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Local geology around Bandbox Mountain (Little Belt Mountains) with emphasis on a Mississippian Age carbonate buildup Judith Basin County Montana

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LOCAL GEOLOGY AROUND BANDBOX MOUNTAIN (LITTLE BELT MOUNTAINS) WITH EMPHASIS ON A MISSISSIPPIAN AGE CARBONATE BUILDUP, JUDITH BASIN COUNTY, MONTANA

by

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B.A., University of Montana, 1982

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1984

Approved by:

Chairman, Board of Examiners

Dean, Graduate School

May 30, 1984
Date

ABSTRACT

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Local Geology around Bandbox Mountain (Little Belt Mountains) with Emphasis on a Mississippian Age Carbonate Buildup, Judith Basin County, Montana (121 pp.)

Director: George D. Stanley Jr. GDS

An area on the eastern flank of the Little Belt Mountains is mapped. Exposed units range from Park Shale (Middle Cambrian) to Kibbey Sandstone (Upper Mississippian). The Dry Wolf Laccolith intruded the northern part of the area and the Sheep Mountain pluton in the south. Two episodes of dikes cut sediments. Emplacement of plutons caused compressive forces which generated an anticline/syncline pair and small faults.

A lensoid carbonate buildup occurs in the Lodgepole Formation on Bandbox Mountain. The buildup is a carbonate bank according to Heckel's (1974) classification. It is dominated by fine-grained lime mud and contains an "inner core" of crinozoan grainstone and an "outer core" of bryozoan wackestone. It is in the Woodhurst Member of the formation and similar to other "Waulsortian type" banks in the Paine Member of the Lodgepole Formation. Petrographic analysis of thin sections and whole rock samples indicate the Lodgepole Formation records cyclic subwave base to shallow water sedimentation. The cycle begins with laminated wackestone, pass upward through mixed wackestone/grainstone beds and terminate with coarse grainstone. The buildup is located in the second cycle.

Seventy-one taxa are identified representing eight phyla. The fauna is divided into four communities that approximately correspond to rock facies. Two communities represent "normal" deep water fauna. The third is a deep water bank community and the fourth developed in shallow water during the first regressive cycle. All communities are dominated by low level filter feeding organisms.

Hydrocarbon potential is judged to be poor based on lack of source beds, overmaturity of sediment, lack of migration pathways, low porosity and permeability and small size of the buildup.

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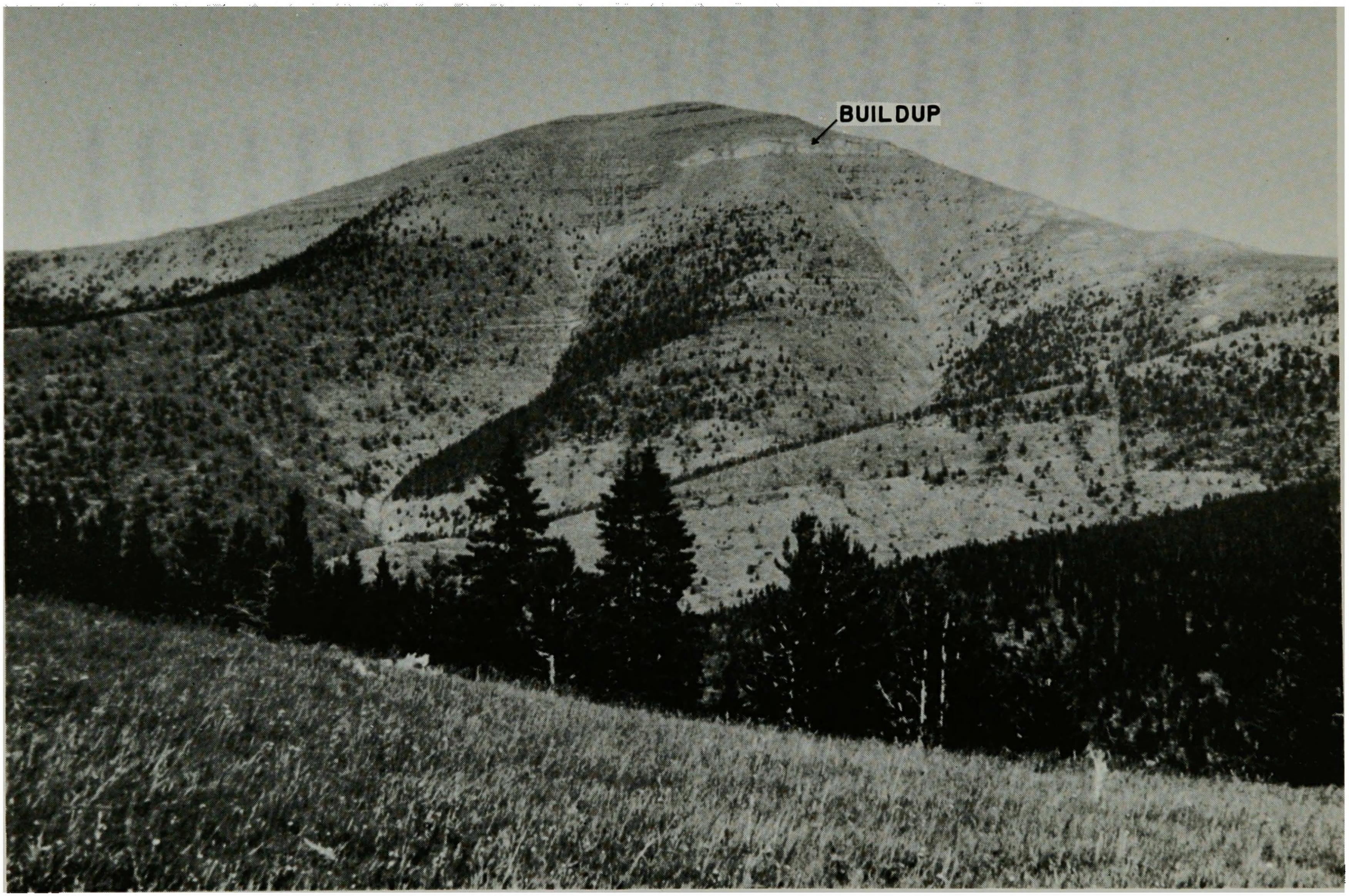


Plate I. West Face of Bandbox Mountain.

CHAPTER I

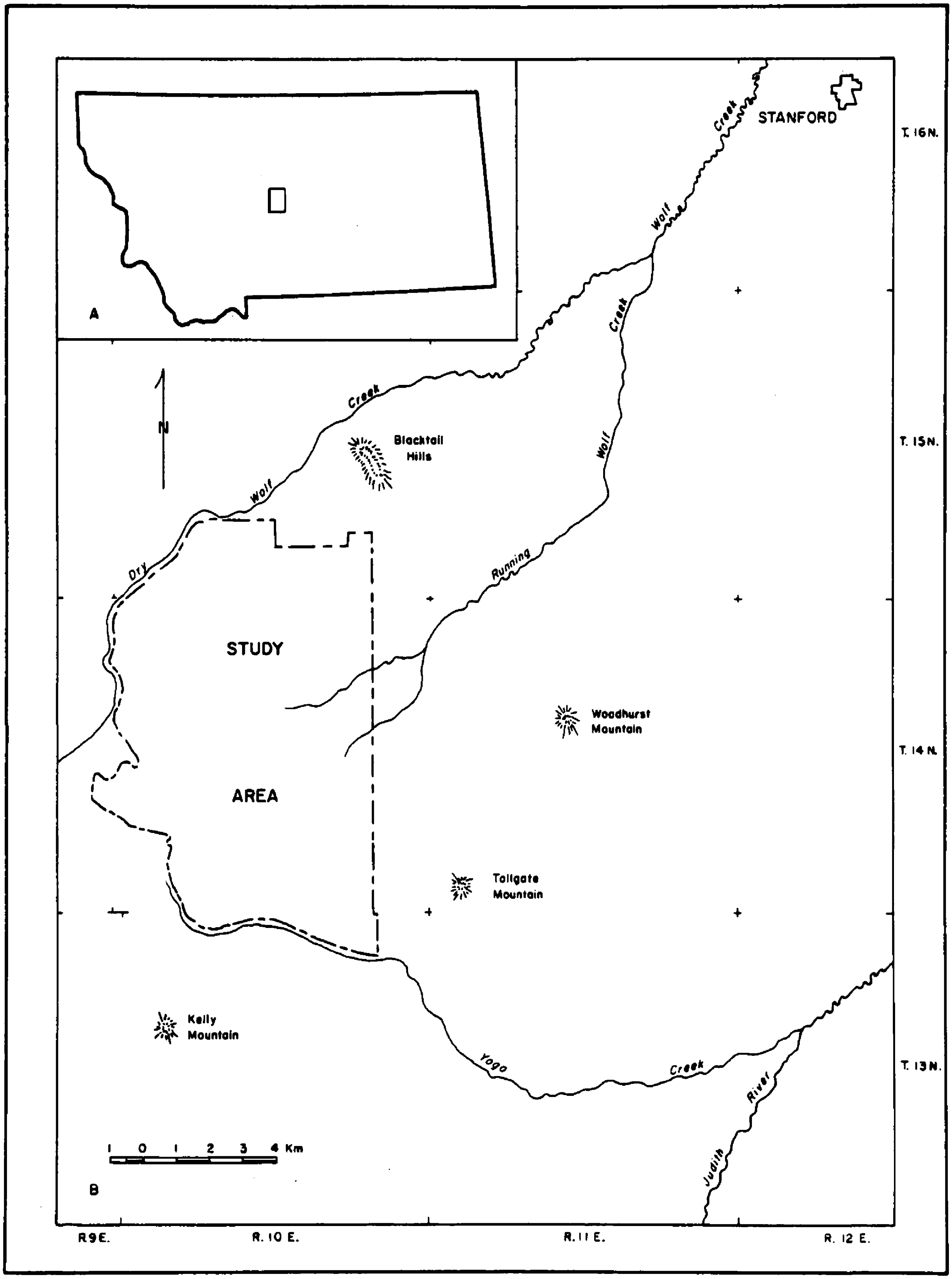
INTRODUCTION

Purpose and Goals of Study

The rocks exposed on and around Bandbox Mountain contain the only known, well preserved Mississippian age carbonate buildup in Montana (see page 46 for definition of buildup). Not only is the buildup well exposed, but the rocks contain a diverse and unique fauna. The combination of these factors make the Bandbox Mountain area unequaled as a site for interpretation of conditions in the Mississippian sea. The general goals of this study are interpretation of fauna and depositional history of this area related to the regional setting of the Mississippian Sea. More specifically the goals are:

1. Prepare a geologic map of the area surrounding Bandbox Mountain to describe local geology as well as determine if other buildups exist (see Figure 1).
2. Determine the type of buildup and whether it can be recognized as an ecological reef or if some more appropriate term should be assigned.
3. Review the regional depositional history and document the depositional environment of Bandbox Mountain in relation to the broader stratigraphic framework.
4. Develop ecological framework of the rocks and document the biotic and taxonomic composition.

Figure 1. A. Outline map of Montana showing the location of B.
B. Regional map showing the location of the study area.


A
B
N
STANFORD
Wolf Creek
Wolf Creek
Dry Wolf Creek
Running Wolf Creek
Yogo Creek
Judith River
Blacktail Hills
Woodhurst Mountain
Tollgate Mountain
Kelly Mountain
STUDY AREA
T. 16 N.
T. 15 N.
T. 14 N.
T. 13 N.
R. 9 E.
R. 10 E.
R. 11 E.
R. 12 E.
1 0 1 2 3 4 Km

5. Assess the potential for hydrocarbons in the buildup and surrounding rocks.

Stratigraphy

Peale (1893) applied the name Madison Limestone to rocks above the Devonian Three Forks Formation and below the upper Carboniferous Quadrant Formation in the area of Three Forks, Montana. Weed (1899, 1900) recognized similar rocks forming ridges and cliffs around the core of the Little Belt Mountains, which he named the Paine Shale, Woodhurst Limestone and the Castle Limestone. Collier and Cathcart (1922) named the Lodgepole and Mission Canyon Formations in the Little Rocky Mountains and elevated the Madison to group. Sloss and Hamblin (1942) combined and reorganized the stratigraphic nomenclature of the Mississippian age rocks recognizing the Lodgepole Formation and Mission Canyon Limestone of the Madison Group (see Figure 2). The Lodgepole Formation is a basal thin-bedded argillaceous limestone containing two members, the lower Paine Member and the upper Woodhurst Member. Sandberg and Klapper (1967) identified a third member, the Cottonwood Canyon, at the base of the Lodgepole Formation throughout much of its area of exposure. Above the Lodgepole is the Mission Canyon Limestone, a massive cliff forming unit. For a more detailed account of the development of this nomenclature see Smith and Gilmour (1979) and Peterson (1981).

The Lodgepole Formation rests unconformably on Cambrian and Devonian age strata in the Little Belt Mountains. According to

Figure 2. Stratigraphic column showing the development of current Mississippian age unit names.

<table>
<tr><th colspan="3">Three Forks Area
Peale (1893)</th><th colspan="3">Little Belt Mountains
Weed (1900)</th><th colspan="3">Central Montana
Collier & Cathcart(1922)</th><th colspan="4">Central Montana
Sandberg & Klapper(1967)</th></tr>
<tr><td rowspan="11">Carboniferous</td><td colspan="2" rowspan="7">Quadrant Formation</td><td rowspan="5">Carbonifer- Triassic ?</td><td colspan="2" rowspan="2">undifferentiated ?</td><td rowspan="11">Mississippian</td><td colspan="2">Not described</td><td rowspan="11">Mississippian</td><td colspan="3" rowspan="7">Big Snowy Group</td></tr>
<tr><td rowspan="6">Quadrant Fm.</td><td rowspan="2">Alaska Bench Fm</td></tr>
<tr><td rowspan="5">Quadrant Gp.</td><td rowspan="3"></td></tr>
<tr><td>Gray Shale</td></tr>
<tr><td>Tyler Ss.</td></tr>
<tr><td rowspan="6">Lower Carboniferous</td><td>Otter Shale</td><td>Otter Shale</td></tr>
<tr><td>Kibbey Sandstone</td><td>Kibbey Sandstone</td></tr>
<tr><td rowspan="4">Madison Limestone</td><td>Jaspery Limestone</td><td rowspan="4">Madison Limestone</td><td>Castle Limestone</td><td rowspan="4">Madison Group</td><td>Mission Canyon Limestone</td><td rowspan="4">Madison Group</td><td colspan="2">Mission Canyon Limestone</td></tr>
<tr><td>Massive Limestone</td><td>Woodhurst Limestone</td><td rowspan="3">Lodgepole Limestone</td><td rowspan="3">Lodgepole Fm.</td><td>Woodhurst Member</td></tr>
<tr><td rowspan="2">Laminated Limestone</td><td rowspan="2">Paine Shale</td><td>Paine Member</td></tr>
<tr><td>Cotton-wood Canyon Member</td></tr>
<tr><td>Devonian</td><td colspan="2">Three Forks Formation</td><td>Devonian</td><td colspan="2">Three Forks Formation</td><td>Devonian</td><td colspan="2">Jefferson Limestone</td><td>Devonian</td><td colspan="3">Three Forks Formation</td></tr>
</table>

Gutschick, Sandberg and Sando (1980), the unit represents marine deposition on a shelf margin and carbonate platform. These authors have summarized the geologic history as:

1. Early Kinderhookian--The development of a narrow northeast trending seaway bounded by coastal plains. Sedimentation was dominated by fine clastics. These lithified into the shale, siltstone and dolomite of the Cottonwood Canyon Member of the Lodgepole Formation. This member is not continuous across the entire area of Lodgepole exposure. Smith (1982) reviews the structural setting across Montana and demonstrates a tectonic origin.
2. Late Kinderhookian--Development of a carbonate platform across Montana. Sedimentation alternated between carbonate and silt, forming the Paine Member of the Lodgepole. During this time, the basal deposition of the Lodgepole occurred in the area of Bandbox Mountain.
3. Early Osagian--The shelf margin retreated into a deep water basin across central Montana. Deposition of the Woodhurst Member took place as well as formation of the buildup on Bandbox Mountain.

