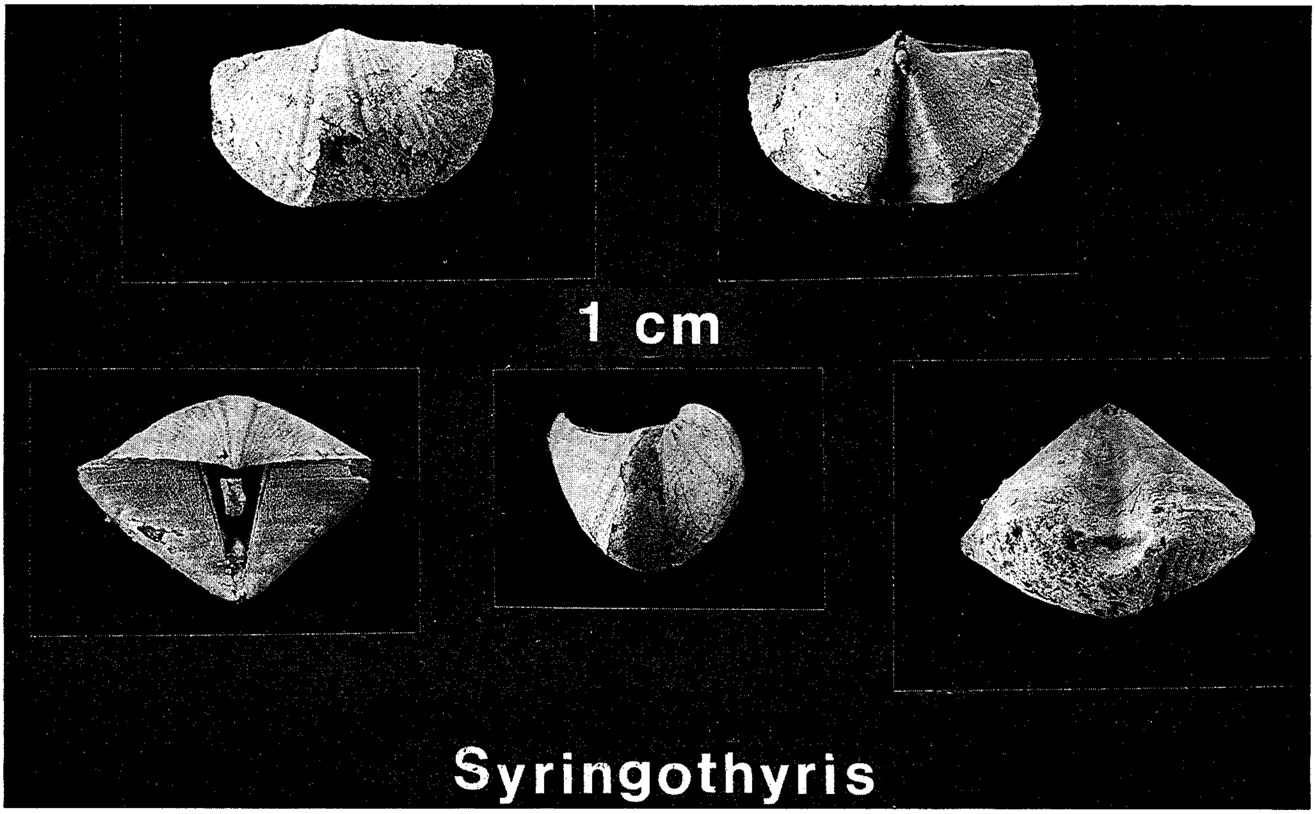


FIGURE 31.—*Syringothyris hannibalensis* (Swallow) from the middle member of the Pilot Shale, Leatham, and Sappington rocks. Dorsal, ventral, posterior, lateral, and anterior views of a silicified Pilot specimen.