Numerous regional stratigraphic and sedimentological studies have been conducted. For bibliography on the Lodgepole Formation see Smith and Gilmour (1979) and Peterson (1981). Studies in the vicinity of the Little Belt Mountains include those by Sloss and

Hamblin (1942), Nordquist (1953), Andrichuk (1955), Wilson (1969), Craig (1972), Sando (1967, 1976), Smith (1972, 1977, 1979, 1982), Gutschick and others (1976), Rose (1976), Smith and Gilmour (1979), and Peterson (1981). Paleontological studies include crinoids (Laudon & Severson, 1953); corals (Sando, 1960), (Sando & Dutro, 1960); and brachiopods (Rodriguiz & Gutschick, 1968, 1969), (Shaw, 1962). Merriam (1958) conducted a systematic study of the Big Snowy Mountains buildup. Cotter (1963, 1965, 1966) and Stone (1971, 1972) studied the buildups in the Big Snowy and Bridger Mountains including thin section notation of fossils. Diagenesis in the Lodgepole Formation along Belt Creek, in the central part of the Little Belts was studied by Jenks (1972).

Methods

Field work was carried out in July and August of 1983. Approximately 76 km^2 were mapped on portions of the Bandbox Mountain, Wolf Butte, Mixes Bauldy and Yogo Peak U.S. Geological Survey 7½ minute Quadrangle maps. Mapping was by east-west traverses and contacts between rock units were sketched between traverses. Six sections were measured by compass and Jacob staff. Samples were collected at intervals of 1.5 m unless lithologic changes warranted closer sampling.

Laboratory work included the microscopic examination and analysis of thin sections and slabbed rock samples. Fossils were identified from published descriptions and photographs and by comparison to identified material in the University of

Montana collection. Porosity was estimated from thin sections. Trypan Blue stain distinguished dolomite from limestone on cut rock samples as outlined by Friedman (1959). Dunham's (1962) classification of carbonate rocks is used throughout. Fossils in thin section were identified using Scholle, 1978; Johnson & Konishi, 1956; Horowitz & Potter, 1971. Microfacies were developed using the outline in Flügel (1982). All fossil specimens are catalogued into the University of Montana Museum of Paleontology collection, petrographic specimens into the University Petrology collection.

CHAPTER II

LOCAL GEOLOGY

Local Geology of Mapped Area

Geologic mapping in the Little Belt Mountains and surrounding area has concentrated on economic exploration. Ground water studies of the high plains surrounding the Little Belts have been published by Zimmerman (1962, 1966), Perry (1932), and Feltis (1977). Westgate (1921), Silverman & Harris (1967), Vine (1956), and Vine & Johnson (1954) studied coal deposits, of the surrounding Mesozoic rocks. Within the study area, Goodspeed & Fitzsimmons (1946a, 1946b) and Roby (1949) investigated mineral deposits. U. S. Geological Survey mapping in the northern and central Little Belts includes the 15 minute Barker Quadrangle (Witkind, 1971) and the western half of the Neihart 15 minute Quadrangle (Keefer, 1969, 1972).

Three drainages mark the boundaries of the study area, Dry Wolf Creek on the west, Running Wolf on the east and Yogo Creek on the south. Weed (1900) mapped this area on a 1:62,500 scale. With the exception of local mineral deposit maps, little is published on the detailed geology of this area. The purpose of the present mapping is to determine if other buildups occur within this area and to define the geologic occurrence of the buildup in relation to the local geology. A geologic map of this area is contained in a pocket at the end of this thesis (Figure 3).

Individual rock units were identified using the general descriptions of stratigraphic units supplied by Witkind (1971).

In the mapped area no other buildups were found. Two areas contained concentrations of the colonial coral Syringopora. These are located in Sec. 19 and Sec. 32, T. 14 N., R. 10 E. In both cases exposure was so poor that no sections could be measured.

Structure of this area is dominated by gentle folding of the Paleozoic rocks around the eastern side of the Little Belt Mountains. Igneous intrusions complicate the area between Gibson Peak and Sheep Mountain. Compressive forces have generated a small, doubly plunging anticline/synclinal pair less than 5 km long through Sec. 17, 18, 19, 20, and 21, T. 14 N., R. 10 E. The structures strike approximately east-west. Along Dry Wolf Creek another syncline formed in Sec. 6 & 7, T. 14 N., R. 10 E., due to compression between the Dry Wolf and Butcherknife Mountain Laccoliths. Small faults are mapped in Sec. 6 & 33, T. 14 N., R. 10 E. The faults formed in response to the compressive stress of the intrusions. I interpret them as reverse faults.

Stratigraphy

A brief description follows of the rock units mapped in the study area. Refer to Figure 3 for location and precise details of exposure.

Park Shale

The Park Shale is a thin-bedded, often platy, micaceous shale. Color varies from green to bluish green to reddish brown.

The unit contains a few limy beds toward the top. Tracks and trails occur commonly in other beds. The base of this unit is not exposed; however, in the Barker Quadrangle, to the west, it ranges from 55 to 80 m (Witkind, 1971). The best exposure of the Park Shale is in a small gully between Lion Gulch and Bandbox Mountain in the NE¼, Sec. 19, T. 14 N., R. 10 E. Perry (1962) places the age of the Park Shale as Middle Cambrian.

Pilgrim Limestone

The Cambrian age Pilgrim Limestone conformably overlies the Park Shale. The Pilgrim forms prominent ridges of medium-bedded, medium to light gray limestone. Common intraformational conglomerate beds range from 0.1 to 0.8 m thick. In the vicinity of intrusions, color becomes very dark and the rock takes on a laminated look. The Pilgrim Limestone is about 35 m thick in the map area and is best exposed on the western flank of Bandbox Mountain in the SW¼, Sec. 20, T. 14 N., R. 10 E. (see Figure 3).

Maywood Formation

The Maywood Formation unconformably overlies the Pilgrim. The Maywood is considered to be Devonian age (Perry, 1962). It forms ledgy outcrops of platy siltstone and shale. Color is variable, but generally consists of shades of yellow, brown and red. The sediment is well sorted and contains soft sediment deformation structures and the trace fossil Cruzinia (?). In the map area the unit is approximately 25 m thick. A good exposure occurs along the southwestern flank of Bandbox Mountain in SW¼, Sec. 20, T. 14 N., R. 10 E.

Jefferson Dolomite

The Jefferson Dolomite conformably overlies the Maywood. In the Barker Quadrangle, Witkind (1971) divides the Jefferson into three members; basal, middle, and Birdbear. The basal member is a light to medium gray, medium-bedded to massive dolomite. Black chert is locally abundant. Fossil stromatoporoids form small cabbage-like heads 2 to 5 cm across. In the mapped area these are confined to the lower member and locally form beds up to 0.3 m thick. Rare brachiopods and bryozoans occur in the lower member. Gray to dark gray or nearly black saccaroidal dolomite forms the middle part of the Jefferson. Fossils are absent from the middle section. The upper part, the Birdbear Member, is light gray to nearly white, fine-grained dolomite. Two locations expose this member as massive dolomite, in other parts of the map area it is covered. No fossils are found in the Birdbear Member, probably due to intense recrystallization of the original limestone. Thickness ranges between 80 and 115 m. Best exposures are in Flat Gulch west of Bandbox Mountain in the NE¼, Sec. 19, T. 14 N., R. 10 E., and in the saddle between Bandbox Mountain and Tucken Peak along the boundary of Sec. 8 & 17, T. 14 N., R. 10 E. At these two localities the three members of the Jefferson were identified, however, because of generally poor exposure, the members were not mapped.

Three Forks Formation

The Three Forks Formation rests conformably on the Jefferson Dolomite. Conodont studies date the Three Forks as uppermost Devonian. These rocks consist of a thin series of multicolored siltstone, shale and dolomite. The west face of Bandbox Mountain exposes these rocks in the SW¼, Sec. 20, T. 14 N., R. 10 E., where they are about 20 m thick.

Madison Group

Lodgepole Formation

The Lower Mississippian Lodgepole Formation overlies the Three Forks Formation with the boundary marked by an erosional unconformity. The Lodgepole extends across much of the map area, however, most exposures are poor. The best exposure is on the southwest face of Bandbox Mountain in the NW¼ and SW¼, Sec. 20, T. 14 N., R. 10 E. Other areas of fair exposure include Sheep Mountain (Sec. 28, T. 14 N., R. 10 E.) and an unnamed ridge between Skunk Gulch and Elk Creek, southeast of Elk Saddle (Sec. 32 &33, T. 14 N., R. 10 E.). Relative to other formations, the Lodgepole is thick, varying within the map area from 220 to 230 m. The unconformity at the base exposed on Bandbox Mountain undulates slightly. The basal 10 m are dark-gray, medium-bedded limestone with 2 to 6 cm thick beds and nodules of black chert. Above the base, medium-bedded light-gray limestone interbed with argillaceous lime mudstone. Locally red and yellow stains color these beds. Stratigraphically higher, the lithology becomes varied and both light and dark bioclastic limestone is common. The buildup occurs in this sequence. Fossils are abundant throughout the section and this formation is easily identified from loose rock by abundant crinoid stems, brachiopods and bryozoans. Because of poor exposure throughout much of the map area, no attempt was made to map the members of the Lodgepole, although they are well exposed on Bandbox Mountain and discussed in the section on carbonate petrology.

Mission Canyon Limestone

The Mission Canyon Limestone forms cliffs along the flanks of the Little Belt Mountains. The unit conformably overlies the Lodgepole and the contact between the two units is a depositional gradation from one to the other. The Mission Canyon is light yellow brown to cream in color. The formation contains many caverns and cavities formed by surface weathering solutions. A prominent solution breccia described from the Barker Quadrangle by Witkind (1971) occurs 30 m above the base of the Mission Canyon. This feature was recognized in the map area and used to place the contact. The Mission Canyon Limestone varies in thickness from 225 to 250 m in this portion of the Little Belts. Excellent exposures occur along the road up Dry Wolf Creek and across the entire northern end of the map area.

Big Snowy Group

Kibbey Sandstone

The Kibbey Sandstone unconformably overlies the Mission Canyon Limestone. This unit is exposed in a roadcut along Nickerson Coulee in the SE¼, Sec. 26, T. 15 N., R. 10 E., in the northern part of the map area. The formation is composed of tan, light brown and reddish brown, well-rounded, well-sorted sediments. Thin-bedded, platy siltstone and fine-grained sandstone dominate the lithology. The top of this formation is not exposed in the mapped area.

Alluvium

Unconsolidated, unsorted sand, silt and gravel occurs along major drainages. In the northern part of the map area terrace gravel is included. These are not differentiated on the map.

Igneous Rocks

Dry Wolf Laccolith

Rocks of syenitic composition make up the Dry Wolf Laccolith. Colors vary from light to dark gray. Textures are dominated by fine-grained ground mass and phenocrysts of feldspar (a few mm long), biotite and ? hornblende. Feldspar dominates the ground mass. Exposures of this laccolith occur along Dry Wolf Creek and in a large area of the northern part of the map. The floor, exposed along Dry Wolf Creek in Sec. 6,

T. 14 N., R. 10 E., dips gently northward at about 12^{o}. The base rests nonconformably on beds of the Lodgepole Limestone. Exposures of Madison Group border the northern edge of the laccolith and led Witkind (1973) to believe the laccolith was emplaced into the Madison Group. However, along the southern and eastern edge of the laccolith, the igneous rocks are in direct contact with units of the lower Paleozoic section. Fault contact cannot be ruled out, but no evidence was found. Lower Paleozoic rocks may represent drag structures formed as the magma was emplaced. Witkind (1973) reviews models of laccolith emplacement as they may pertain to the Little Belt Mountains. Age of the intrusives determined by radiometric dating indicate they were emplaced in the Eocene (Witkind, 1973).

Sheep Mountain Pluton

Sheep Mountain pluton is composed of syenitic rocks similar to those of Dry Wolf Laccolith. This pluton forms a linear body that trends from the southern end of Sheep Mountain northeast beyond the mapped area. Because the floor was not identified and because of the elongate geometry of this body, I do not consider it a laccolith.

Igneous Dikes

Numerous small igneous dikes occur across the map area. Some are similar to the major plutons and are undoubtedly related. Possibly some are large plutons just being exposed.

Other dikes have extremely different compositions. Without exception, exposure of the dike is limited and they can be traced laterally only a few tens of meters. Because of poor exposure, the true relationship to enclosing rocks cannot be determined and some may be sills. Because of the small size and poor exposure, dikes are not included on the geologic map.

Shonkinite dikes occur on the ridge east of Elk Saddle in Sec. 30, T. 14 N., R. 10 E., and southwest of Gibson Peak in Sec. 8, T. 14 N., R. 10 E. Coarse-grained textures and dark colors typify these rocks, weathering produces reddish brown colors. Mineralogy includes varying percentages of biotite, olivine, pyroxene (augite?) and plagioclase feldspar.

A rhyolitic dike trends NE-SW across Elk Saddle in Sec. 30, T. 14 N., R. 10 E. Light colors and fine-grained ground mass associated with phenocrysts of quartz and feldspar dominate these rocks. Mafic phenocrysts form less than 5% of the rock and are dominated by small euhedral biotite crystals. A few elongate needles of hornblende indicate possible flow direction.

Minette (biotite lamprophyre) dikes cross the west face and top of Bandbox Mountain in Sec. 20, T. 14 N., R. 10 E. (Identified by D. H. Hydman, 1983, personal communication.) Composition of these dikes is dominated by aphanitic to fine-grained light to medium gray rocks which weather greenish gray. Biotite phenocrysts up to 20 mm in length occur abundantly.

Witkind (1973) identified at least two stages of dike intrusion in the Barker Quadrangle. Both are dated as Eocene, however, they are considered later than the major intrusion of the laccoliths.

CHAPTER III

DEPOSITIONAL ENVIRONMENTS

Depositional Environment Introduction

The Bandbox Mountain buildup is unique among the known Mississippian age buildups of Montana. Diagenesis has altered all other known examples to the point where little of the original depositional fabric is preserved. On Bandbox Mountain, alteration has not occurred, bold exposures, a well preserved and diverse fauna create a study opportunity unequaled in other buildups.

Outcrop and thin section interpretations of observations are used to build the depositional history of this buildup. Assimilation of this information into the regional setting provided by Smith (1972) expands the picture of the Mississippian sea. In following chapters the buildup is compared with others known from Mississippian age rocks and the faunal composition is described. A comparison is made between the buildup fauna and other fauna from the Lodgepole Formation.

Regional Stratigraphy and Sedimentation

A major transgression occurred in Montana during the Mississippian (Gutschick, et. al., 1980). The initial Early Mississippian (middle Kinderhookian) advance came from the southwest as a narrow sea opened across Nevada and Utah, then expanded covering most of Wyoming and southern Montana. By late Kinderhookian, as the sea flooded the unstable shelf of

Montana, it filled two east-west synclinal troughs, the Big Snowy to the north and the Crazy Mountain basin to the south, separated by an anticline, the central Montana high (Figure 4). These structures developed as drape folds over faults in the Precambrian basement (Smith, 1982).

The transgression into Montana was rapid and quickly developed into deep water depositional environments recorded in the Lodgepole Formation. Smith (1972, p. 102) recognized five depositional cycles in this unit, he describes:

> "....each Lodgepole cycle consists of thin bedded, fine-grained lower unit capped by thicker coarse-grained bioclastic and oolitic grainstone beds....
> Cycle A includes the Paine Member and the lowermost bioclastic and oolitic limestone of the Woodhurst.
> Cycle B through E, in addition to the bioclastic beds capped Cycle A, compose the Woodhurst."

Smith interprets the Lodgepole cycles to represent fluctuations in wave and current turbulence during transgression and regression of the Lodgepole sea.

The western end of the central Montana high terminates in this section of the Little Belt Mountains. The area was high during the initial stages of the Mississippian transgression and the Cottonwood Canyon Member of the Lodgepole was not deposited, but occurs a few kilometers to the south. During the middle to late Kinderhookian, the sea advanced across the Bandbox Mountain locality and the Paine Member was deposited. During the early Osagean, the Woodhurst Member was deposited across the area as a wedge of sediment building from the shallow water

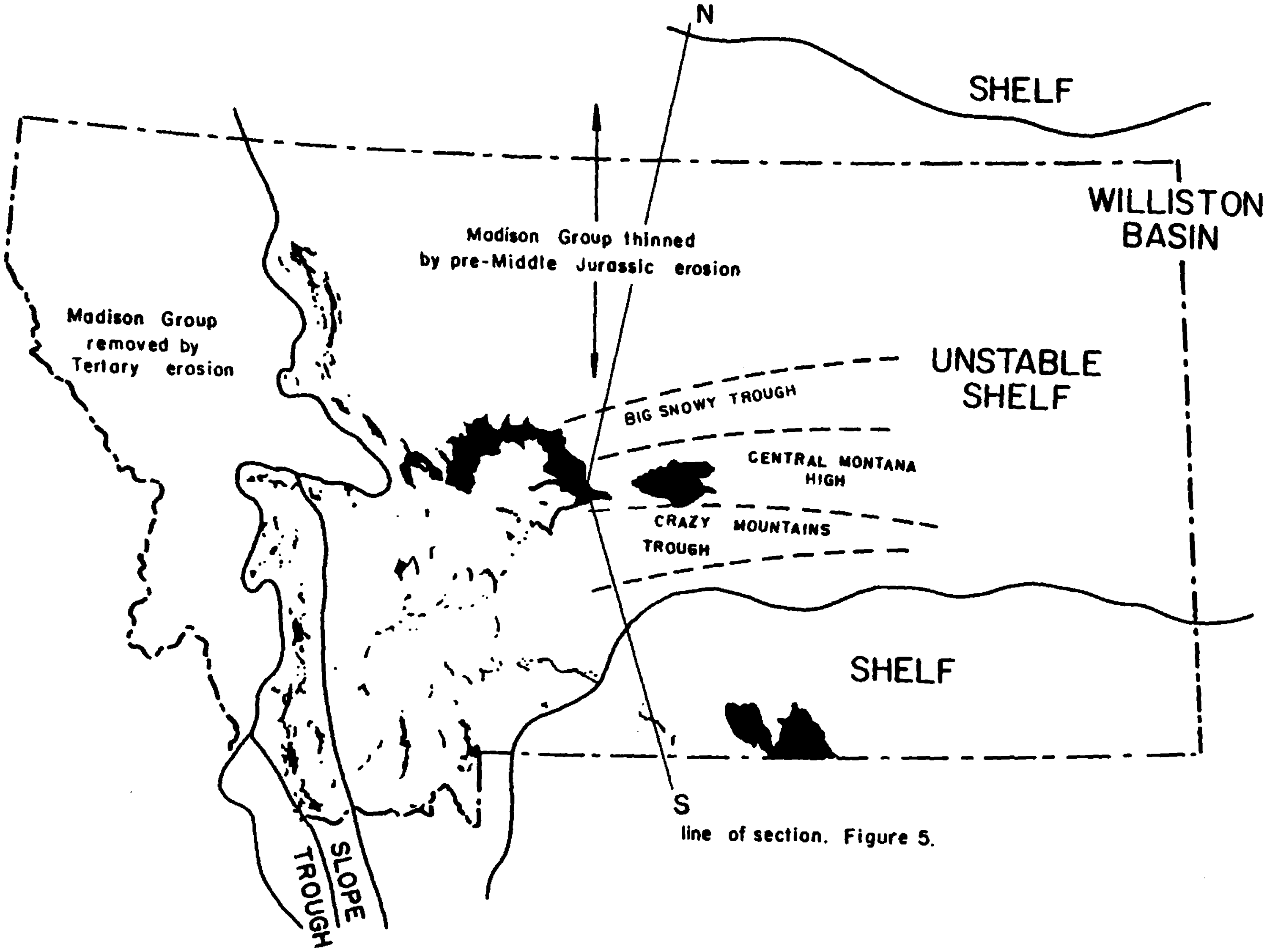


Figure 4. Tectonic map of Montana during the Mississippian. Modified and redrawn from Smith, 1982.

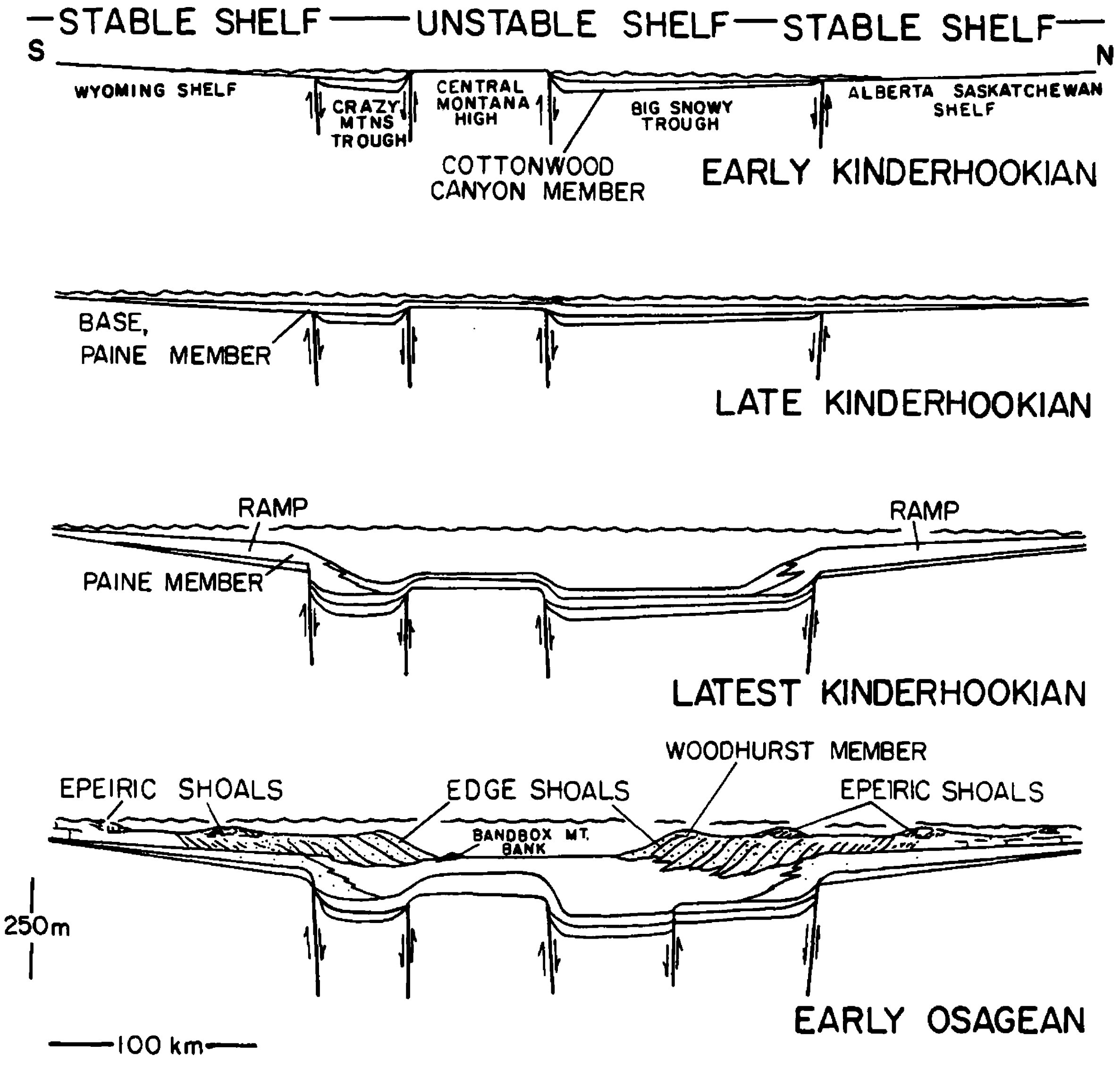


Figure 5. Cross sections across the Montana shelf. Modified and redrawn from Smith, 1982.

Wyoming shelf into the deeper water of the unstable shelf of central Montana (Figure 5).

Across the northern end of the Little Belt Mountains the Paine Member of the Lodgepole Formation is characterized by alternating layers of argillaceous limy mudstone and thin to medium-bedded limestone. The Woodhurst Member contains medium to thick beds of dark limestone above the Paine. The Bandbox Mountain buildup is located in the lower part of the Woodhurst Member. This buildup like others in Montana was deposited on the edge of the fault developed high.

Carbonate Petrology

Six stratigraphic sections were measured through the buildup and one was measured from the base of the Lodgepole Formation to the top of Bandbox Mountain (Appendix II). These sections were divided into ten consistently recurring facies types. The term "facies" is used throughout to denote a "package" of sediment having similar lithologic and fossil characteristics. Gross rock character in the field as well as thin section examination forms the basis for facies identification. Inference of wave and current intensity or depositional turbulence is based on comparative information with modern environments (Flügel, 1982; Wilson, 1975; Bathurst, 1975). Facies types are listed according to depositional turbulence in Figure 6. "Low turbulence" facies were deposited in calm water environments. "Moderate turbulence" facies were deposited near wave base. Typically they consist of interbedded sequences that alternate between "low turbulence" and

Low Turbulence	Moderate Turbulence	High Turbulence
Bryozoan Dark Wackestone Facies		
Dark Mudstone Facies		
Bryozoan Light Wackestone Facies		
Coral Framestone/Wackestone Facies		
Mixed Light Mudstone/Grainstone Facies		
	Basal Paine Facies	
	Dolomitic Facies	
		Bryozoan-Crinozoan Grainstone Facies
		Crinozoan Grainstone Facies
		Ooid Crinozoan Grainstone Facies

Figure 6. Classification of Facies types based on wave and current turbulence.

"high turbulence". "High turbulence" facies were produced by considerable wave action or currents that winnowed fine mud, rounded coarse grains, and sorted grains.

Classification of carbonate rocks given below follows Dunham (1962). Bedding thickness is based on Ingram's (1954) classification and sediment size classification follows Wentworth (1922).

The terms "sparse, moderately abundant, and abundant" refer to the relative amount of rock components seen in thin section. Sparse refers to less than 10 percent, moderately abundant to amounts between 10 and 30 percent and abundant to constituents greater than 30 percent.

Facies Description and Interpretation

Basal Paine Facies

Description: The Basal Paine Facies forms a cliff 3 m high above the contact between the Lodgepole and Three Forks Formation (Figure 7 & Plate II, A). The facies is dominated by fine-grained mud (40%) and euhedral dolomite crystals (50%). An unidentified spicule or spine-like grain dominates the bioclasts. They may be brachiopod spines or large sponge spicules, but recrystallization has altered the original structure beyond recognition (Plate II, B). Fenestellate and the ramose bryozoa ? *Rhombopora* are moderately abundant. Brachiopod shell fragments and crinoid columnals are rare. The percentage of bioclasts vary from bed to bed but wackestone and packstone rock types dominate.

The outcrop weathers light brownish gray, fresh surfaces are dark gray. Brownish black chert forms beds and irregular blobs in the lower 2 m of the facies. Horizontal laminations and small scale ripple cross laminations are preserved because the lime mud was not bioturbated.

Diagenesis in this facies has produced fractures and cavities filled with sparite and fractures filled with dolomite. Euhedral dolomite is common. Chert has replaced 10 to 15 percent of the dolomite crystals and fossil grains.

Interpretation: The Basal Paine Facies is described by Smith (1972) from the Big Snowy and Bridger Mountains. In both areas this facies is a glauconitic wackestone, resting conformably on the Cottonwood Canyon Member of the Lodgepole, but glauconite was not found at Bandbox Mountain. Smith (1972, p. 19) interprets the facies as:

> "....probably below wave base, in which currents and waves strong enough to remove lime mud were lacking or in which lime mud was pelleted by crinoids and deposited."

Mixed Light Mudstone/Grainstone Facies

Description: Beds of the Basal Paine Facies grade into 27 m of mixed mudstone and grainstone (Figure 7). The Mixed Light Mudstone/Grainstone Facies is composed of interbedded argillaceous lime mudstone and grainstone. The mudstone occurs more commonly at the base of the facies. Tracks and trails are common in the pelloidal mudstone portions. Thickness of mudstone intervals vary, but generally decrease upward as the grainstone thickness increases. Within the grainstone beds, textures range from packstone to grainstone. Sparite and micrite occur between the bioclasts in the packstone beds. Sparite fills intergranular space in the grainstone (Plate II, D). Organic micritic (?) envelopes coat grains in both rock types.