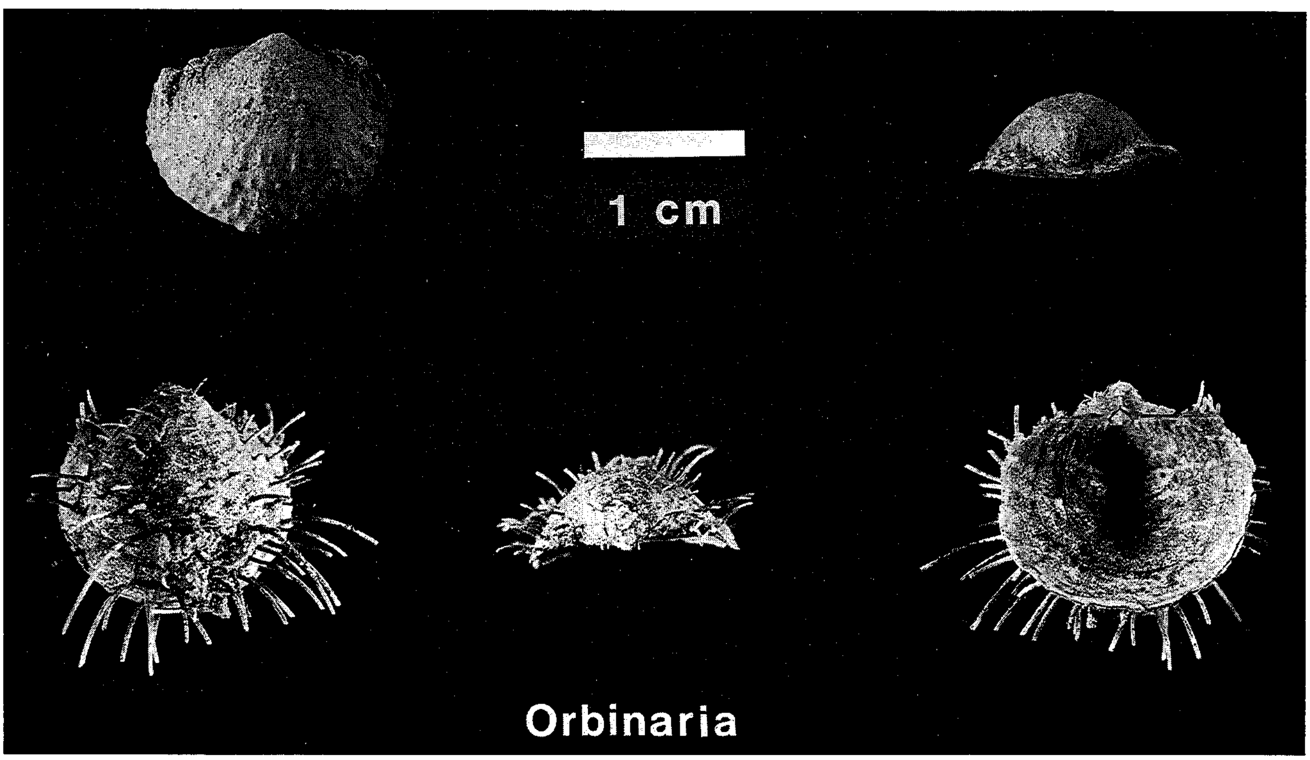


FIGURE 32.—*Orbinaria* from the Pilot Shale and Leatham Formation. Ventral and posterior views above; ventral, anterior, and dorsal views below.

tham–Middle Pilot–Slaven, Woodford-Caballos Novaculite–Arkansas Novaculite, New Albany, Ohio, and Chattanooga (Gutschick and Moreman 1967). Recently Berry and Wilde (1978) have suggested that early Paleozoic seas were more anoxic and less ventilated, with oxygen limited to very shallow depths. Ventilation was regulated in large measure by glaciation, with fresh, oxygenated cold water down-welling from polar areas; thus Late Devonian equatorial tropical conditions (fig. 2) produced only shallow ventilation of the seas. This idea needs to be more thoroughly explored for the Late Devonian.

Following deposition of the black shale unit and basin filling, another episode of moderate epeirogenic uplift took place. It resulted in a widespread surface of erosional discontinuity followed by the incursion of a shallow-water transgressive sea (fig. 17). The initial role of this marine sheetwash was to rework, winnow, and spread a very thin (<.25 m) blanket of sandstone over the flat, slightly irregular surface similar to that of the *Chomatichnus* sandstone (compare figs. 11C and 15). This post-black shale lag sandstone carries fish remains, conodonts, *Tasmanites* (fig. 11D), and sole traces of *Lumbricaria* (figs. 16, 18) and can be recognized at this stratigraphic position from southeastern Nevada to northwestern Montana.