Fossils near the base consist of rare and moderately abundant gastropods, articulated crinoid calices and brachiopods. Near the top of this facies, the fauna becomes more diverse with abundant brachiopods, bryozoans and crinoid columnals. The solitary rugose croal <u>Rylstonia</u> sp. is abundant in the uppermost three meters. The fossils especially near the top, appear to be a life assemblage bearing little or no evidence of transport. Delicate fenestrellate bryozoan zooaria are well preserved and draped over crinoid columnals. Brachiopod shells are articulated and unabraded.

Dolomite is rare in this facies. Euhedral crystals occur scattered in the matrix of mudstone. Chert replaced dolomite grains and less than 5% of the fossil grains.

<u>Interpretation</u>: Deposition of the Mixed Light Mudstone/Grainstone Facies is interpreted as taking place in an environment that alternated between high turbulence deposition of grainstone and low turbulence deposition of mudstone. Modern environments that create similar depositional sequences occur between fair weather and storm wave base. The combination of this environment and the decreasing sea level described by Smith (1972) progressively winnowed most of the mud from the depositional environment.

Bryozoan-Crinozoan Grainstone Facies

Description: Twenty-three meters of ledges dominated by grainstone occurs above the Mixed Light Mudstone/Grainstone. Bed thickness ranges from thin to medium and some pinch and swell (Figure 9). The Bryozoan-Crinozoan Grainstone Facies contains minor thin beds of argillaceous lime mudstone near the base. Crinozoan columnals make up 20 to 30 percent of the total rock and bryozoans range from 5 to 20 percent (Plate II, F). Echinoid spines and brachiopod fragments are rare. All fossil fragments are broken and rounded. Algal (?) or organic crusts coat some fragments (Plate II, E).

Euhedral dolomite comprises less than 5 percent of the total rock volume. Most dolomite grains have been replaced by chert. Chert also replaces fossil grains.

Interpretation: This facies continues the increasing turbulence from the Mixed Light Mudstone/Grainstone Facies below. Continued reduction of sea level produced an environment above fair weather wave base. This environment records the high turbulence and reworking near the top of Smith's (1972) Cycle A.

Dolomitic Facies

Description: Resting above the grainstone, the Dolomitic Facies contains 16 m of wackestone, packstone and grainstone (Figure 7). Three crinozoan grainstone beds, each less than a meter thick, are interbedded with laminated dark gray dolomitized wackestone and packstone. Dolomite in this section ranges from 10 to 50 percent. In beds that contain high amounts of dolomite,

PLATE II

A. Basal Paine Facies at the southwestern face of Bandbox Mountain. Dark brownish packstone/grainstone with globular brownish black chert.

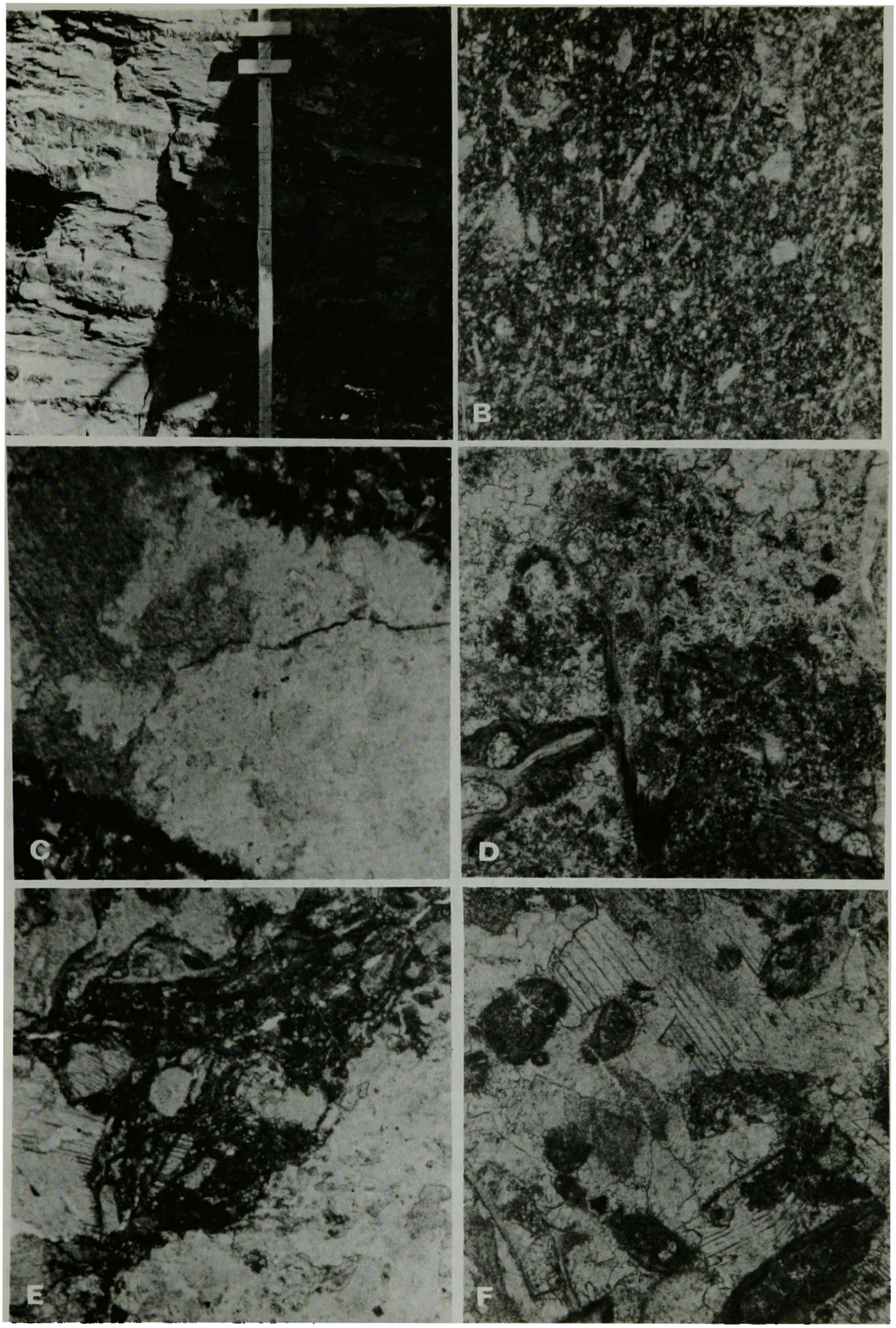
B. Basal Paine Facies. Recrystallized packstone with mud matrix and fossil fragments (LBF-4, plane polarized, x20).

C. Dolomitic Facies. Boring filled with sparite (LBF-183, plane polarized, x20).

D. Mixed Light Mudstone/Grainstone Facies. Fossil grains cemented with sparite (LBF-35, plane polarized, x20).

E. Bryozoan-Crinozoan Grainstone Facies. Fossil grains with ? algal envelopes (LBF-148, plane polarized, x20).

F. Bryozoan-Crinozoan Grainstone Facies. Sparite cement between echinoderm columnals and bryozoan fragments (LBF-165, plane polarized, x20).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fossil grains are recrystallized, partially eroded and fractured. Beds with low dolomite content contain crinozoan columnals, bryozoans and brachiopod shell fragments. One thin section contained the green codiacean alga _Garwoodia_ sp. (Plate III, B). Sparite filled borings cut both grains and matrix in samples taken 1.3 m below the upper contact (Plate II, C).

Interpretation: The crinozoan grainstone beds of this facies mark the top of Smith's Cycle A. The stratigraphically higher wackestone and packstone beds suggest deposition in an environment that fluctuated between high and low turbulence. The packstone and wackestone mark the base of Smith's Cycle B and represent deposition between storm and fair weather wave base.

The origin of the dolomite is illusive. Bathurst (1975) reviews methods of dolomite formation. Two models of secondary dolomitization are favored. The first is seepage reflux (Adams & Rhodes, 1960). This model assumes an interaction between fresh and marine water creating a zone of favorable dolomite precipitation. The second is early subareal exposure. At Bandbox Mountain the packstone-wackestone sequence and the flat top of this facies tend to favor the latter. Unfortunately, exposure is small and conclusive evidence was not obtained.

Borings indicate some sediment was lithified early. Hardground formation occurs commonly in submarine environments where fresh water and marine water interact. Shinn (1969) describes hardground surfaces developed on wave swept surfaces.

Crinozoan Grainstone Facies

Description: Sharply overlying the Dolomitic Facies is the massive Crinozoan Grainstone Facies (Figure 7, Plate III, D). This facies forms the "inner core" of the cliff forming the buildup. Thickness varies, but attains a maximum of 4 m. Light colors contrast with darker rocks below.

Crinozoan columnals dominate the bioclasts composing 40 to 60% of the rock. Fragments of bryozoan colonies are moderately abundant to abundant. Echinoid spines and brachiopod shell fragments are rare.

Tiny euhedral dolomite crystals, less than 0.1 mm long, make up less than 5 percent of the rock. Minor amounts of chert have replaced dolomite and less commonly fossil grains.

Interpretation: In buildups described from the Bridger Range, Stone (1971, 1972) identified an inner core composed of bryozoan grainstone. Stone (1972) believed the inner core was formed by a bryozoan thicket that was later sparite filled. These organisms are believed to have initiated the buildup. The origin of the inner core on Bandbox Mountain is unknown.

Bryozoan Light Wackestone Facies

Description: The Crinozoan Grainstone Facies grades upward into the Bryozoan Light Wackestone Facies (Figure 7 & 8). Within this massive unbedded facies, colonies of the coral *Syringopora* sp. up to 0.3 m across occur in growth position. Undisturbed mud matrix occurs at the base, but bioturbation increases near the top (Plate III, F).

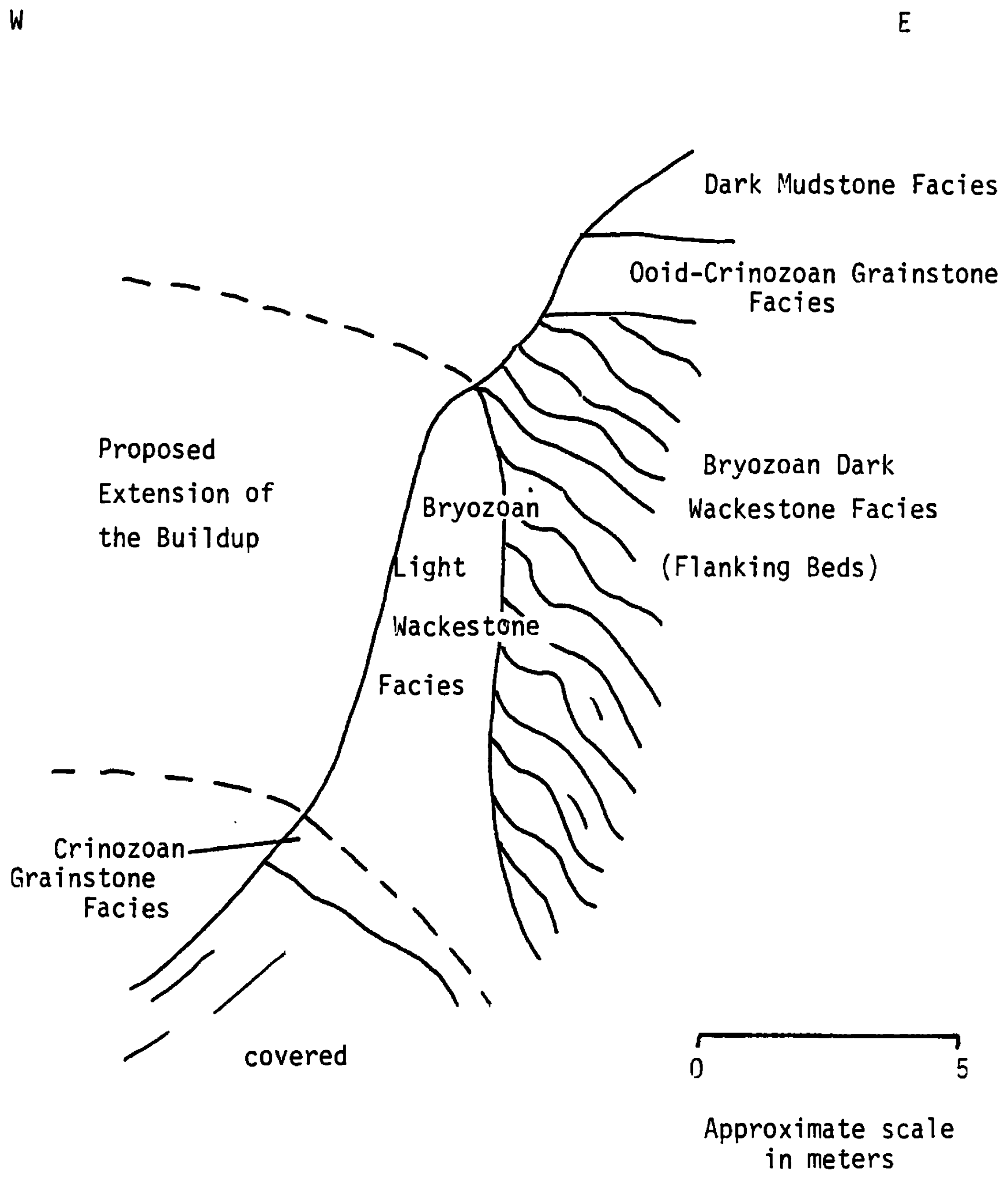


Figure 8. Field sketch showing the relationship of various facies of the buildup. Looking to the northwest.

PLATE III

A. Dolomitic Facies. Crinozoan grainstone from one of the three beds in the lower part of this facies (LBF-190, plane polarized, x20).

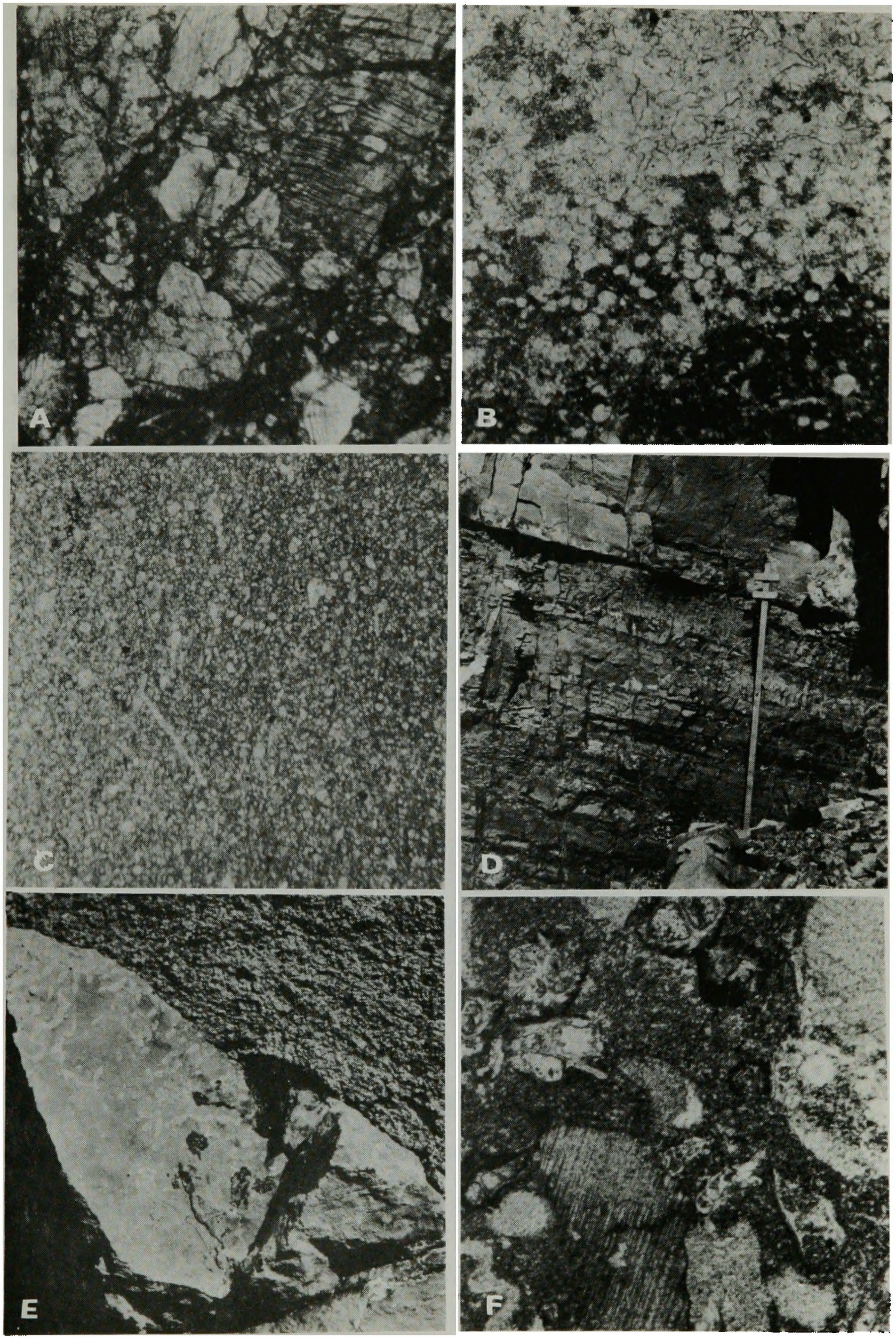
B. Dolomitic Facies. Wackestone/grainstone of the Dolomitic Facies showing the green alga *Garwoodia* sp. (LBF-204, plane polarized, x20).

C. Dolomitic Facies. Dolomitic grainstone/packstone at contact between the Dolomitic Facies and Crinozoan Grainstone (LBF-213, plane polarized, x20).

D. Contact between the Dolomitic Facies and the Crinozoan Grainstone on the west face of Bandbox Mountain.

E. Contact between Coral Framestone/Wackestone Facies and the overlying Crinozoan Grainstone Facies.

F. Bryozoan Light Wackestone Facies. Thin section near the base showing grains supported in a mud matrix (LBF-258, plane polarized, x20).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Fenestella sp. and other bryozoans dominate the bioclasts. Brachiopod shell fragments, sponge spicules, crinozoan columnals and echinoid spines are rare. Near the top, bioclasts increase and are more fragmental.

Small dike-like structures cross the wackestone. These contain friable crinozoan grainstone. Numerous fractures a few millimeters wide occur filled with sparite. Many brachiopod shells have been recrystallized. Dolomite is common especially near the middle.

Interpretation: This wackestone facies forms the main body of the buildup. The fine-grained matrix was deposited in a low turbulent environment. The dike-like structures and sparite filled fractures are believed to reflect early compaction and volume reduction. The origin of the mud and the trapping mechanism remain undiscovered. Possible mechanisms suggested by Wilson 1975 p. 165 include:

> "....(1) hydrologic accumulations shaped by currents, (2) entrapment and/or precipitation by algae to create local piles of carbonate mud, (3) entrapment of lime mud by baffling action of bryozoans and crinoid, or (4) a combination of baffling and trapping by thickets of these organisms with accumulation in the lee of such thickets induced by gentle currents."

The absence of brachiopods and the "churned" appearance of the upper part of the buildup may suggest the presence of dense algal growth. Decay of this material and compression of the space occupied by the plants could generate the dike-like fractures.

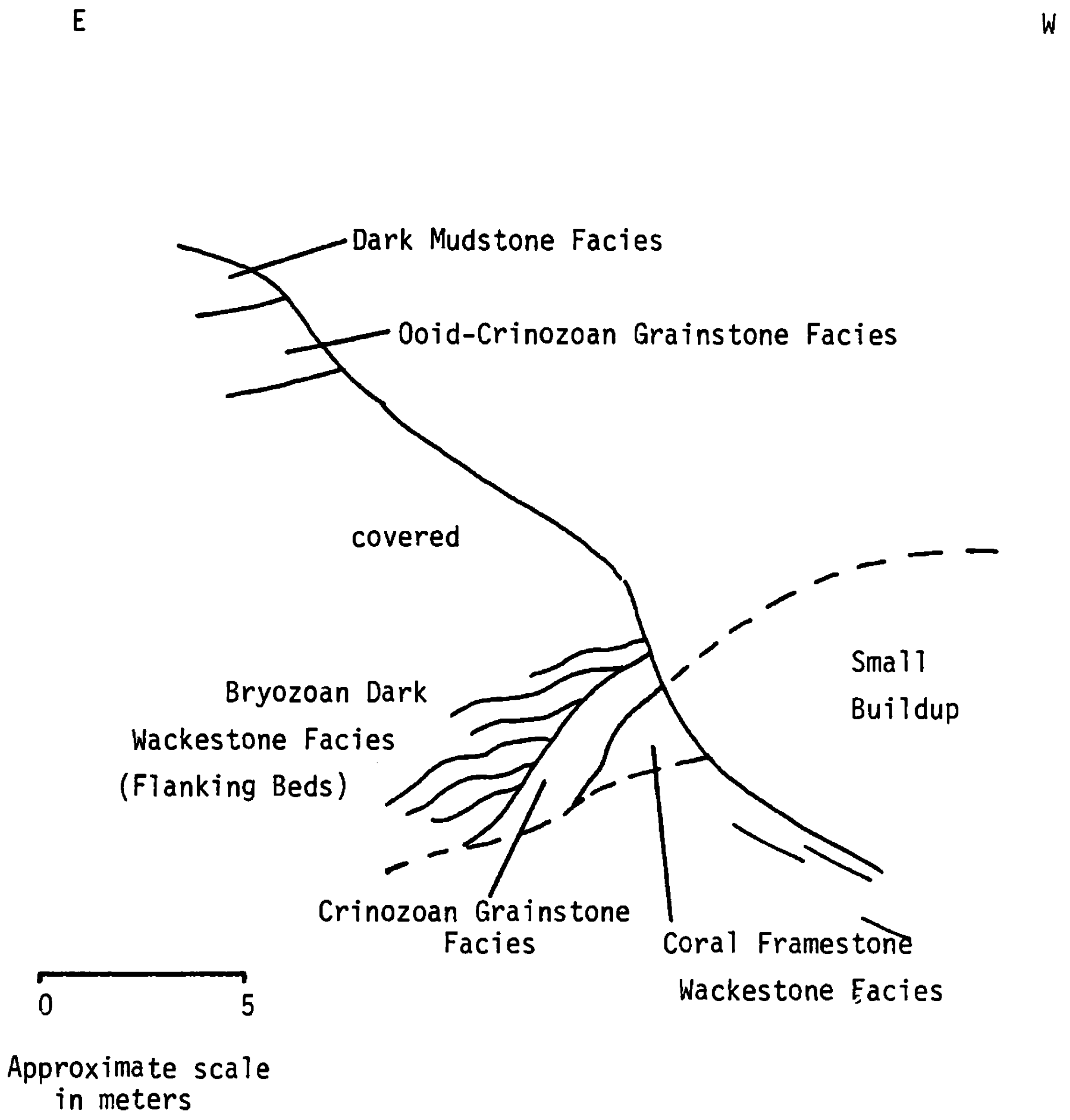


Figure 9. Field sketch showing facies relationships within the buildup and the proposed small southern buildup. Looking southeast.

Coral Framestone/Wackestone Facies

Description: Along the southern end of the buildup is an eight meter interval containing numerous colonies of coral scattered in light colored wackestone (Figure 7). The Coral Framestone/Wackestone Facies is isolated from the main body of the buildup by covered intervals. The wackestone between coral colonies resembles that of the Bryozoan Light Wackestone Facies. This facies is separated because of the high concentrations of corals and the association with other facies cannot be observed. Crinozoan Grainstone Facies occurs above this facies (Plate III, E).

Bioclasts in the wackestone are fragmental. Bryozoan and crinozoan columnals are dominate. Percentage bioclast is variable and dominated by bryozoan and crinozoan columnals. Bioturbation and pelloids occur in some beds. Brachiopod shell fragments, sponge spicules and echinoid spines are rare (Plate IV, A).

A stylolite, accentuated by limonite concentration, cuts 60 to 70 percent of the exposure. Euhedral dolomite is associated with the iron oxide (Plate IV, C).

Interpretation: The Coral Framestone/Wackestone was deposited in a similar environment as the Bryozoan Light Wackestone. The wackestone filling between coralites and coral colonies probably formed a similar way as the main part of the buildup. The Coral Framestone/Wackestone Facies represents either an earlier buildup or the edge of a second buildup.

Bryozoan Dark Wackestone Facies

Description: The Bryozoan Dark Wackestone rests in sharp contrast on the light colored facies below (Figure 7). The thickness varies but attains a maximum of four meters. This facies appears to lap onto the underlying Bryozoan Light Wackestone Facies (Figure 8). Bedding is irregular and rounded, bored coral rubble is common in the lower part. Colonies and parts of colonies up to 6 cm across occur randomly oriented to the bedding.

Fenestrella sp. bryozoans are abundant and occur randomly as scattered zoaria fragments often aligned parallel to the bedding. Crinozoan columnals are also abundant. Brachiopods, sponges, spicules and echinoid spines are rare. The upper part is burrowed and contains 20 to 30 percent pelloids (Plate IV, D).

Interpretation: This facies represents reworked material as wave turbulence increased with decreasing sea level in Smith's (1972) second cycle.

Ooid-Crinozoan Grainstone Facies

Description: Restricted to the top of the Bryozoan Dark Wackestone Facies is the light colored Ooid-Crinozoan Grainstone Facies (Figure 7). This facies reaches a maximum of four meters thick and thins northward. The contact with the underlying facies is abrupt. The Ooid-Crinozoan Grainstone Facies is composed of crinozoan columnals and bryozoan fragments with thin lenses of ooliths. Near the upper surface the number of ooliths increases and compose 20 percent of the rock (Plate IV, E). Ooliths range from 0.4 to 0.6 mm in diameter. They have radial fibers that cross the concentric lamellae.

Interpretation: Deposition of the Ooid-Crinozoan Grainstone Facies occurred in a high turbulent environment. This facies represents the top of Smith's Cycle B and documents the second marine regression. It is restricted to a topographic high created by the reworked material (Bryozoan Dark Wackestone Facies) and the buildup.

Dark Mudstone Facies

Description: The Dark Mudstone Facies occupies the remaining 73 m of Bandbox Mountain (Figure 7). These rocks are poorly exposed and much of the information was gathered from rock fragments. There is probably more than one facies present, but the poor exposure makes division difficult. These rocks contain a series of flat laminated dark mudstone and grainstone. Graded bedding is common, thickness ranges from one to five centimeters. Fossils are rare, except close to grainstone beds where brachiopods, gastropods, echinoderm stems and crinoid calices are abundant. Fenestrellate bryozoans and corals are rare. The trace fossils Zoophycus, Rhizocorallium and ? Cruziana are common. Pelloids make up as much as 30 percent of some beds. Sponge spicules are relatively abundant in wackestone layers.

Interpretation: Laminated beds and abundant burrows suggest this facies was deposited in a low turbulent environment.

PLATE IV

A. Coral Framestone/Wackestone Facies. Thin section through a Syringopora colony showing the fine-grained matrix and fragmental bioclasts (LBF-2-7, plane polarized, x20).

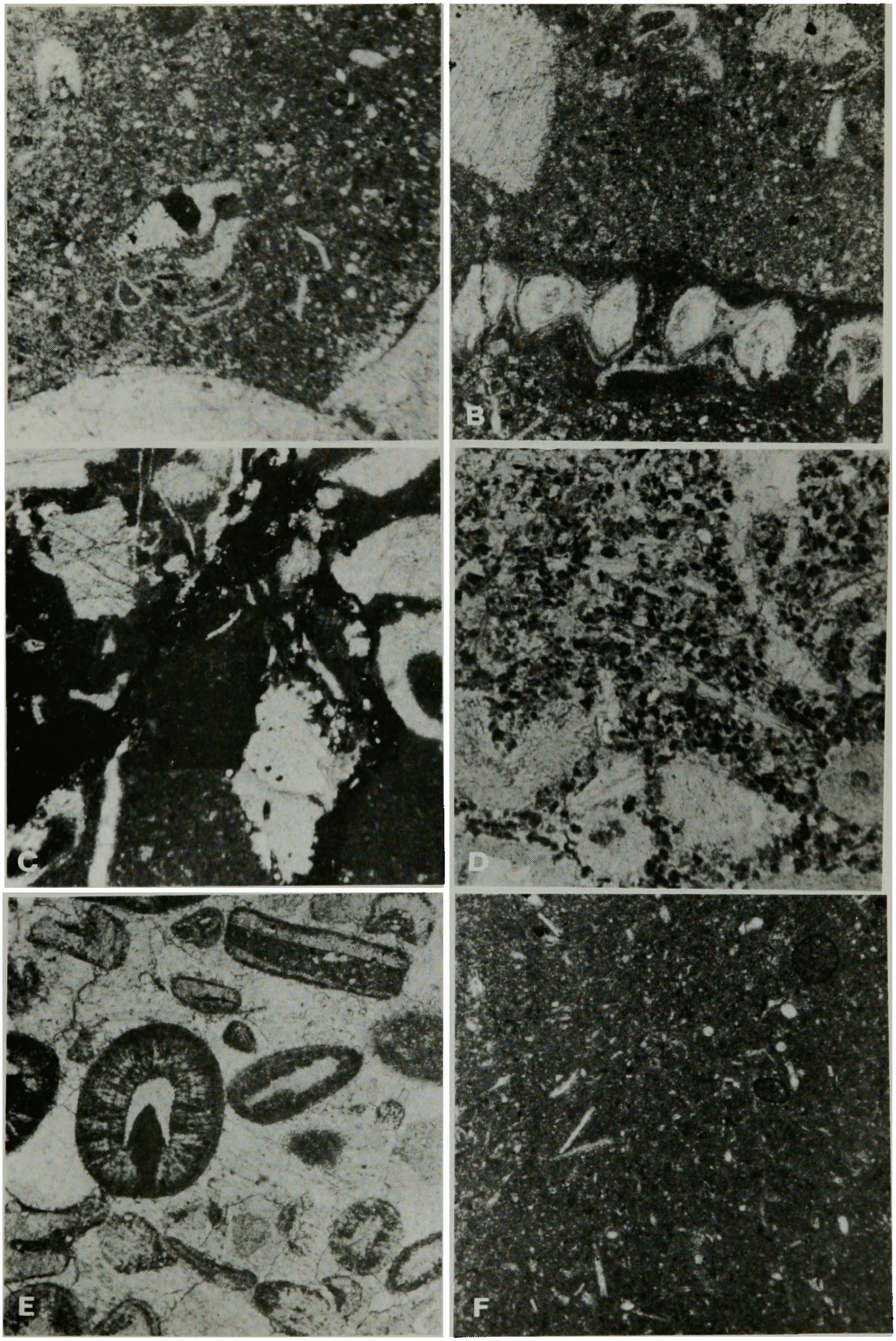
B. Bryozoan Light Wackestone Facies. Upper portion of this facies showing burrowed wackestone (LBF-260, plane polarized, x20).