Following in rapid succession is a blanket pall of black mud spread out in very shallow water. It is represented by unit C of the Sappington Member and its equivalent unit in the Leatham Formation and middle member of the Pilot Shale. This conchostracan-bearing shale (figs. 17, 19) is thin with a wide geographic distribution. Conchostracans, ubiquitous in this shale, are today commonly associated with fresh or brackish water at very shallow depths. Marine fossils associated with the conchostracans include brittle starfish, inarticulate brachiopods, and goniatite cephalopods in these rocks. In places the conchostracans have been found with their delicate articulation intact. Quiet reducing conditions in shallow water are indicated—perhaps an algal flotant restricted oxygenation of the muds in a brackish-water environment.

A third biofacies, unit D, is present in Montana. It marks the change from anaerobic to aerobic conditions of mud deposition that continued with marine transgression into development of a subtidal marine oncolite bank and shell community habitat (fig. 17, unit E). The sponge-bearing oncolite bank is common to the middle Pilot, Leatham, and Sappington stratigraphic units (figs. 22, 25). There may be some differences in the bank related to distance offshore and the amount of energy over it; they are reflected in the growth patterns of the

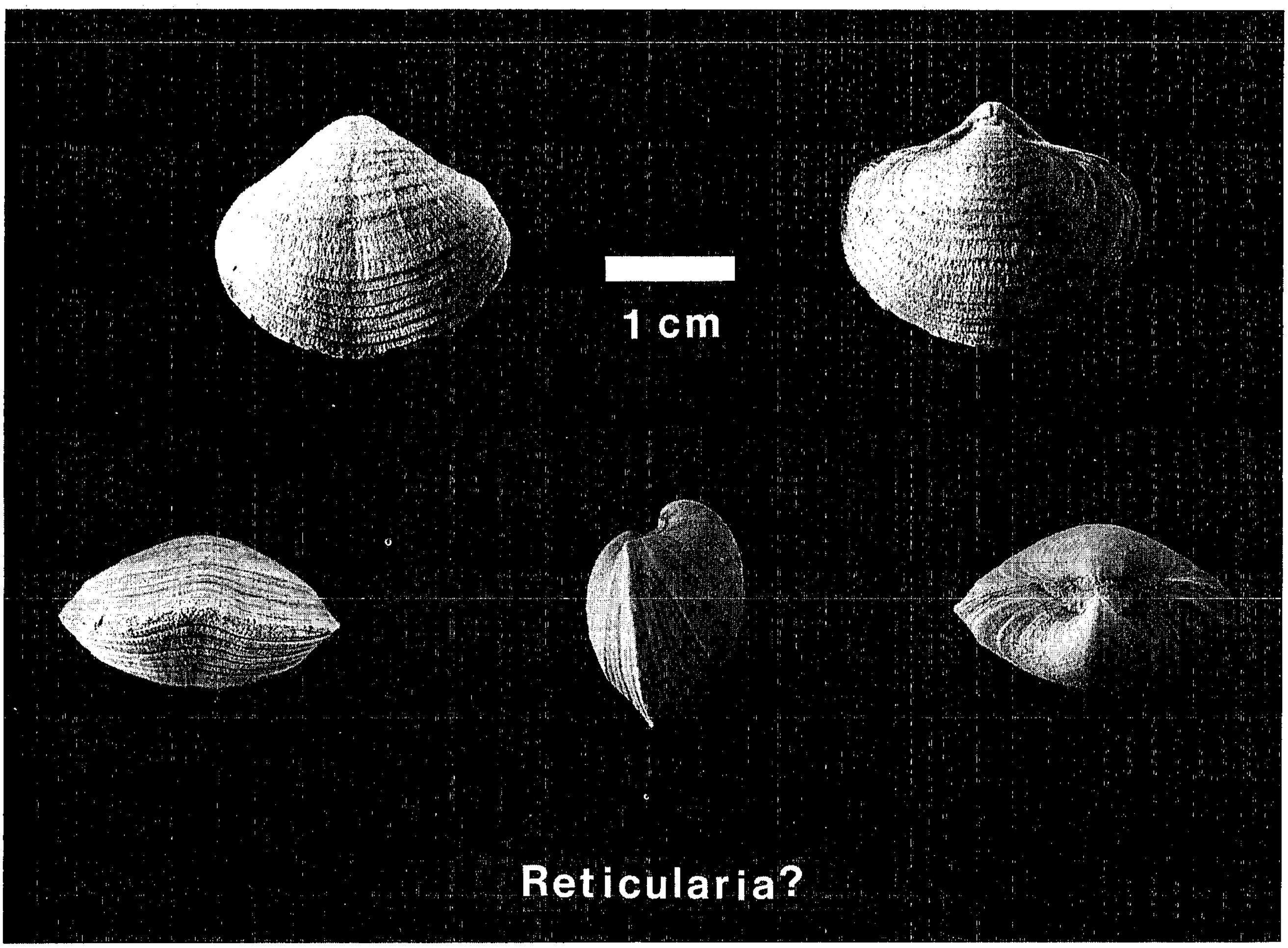


FIGURE 33.—*Reticularia*? found in the Pilot, Leatham, and Sappington rocks. Ventral, dorsal, anterior, lateral, and posterior views.