C. Coral Framestone/Wackestone Facies. Thin section showing stylolitic boundary (LBF-B, plane polarized, x20).

D. Bryozoan Dark Wackestone Facies. Section showing crinozoan columnals and pelloids (LBF-249, plane polarized, x20).

E. Ooid-Crinozoan Grainstone Facies. Upper oolith sequence (LBF-289, plane polarized, x20).

F. Dark Mudstone Facies. Typical mudstone with pelloids and sponge spicules (LBF-524, plane polarized, x20).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This facies represents the sediment wedge moving into the deep water trough. Flat laminated beds are periods of normal deposition and graded grainstone beds represent slumps of material down the wedge front.

CHAPTER IV

REEF VERSUS NONREEF

Introduction

The terms buildup, reef, bioherm, and a number of others that refer to mound-like structures have been used differently by different geologists. Reef originally designated an accumulation of coarse rock, bedrock or sand that could be hit by a ship (Cuming, 1932). Since the early definition, the term has developed a dual meaning as either a stratigraphic reef or ecologic reef (Duhnam, 1970). The former refers to a descriptive meaning, the later to a genetic meaning. Heckel (1974) reviewed these terms and defined them in terms of environmental factors. Heckel's work did not stop the controversy surrounding the reef concept and an additional attempt to clarify the situation was made by Tsien (1981).

Buildup is defined by Heckel (1974, p. 91) as:

> ".....(1) differs in nature to some degree from equivalent deposits and surrounding and overlying rocks; (2) is typically thicker than equivalent carbonate; (3) probably stood topographically higher that the surrounding sediments during some time in its depositional history."

Heckel subdivides buildups into seven sub-types depending on evidence of wave resistance and control over the surrounding environment (see Figure 13 for Heckel's complete classification). Banks show no control over the surrounding environments, reefs control local sedimentation. Much of the controversy that exists involves the role of organic component. Bank

Figure 10. Usage of terms "reef", "bank" and "buildup". From Heckel, 1974. More general terms (aboved dashed lines) include more specific terms (below dashed lines).

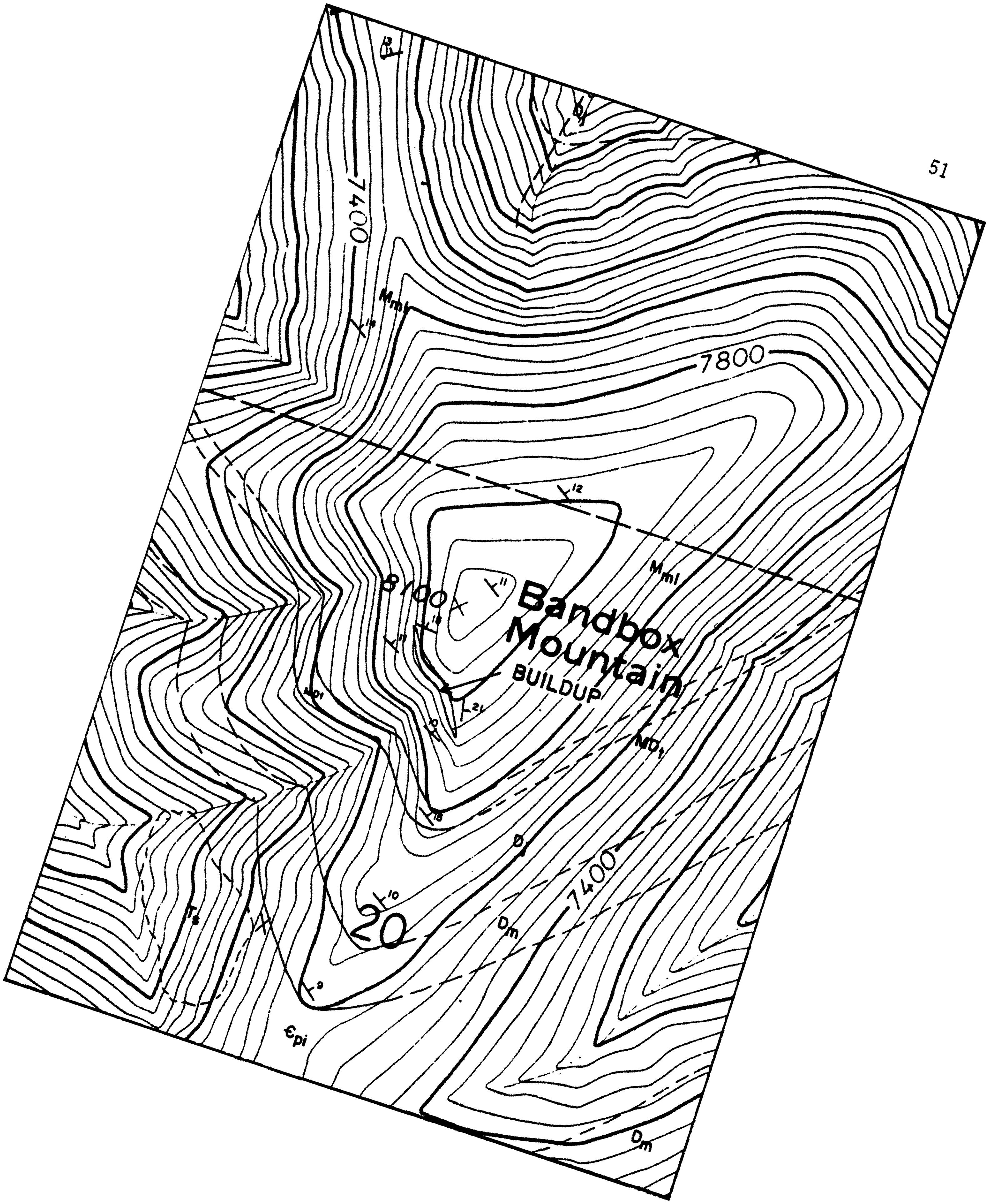
<table>
<tr><td></td><td colspan="7">Evidence of positive topographic relief
BUILDUP (if large, broad, PLATFORM, SHELF)</td></tr>
<tr><td rowspan="2">No evidence of relief. (if high skeletal content, BIOSTROME)</td><td rowspan="2">No evidence of type indicated at right</td><td colspan="6">Evidence of potential wave resistance or of turbulent water, implying wave resistance & evidence of some degree of control over surrounding environments.
REEF (if built mainly by organisms, ORGANIC REEF)</td></tr>
<tr><td colspan="3">wave-washed talus absent</td><td colspan="3">wave-washed talus present
FRAMEWORK REEF</td></tr>
<tr><td colspan="2">BANK</td><td>Organic framework present, but no evidence of water turbulence
POTENTIAL REEF
(in deep or calm water)</td><td>Abraded-grain calcarenites + remains of rooted organisms
ORGANICALLY? BOUND SKELETAL-DEBRIS REEF</td><td>Early rims of drusy spar
SPAR-CEMENTED DEBRIS REEF</td><td>Talus calcilutite: if stromatolitic, STROMATOLITE REEF;
if abraded mud clasts, MUD-FRAMEWORK REEF</td><td>Talus inorganically bound by spar cement
INORGANIC-FRAMEWORK REEF;
SPAR-CEMENTED FRAMEWORK REEF</td><td>Talus organically bound + large skeletal fragments
ORGANIC-FRAMEWORK REEF</td></tr>
</table>

organisms are passive and incapable of raising their substrate (Lowenstam, 1950). The resulting carbonate sedimentation creates a bank that is unconsolidated and develops low angle slopes because it lacks debris-binding organisms. Reefs have actively growing organisms that are capable of raising their substrate, binding organisms may create rather high angle slopes (Lowenstam, 1950). The distinction between reef and bank is the determination of the role of the organisms as active or passive. Because of selective preservation and the knowledge of some fossil groups, the role of the organic component is the major point of controversy in differentiating reefs and banks.

On Bandbox Mountain, there is little doubt that the term buildup describes the lensoidal outcrop. Figure 7 shows clearly that the outcrop differs from the surrounding rocks and that it is thicker than the equivalent strata. Topographic relief is illustrated in Figure 11 where flanking beds of the Bryozoan Dark Wackestone Facies dip 21° away from the buildup to the east. Regional dip is to the northeast. On the northern end of the exposure, after rotation of all beds to the horizontal, the Bryozoan Dark Wackestone Facies dips 14° to the northwest. Dip of the overlapping beds indicate this lensoidal mass stood as high as 50 meters above the surrounding sea floor.

The buildup can be further classified, according to Heckel (1974), as a bank. Bank is applied because no evidence of control of local sedimentation was seen and there is an absence of

Figure 11. Detailed geologic map of the Bandbox Mountain Area showing the strike and dip of the beds above and below the buildup.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Dm

binding or rooted organisms as well as course-grained sediment. Bryozoans may have functioned as baffles to currents and allowed sediment to accumulate. The role of bryozoans as baffling organisms would produce organisms in an upright position supported by micrite. Fossils in this position were not observed. The role of bryozoans in other Mississippian age buildups is also inconclusive.

Mississippian Buildups

Throughout the Devonian, on a worldwide basis, stromatoporoids and to a lesser amount corals produced buildups ranging from small banks to massive reef complexes (Heckel, 1974). In the latest Devonian and early Mississippian, the number of stromatoporoids was drastically reduced and the major reef-building phase of the Devonian came to a close. Small carbonate buildups of the so-called "Waulsortian type" are common in Mississippian age rocks. These buildups generally contain a core of massive wackestone/ packstone and are flanked by crinozoan grainstone. Sparite is common in both core and flank and consists of cement (or "reef tufa") and Stromatactis structures. Waulsortian buildups are known from Ireland, Britain, Belgium, Canada and United States.

The term "Waulsortian" was first applied to "reef" limestone and dolomite described near Waulsort, Belgium by Edouard Depont in 1863. The Belgium buildups are located on the Midi thrust sheet south of Brussels. These rocks are described in detail by Lees (1982). The buildups are small, 200-400 m long and up to 100 m thick. They are stacked like pancakes forming the "reef". The buildups rest on crinozoan grainstone and are overlain by complex facies that includes biomicrite.

The buildups of Great Britain occur in both the northern and southern parts of the country. They are similar to those in Belgium (Lees, 1982). Algae are rare; this fact coupled with the fine grain size has lead to the conclusion that they formed in deep water, at depths of 100 to 300 m. The Belgium buildups show no evidence of wave turbulence, but the structures of northern Great Britain are thought to have grown into the storm base (Miller, 1982).

In Ireland Waulsortian facies occur in both the northern and southern part of the country (Lees, 1974). A complex of small mounds forms a large barrier reef-like structure 208 km long and 48 km wide across the south. Isolated mounds a few tens of meters thick occur in the northern part of the country (Sevastopulo, 1982). Sevastopulo considered the Irish facies to have been deposited in deep water. The conclusion is based on sedimentary structures, grain size and lack of algae.

North American Waulsortian Facies

Within the United States, Waulsortian buildups have been identified in Tennesse and Kentucky (Lieber, 1978; Lieber & MacQuown, 1978, 1979; MacQuown & Hoffman, 1976; MacQuown & Perkins, 1980; MacQuown, 1982), Arkansas, Missouri and Oklahoma (Anglin, 1966; Harbaugh, 1957; Troell, 1962; Manger & Thompson, 1982), New Mexico (Cowan, 1980; Pray, 1965a, 1965b; Schaefer, 1976; Meyer & Lockmann, 1982; Lane, 1982) and Montana and

TABLE 1. Summary of the Occurrence of Waulsortian Facies in North America.

Location	Geometry	Size	Core Facies	Flanking Beds	Age
Tennesse & Kentucky MacQuown, 1982	subcircular forming a linear trend	several 1,000 m long, 2,000 m wide, 90 m thick	bryozoan-mudstone & wackestone	carbonate & clastic rocks	Kinderhookian
Mid-continent Manger, et. al., 1982	semicircular	max. 180 m in diameter, 19 m thick	bryozoan packstone, wackestone & mudstone	crinoid-bryozoan grainstone	Kinderhookian
New Mexico Pray, 1958	variable	up to 500 m dia., 100 m thick	massive fenestrate bryozoan wackestone	bedded wackestone & grainstone	Osagian
Montana Smith, 1982	semicircular	max. 1350 m across, 50 m thick	mudstone & wackestone	crinoidal wackestone/grainstone	Kinderhookian
Alberta Morgan & Jackson, 1970	probably semicircular	diameter unknown, thickness 100 m	crinoidal bryozoan wackestone	?	Osagian

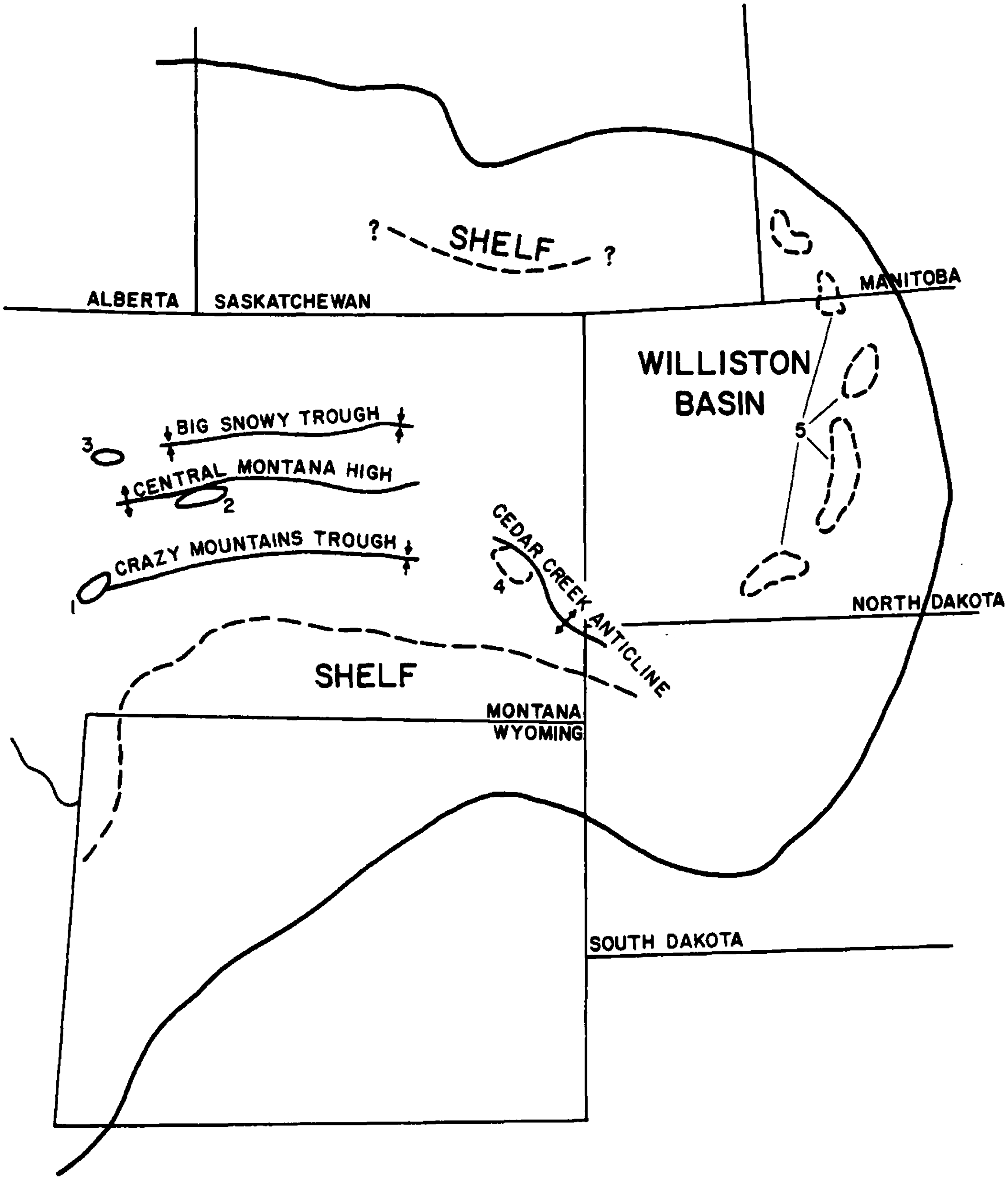
North Dakota (Cotter, 1963, 1965, 1966; Merriam, 1958; Stone, 1972, 1974; Smith, 1982; Bjorlie & Anderson, 1978). In Canada Waulsortian facies have been identified by Morgan & Jackson, 1970. The details of these buildups are summarized in Table 1. As can be seen the size of the buildup varies greatly, however, the general lithology is similar. All these buildups were deposited in deep water with the exception of those in Tennesse which were formed as bryozoans baffled sediment on shallow shoals (MacQuown, 1982).

Montana Waulsortian Buildups

Two Waulsortian buildups have been studied in Montana. Figure 12 shows the location of these and other Waulsortian facies known to occur in the subsurface. Size, stratigraphic location, and surrounding facies between buildups from the Bridger Range, Big Snowy Mountains and Bandbox Mountain appears in Figure 13.

The Waulsortian buildups of the Big Snowy Mountains were studied by Cotter (1963, 1965, 1966). The following summary is based on his work. The buildups rest directly on the Basal Paine Facies near the bottom of Smith's Cycle A. The maximum length is 570 m and maximum thickness is 60 m. The lower contact is abrupt and the upper contact appears conformable and gradual. The buildup includes three facies types: 1. wackestone, 2. sparry calcite, and 3. skeletal debris. Wackestone makes up 60% of the volume of the buildups. Sparry calcite, both in the form of primary cement and rare *Stromatactis* structure makes up about 15%. The remaining 25%

Figure 12. Waulsortian buildups in Montana and the Williston Basin. 1. Bridger Range. 2. Big Snowy Mountains. 3. Little Belt Mountains. 4. Cedar Creek Anticline (subsurface). 5. Williston Basin (subsurface). Compiled from Smith, 1982 and Bjorlie & Anderson, 1978.

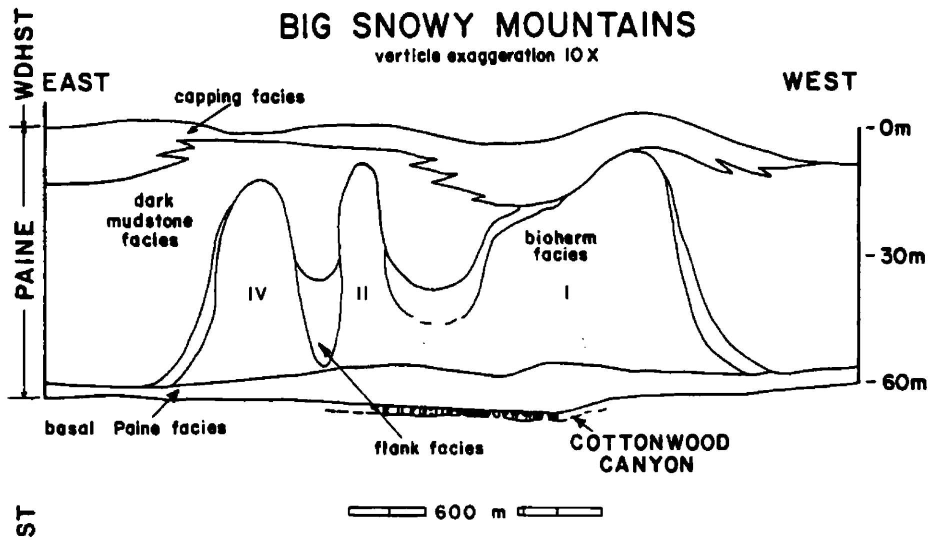

SHELF
?
?
ALBERTA
SASKATCHEWAN
MANITOBA
WILLISTON BASIN
5
BIG SNOWY TROUGH
3
CENTRAL MONTANA HIGH
2
CRAZY MOUNTAINS TROUGH
1
CEDAR CREEK ANTICLINE
4
NORTH DAKOTA
SHELF
MONTANA
WYOMING
SOUTH DAKOTA

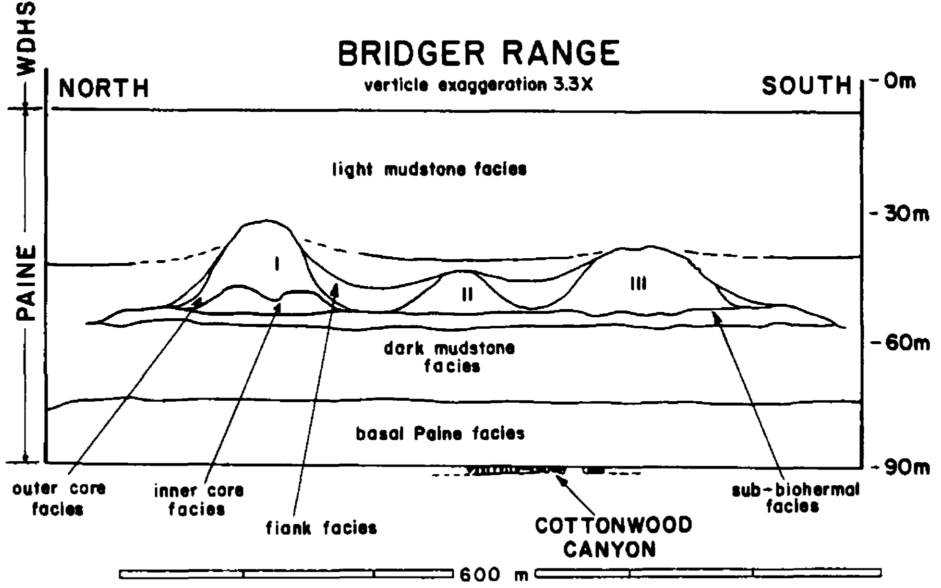
of the volume is composed of fossil debris, primarily fenestrellate bryozoans and crinozoan columnals. The buildup is layered with dips averaging 20-25°. The layers average 0.25 to 0.30 meters thick, each layer is defined by different proportions of the three constituents. A study of the geometry of the layers suggests the buildup stood as much as 50 m above the surrounding sea floor. Dike-like structures and irregular cavities filled with crinozoan stem packstone and grainstone cut the buildup layers. These are intrepreted to be compaction features.

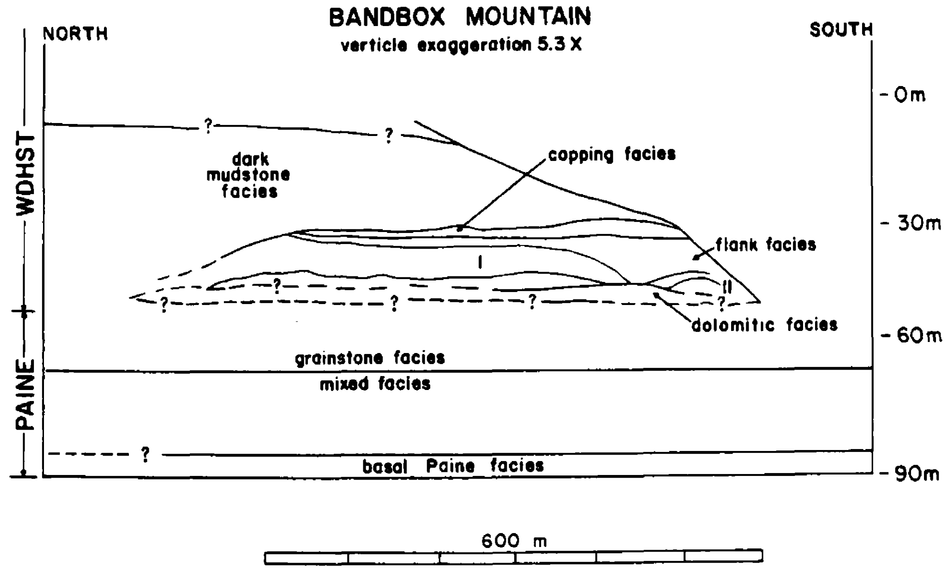
The buildups of the Bridger Range are smaller than those of the Big Snowy Mountains (Stone, 1972). The maximum length is 185 m with a thickness of 18 m. The base of the buildups are 35 m above the basal contact of the Lodgepole, still within Smith's Cycle A. Basal contact is abrupt and the upper contact grades into enclosing mudstone. Bryozoan grainstone forms the "inner core". The bryozoan zoaria are cemented by sparite and dip at angles up to 40° to the bedding. Lime mudstone with sparse fossil bryozoans and crinozoan columnals form the "outer core". Dike-like features present in the Big Snowy buildups are absent in the Bridger Range but, smaller brecciated zones suggest similar compaction processes. *Stromatactis* structures are rare.

The Bandbox Mountain buildup is 250 m long and reaches a maximum thickness of 24 m. It is located 65 m above the base of the Lodgepole Formation in the Woodhurst Member. The base

Figure 13. Comparison of the Big Snowy, Bridger Range and Bandbox Mountain Waulsortian buildups. Roman numerals represent either separate buildups or lobes of the same buildup. A. & B. redrawn from Smith, 1982.


BIG SNOWY MOUNTAINS
verticle exaggeration 10 X
EAST
WEST
WDHST
PAINE
capping facies
dark mudstone facies
bioherm facies
IV
II
I
basal Paine facies
flank facies
COTTONWOOD CANYON
-0m
-30m
-60m
600 m


BRIDGER RANGE
verticle exaggeration 3.3X
NORTH
SOUTH
WDHST
PAINE
light mudstone facies
I
II
III
dark mudstone facies
basal Paine facies
outer core facies
inner core facies
flank facies
COTTONWOOD CANYON
sub-biohermal facies
-0m
-30m
-60m
-90m
600 m


BANDBOX MOUNTAIN
verticle exaggeration 5.3 X
NORTH
SOUTH
WDHST
PAINE
dark mudstone facies
copping facies
flank facies
I
II
dolomitic facies
?
grainstone facies
mixed facies
basal Paine facies
-0m
-30m
-60m
-90m
600 m

of Smith's Cycle B occurs 9 m below the base of the buildup. The lower contact is abrupt while the upper contact is gradational. The dominant rock facies are crinozoan grainstone and bryozoan wackestone. Grainstone forms the base of the buildup and may correspond to the "inner core" described by Stone (1972). The bulk of the structure is composed of bryozoan wackestone. The buildup is massive and shows no bedding. Small dike-like structures are filled with poorly consolidated crinozoan grainstone. Structures attributable to *Stromatactis* are rare.

The brief description above compares the three localities. The Bandbox Mountain buildup shows many similarities to those of the Bridger Range and the Big Snowy Mountains. These include rare *Stromatactis*, dike-like compaction features and fauna. However, it is more similar to the Bridger Range buildups in size and lithology. It differs though, in that the basal lithology of the Bridger Range contains bryozoan grainstone and the Bandbox Mountain locality contains crinozoan grainstone. The major difference between the Bandbox Mountain buildup and the other two is stratigraphic position. Both the Big Snowy Mountains and Bridger Range buildups are within the Paine Member of the Lodgepole, the Bandbox Mountain buildup is within the Woodhurst Member, considerably higher in the section.

CHAPTER V

PALEONTOLOGY

General Paleontology

The Lodgepole Formation on Bandbox Mountain is highly fossiliferous. Identified were sixty-two taxa of invertebrates, two types of fish teeth, at least five trace fossils, a uniserial foraminifer, and the green alga *Garwoodia* sp. The fossil taxa along with relative abundance are listed in Table 2. Although detailed systematic paleontology and paleoecology are beyond the scope of this study, identifications are valid enough to permit preliminary paleoecology and comparison of this fauna with others reported from the Lodgepole.