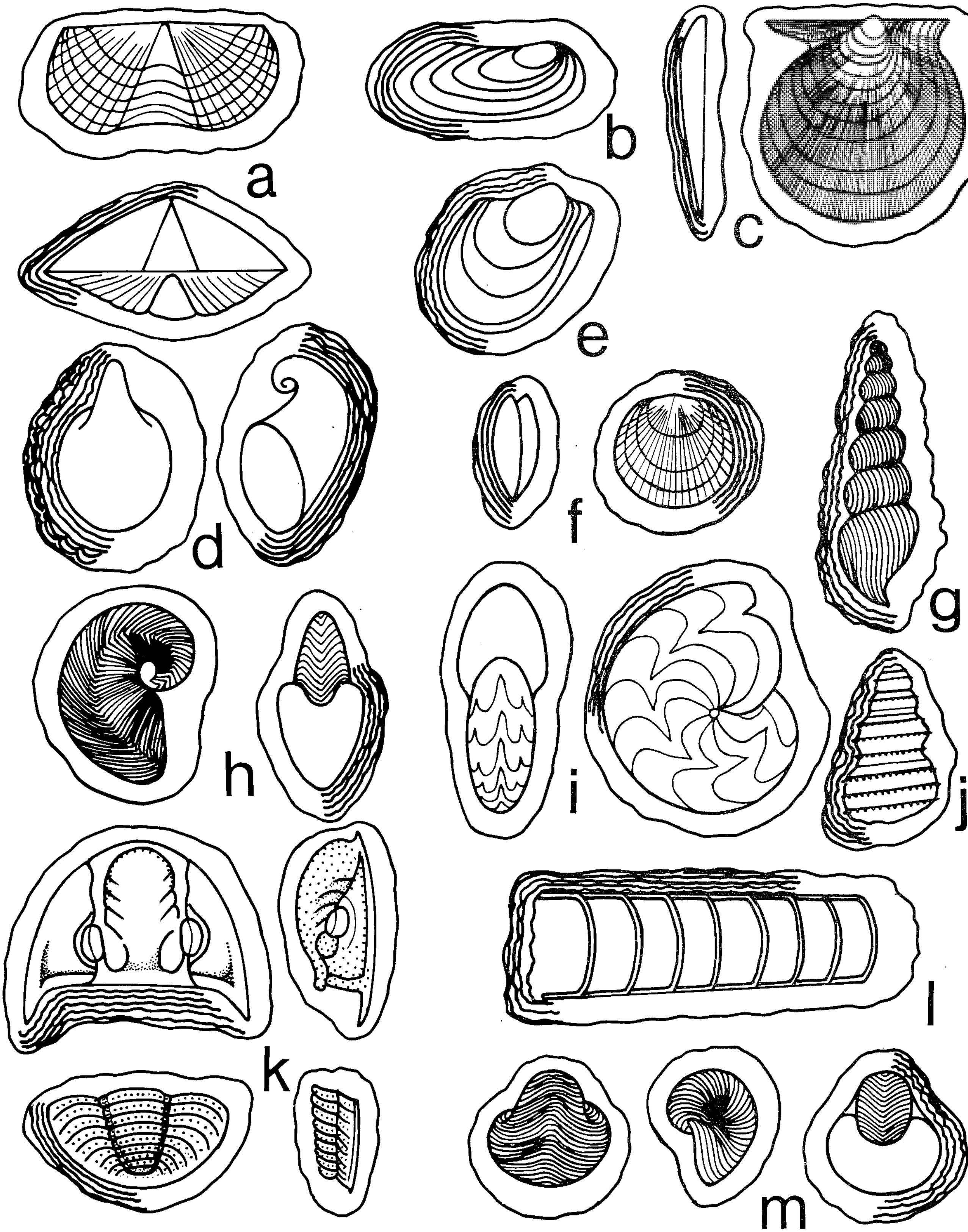


FIGURE 34.—Some typical fossils in the nodular oncolite fauna from the Confusion Range. a.—*Syringothyris hannibalensis* (Swallow). b.—*Parallelodon.* c.—*Aviculopecten marbuti.* d.—Platycerid. e.—*Leiopteria.* f.—*Rhipidomella missouriensis* (Swallow). g.—*Loxonema.* h.—*Tropidodiscus.* i.—*Imitoceras.* j.—*Murchisonia.* k.—*Proetus* (*Pudoproetus*) *missouriensis* Shumard. l.—Nautiloid orthocone. m.—Bellerophontid.

algae (fig. 26) and activity by borers on the bank (Rodriguez and Gutschick 1970, 1975; Gutschick and Rodriguez 1977). The amount of clastic influx affected the filter-feeding organisms and bank growth; eventually mud and silt deposition increased and stifled the bank growth, killing off the filter-feeding organisms which hitherto had dominated the environment. Scavenging deposit-feeding organisms, *Cosmorhaphe* and *Scalarituba* traces, fed on the margins of the bank.

The presence of the lower black shale and oncolite units of the middle Pilot Shale in the south Ruby Mountains raises questions about the paleogeography of the middle member (see figs. 12, 22). Sedimentary constraints imposed by these particular rock types, especially the oncolite unit and bank, suggest subsequent structural separation of the south Ruby Mountains section from those in the Confusion Range. One logical conclusion is that the Pilot Shale sections in western Utah and southeastern Nevada are allochthonous, separated from the autochthonous south Ruby Mountains section during the Antler orogeny or later. Thus, the sedimentary pattern of the Pilot sequence is the clue which strongly suggests this structural dislocation.

The final stage of bank development is marked by abundant *Cosmorhaphe* traces in silty shale and siltstones followed by influx of *Scalarituba* burrowing trails. Offlap to the west is in-

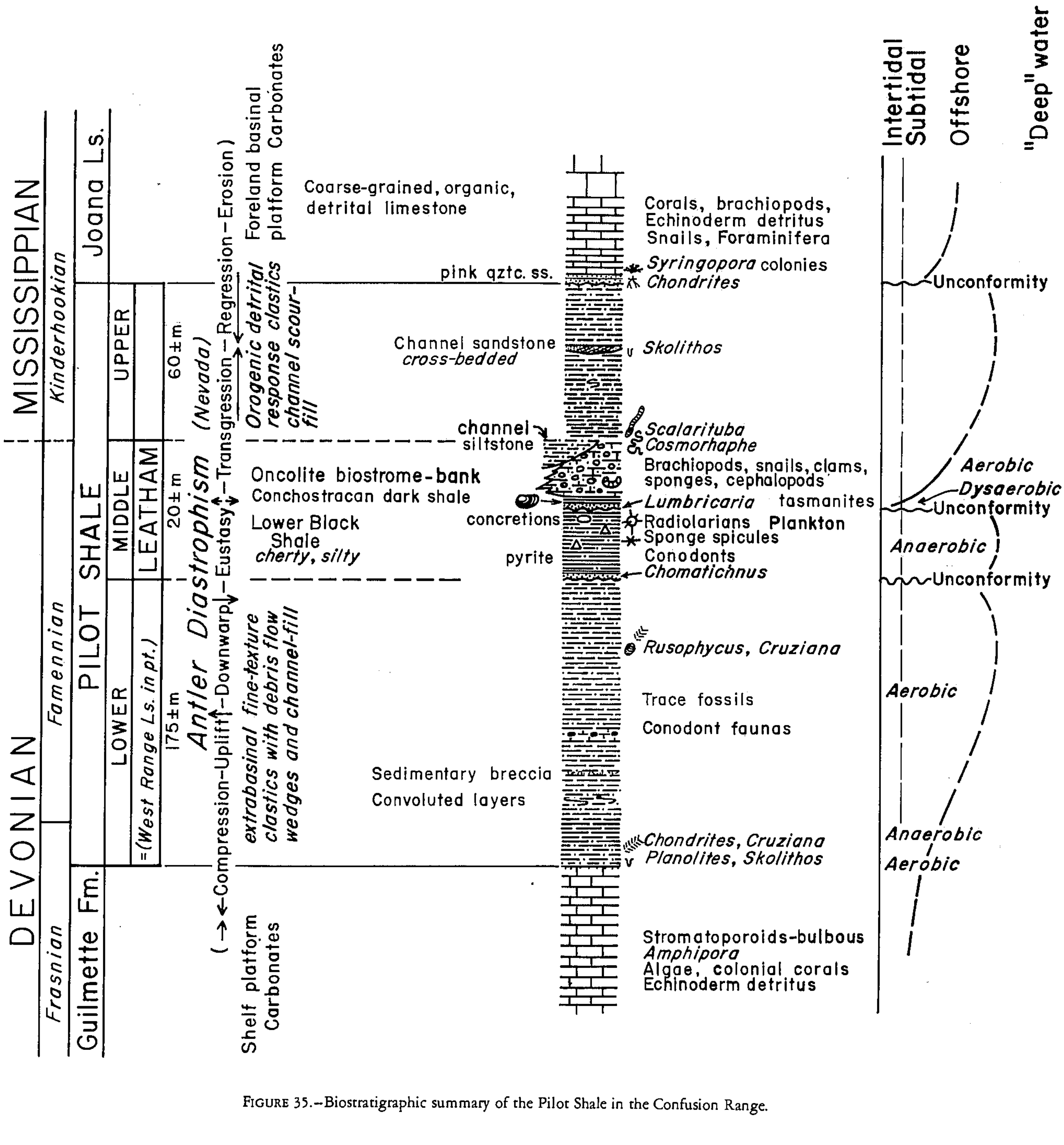


FIGURE 35.—Biostratigraphic summary of the Pilot Shale in the Confusion Range.

dicated in western Montana with the development of extensive mud and silt-fine-sand tidal flats covered with shallow-water sedimentary structures and abundant infaunal burrows such as *Bifungites* (Rodriguez and Gutschick 1970, Gutschick and Lamborn 1975), *Diplocraterion* (Gutschick, McLane, and Rodriguez 1976), *Conostichus* and *Thalassinoides* (Gutschick and Rodriguez 1977), *Zoophycos*, and *Scalarituba*.

During the deposition of the upper member, the Pilot Shale basin was once again affected by Antler downwarping, and an influx of fine clastic sediments is evident; the lower part now consists of the dark organic shales of a restricted anaerobic basin, and most of the upper member is composed of siltstones and silty shales. In southeastern Nevada and western Utah there are few fossils and sedimentary structures on which to base an environmental interpretation; however, in places in the Confusion Range, submarine scour channels were cut down into and through the underlying buried oncolite bank unit. Lastly, a significant thin lag-sandstone layer is present above the *Syringothyris* zone at Bactrian Mountain (southeastern Nevada) which contains an Early Mississippian conodont fauna of the *Siphonodella sulcata* zone (Poole and Sandberg 1977).

As Pilot Shale deposition ceased, the basin was differentially warped with uplift in the Nevada and Utah portions and subsidence to the north. Erosion truncated the flexed Pilot Shale strata, and an unconformity closed the depositional cycle of these rocks (fig. 37). It was followed by a marine invasion of shallow-water seas which again reworked the surface and introduced a basal sandstone unit gradational into the overlying Joana Limestone. A variety of infaunal trace burrows have been described from this basal sandstone unit (Gutschick and Rodriguez 1977). Rapid flysch deposition took place in the subsiding trough in Idaho (fig. 36) during the time of deposition of the Joana Limestone.

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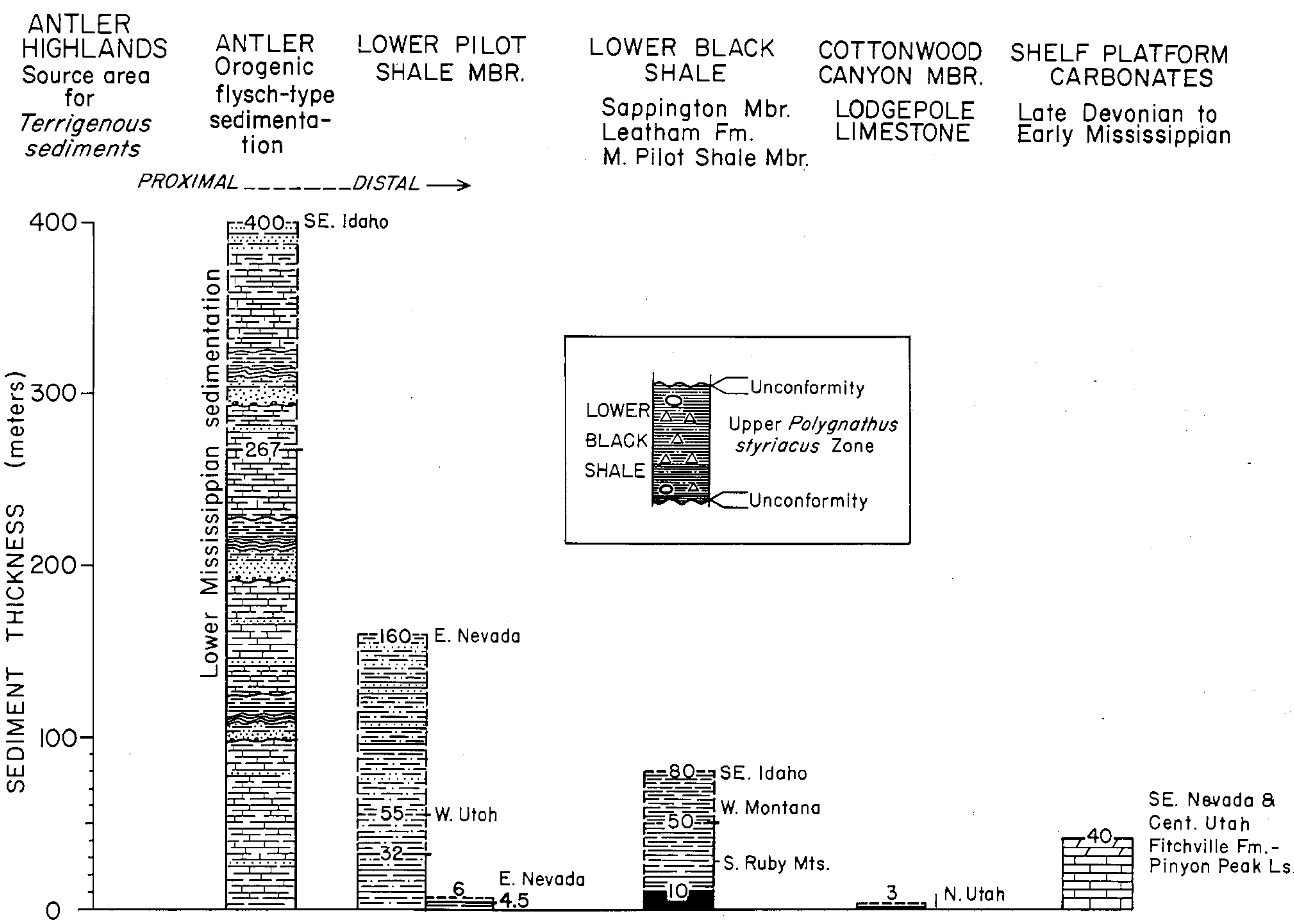

FIGURE 36.—Diagrammatic representation of rates of sedimentation (in m/m.y.) for the Pilot Shale and related rocks. From Sandberg and Poole (1977), based on conodont chronology for time units.

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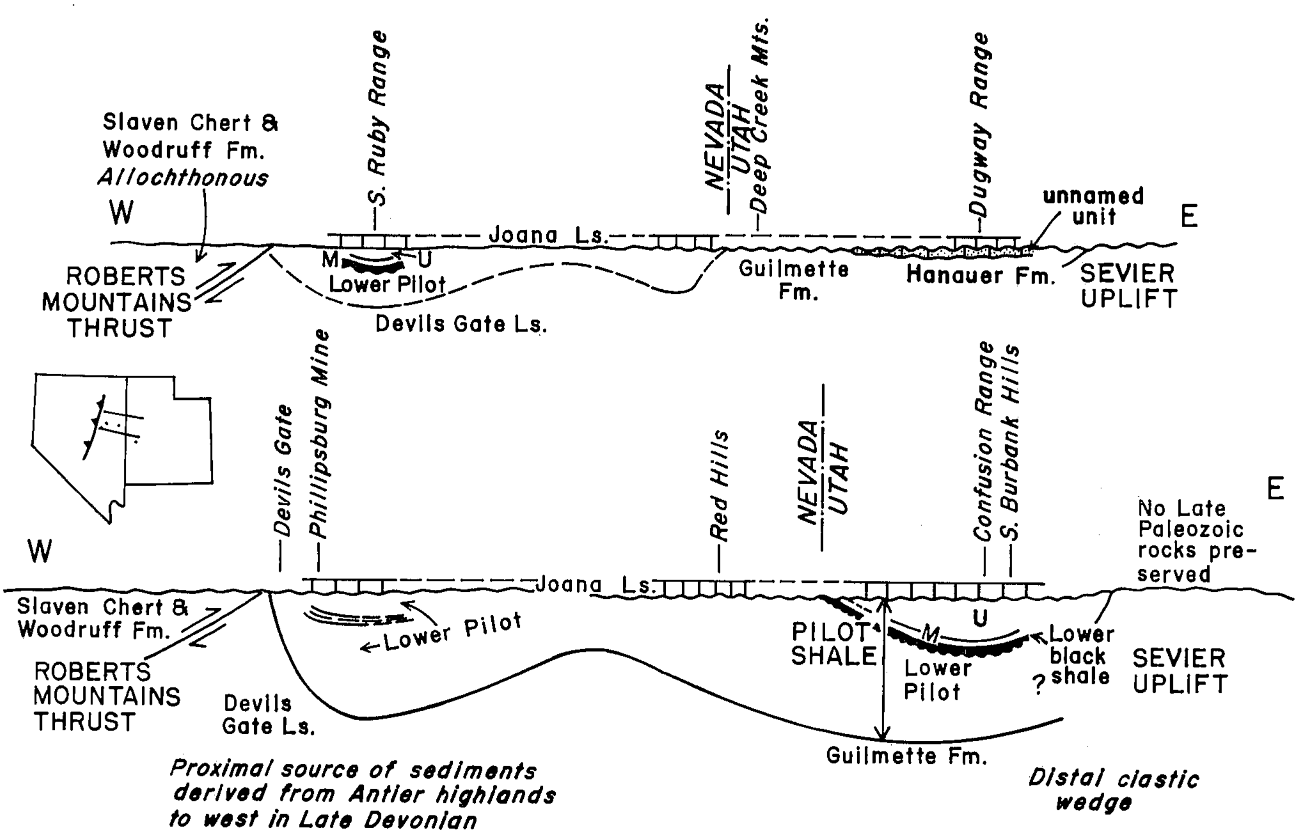

FIGURE 37.—W-E cross-section reconstructions of the Pilot Shale basin showing preserved strata between the Guilmette-Devils Gate carbonates below and the Joana Limestone above. Vertical exaggeration is approximately X20. Data from Sandberg and Poole (1977) and Poole and Sandberg (1977).

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