Paleontological Communities

The term "community" is difficult to define with living examples, let alone fossil ones, but the concept involves the relationship of organisms to their environment and each other. Boucot (1981) reviewed the various meanings and summarized nine different conceptual groups. Paleoecologists have difficult problems in defining "community" because not all organisms have equal chnaces of being preserved. Soft-bodied animals, such as annelids and other worm-like groups are common in modern environments, but nearly absent in the fossil record. Subtle relationships such as parasitism, commensalism and symbiotic relationships are also difficult to evaluate. Because of these problems, Boucot (1981, p. 182) defined "community" as:

TABLE 2. List of Taxa and Their Relative Abundance within The Four Recognized Benthic Communities.

A= abundant, more than 20 collected; C= common, 5 to 20 collected; R= rare, less than 5 collected.

	Community			
	I	II	III	IV
Chlorophyta				
Garwoodia sp.		R		
Protozoa				
unident foraminifera		R		
Cnidaria				
Rylstonia cf. *R. teres* (Girty)		A		R
Vesiculophyllum sp. A		C		
Vesiculophyllum sp. B		R		
Aulopora sp.		R		R
? *Lithostrotion* sp.			R	
Cleistopora placenta (White)		R		
Syringopora aff. *S. suraularia* Girty			A	
Syringopora aculeata Girty			C	
Lithostrotionella microstylum Girty			C	
Bryozoa				
Fenestrella sp. A	C	A		C
Fenestrella sp. B		A		
Fenestrella sp. C		A		R
? *Fenestrellina* sp.		C		
Pennireptepora sp.		C		
? *Fenestralia* sp.		R		
Rhombopora sp.	A	A		A
? *Cheilotrypa* sp.		C		
Sulcoretepora sp.	C	A		C
large trepostomata unident				R
Brachiopoda				
Camarotoechia cf. *C. chouteauensis*	R	R		
Camarotoechia cf. *C. inaequa* Shaw	C	R		A
Reticularia sp.		R		R
Spirifer cf. *S. centronatus* Winchell		A		
Spirifer cf. *S. grimesi* Hall	C	A		
Spirifer grimesi Hall		C		C
Spirifer mudulus Rowley		R		
? *Delthyris* sp.		R		R
Cleiothyridina sublamellosa (Hall)	R	R		R
Chonetes sp. A		R		R
Chonetes sp. B		R		
Linoproductus ovatus (Hall)		C		
Dictyoclostus cf. *D. inflatus*		A		C
Dictyoclostus cf. *D. fernglenensis* (Weller)		C		
Dictyoclostus sp.		C		
Schizophoria chouteauensis Wheller		R		
Schizophoria swalleri (Hall)		C		C
Torynifera montanus Shaw		R		
Composita humilis (Girty)		C		
Brachiopoda continued				
Dielasma sp.		R		
Leptaena analoga (Phillips)		A		R
Schellwienella cf. *inflata* (White & Whitfield)		C		
? *Leptagonia* sp.		R		
? *Atrypa* sp.		R		
Eumetria sp.				A
Schuchertella sp.		R		
Schallwienella sp.		R		R
Mollusca				
Bivalves				
Grammysia cf. *G. welleri*		R		
Edmondia cf. *E. marionensis*		R		
Gastropods				
Spraparallus sp.	C			A
Euomphalus sp.		R		
Platyceras sp.	C			A
(Platyceras) cf. *P. niagarense* (Hall)		A		
Loxonema sp.	R			C
Cephalopoda				
unident nautiloid		R		
Arthropoda				
Trilobites				
Exochops sp.		R		
unident proetaean		R		
unident fragments		C		R
Echinoderms				
Blastoids				
Pentremites sp.		R		
Crinoids				
? *Cactocrinus* sp.	R			
Dinotocrinus sp.	R			
Culmicrinus cf. *C. jeffersonensis* Laudon & Severson	R			
Platycrinus incomptus White				R
Platycrinus bozemanensis Miller & Gurley				C
Chordata				
unident fish 1		R		
unident fish 2				R
Trace fossils				
Zoophycus	R			A
Rhizocorallum	R			A
? *Cruziana*				C
"Snail tracks"				A

> "....recurring associations and relative taxic abundances that proved to be useful to the researcher."

The geographic boundaries of modern communities often grade into each other. The same is true with fossil communities. Paleontological communities not only merge laterally but also horizontally through time. It is important to define the community on a broad enough scale as to eliminate cyclic or seasonal changes within populations of organisms (Boucot, 1981).

On Bandbox Mountain, four communities were identified. Benthic invertebrates predominate, constituting a major component of epifaunal filter feeders. The precise boundaries of these communities are not defined, partially because of the factors mentioned above and partially because precise stratigraphic control of collections was not obtained.

Community I

Community I is the lowermost community, it roughly corresponds to the lower part of the Mixed Light Wackestone Grainstone Facies (see Figure 14). Fossils are not abundant in this community, nor is there a great deal of diversity illustrated by the presence of only fifteen taxa (Table 2 and Figure 15). The most abundant taxa are brachiopods, followed by gastropods and crinoids. Fifty-five percent of the organisms are low level filter feeders; high level filter feeders and scavengers exist in equal proportions. The fossils are unabraded and delicate fossils such as crinoid calices are articulated.

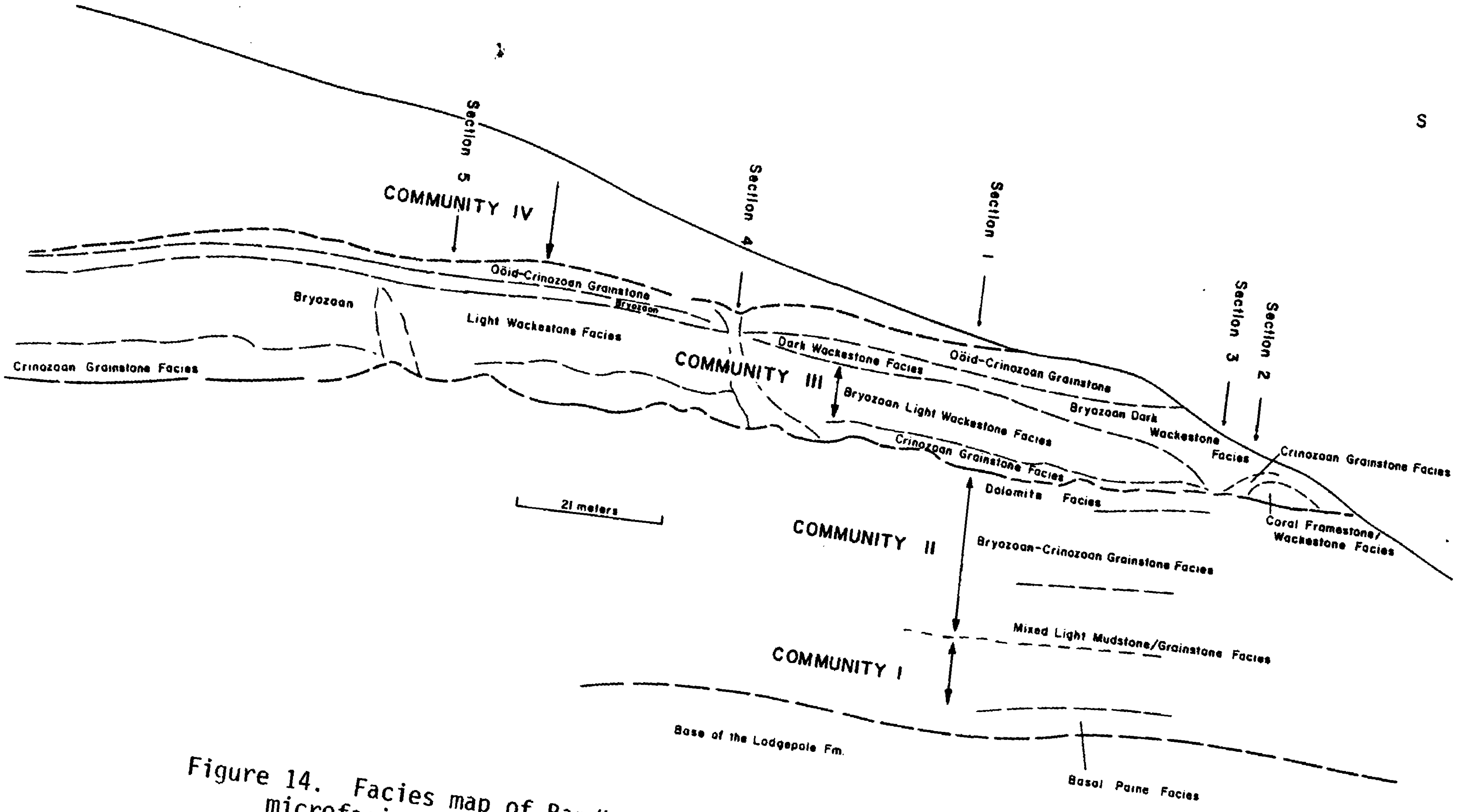
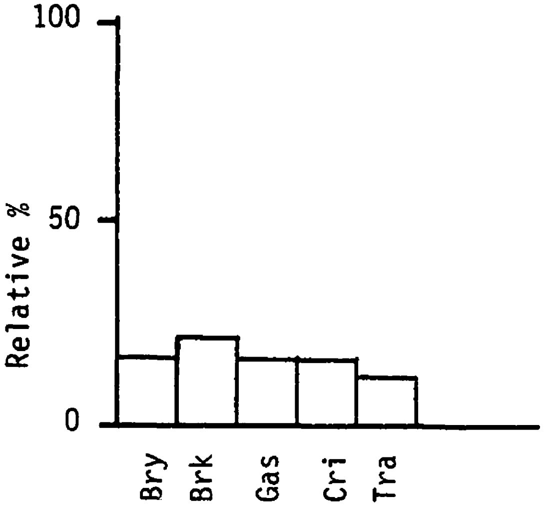
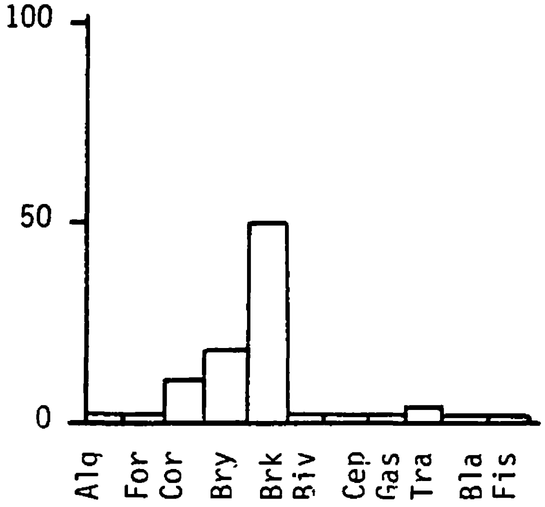


Figure 14. Facies map of Bandbox Mountain showing the relationshin between microfacies and the four biotic communities.

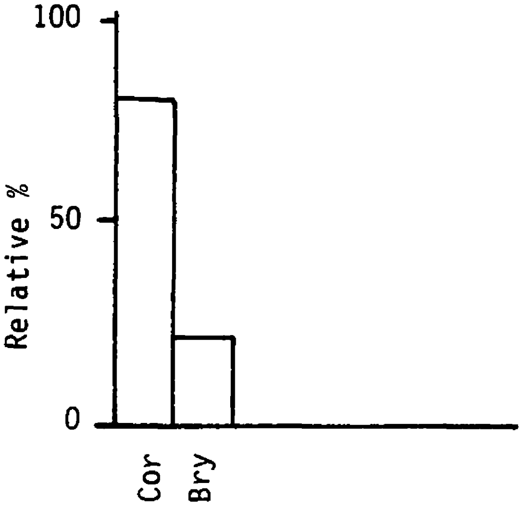
Figure 15. Taxonomic composition of the four communities from Bandbox Mountain.



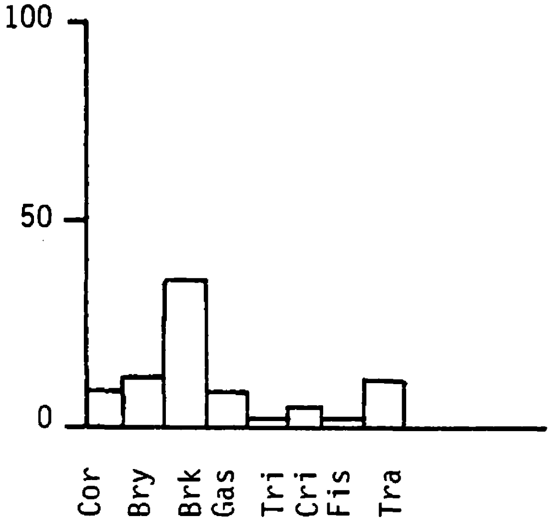
Community I
n=15



Community II
n=50



Community III
n=5



Community IV
n=29

Cor=coral, Bry=bryozoan, Brk=brachiopod, Gas=gastropod, Cri=crinoid, Biv-bivalve, Tri=trilobite, Bla=blastoid, Tra=trace, Alg=alga, For=foraminifera, Cep=cephalopod, Fis=fish.

TABLE 3. General Autecology of the Bandbox Mountain Fauna.

Taxon	Morphology	Life Site & Habits	Feeding Type
Chlorophyta			
Garwoodia sp.		epifaunal	producer
Cnidaria			
Rylstonia sp.	solitary, ceratoid	epifaunal	micro-preditor
Vesiculophyllum sp.	solitary, ceratoid	epifaunal	micro-preditor
Aulpora sp.	solitary, dendroid	epifaunal	micro-preditor
?*Lithostrotion* sp.	colonial, ceratoid	epifaunal	micro-preditor
Cleistopora sp.	colonial, ceratoid	epifaunal	micro-preditor
Syringopora sp.	colonial, phaceloid	epifaunal	micro-preditor
Lithostrotionella sp.	colonial, ceroid	epifaunal	micro-preditor
Bryozoa			
Fenestrella sp.	fenestrellate	epifaunal	low level filter feeder
? *Fenestrellina* sp.	fenestrellate	epifaunal	low level filter feeder
Pennireptepora sp.	fenestrellate	epifaunal	low level filter feeder
? *Fenestralia* sp.	fenestrellate	epifaunal	low level filter feeder
Rhombopora sp.	ramose	epifaunal	low level filter feeder
Sulcoretepora sp.	blade-like	epifaunal	low level filter feeder
? *Cheilotrypa* sp.	encrusting	epifaunal	low level filter feeder
unident trepostome	encrusting	epifaunal	low level filter feeder
Brachiopoda			
Camarotoechia sp.	rhynchonelloid	epifaunal	low level filter feeder
Reticulara sp.	spiriferoid	epifaunal	low level filter feeder
Spirifer sp.	spiriferoid	epifaunal	low level filter feeder
? *Delthyris* sp.	spiriferoid	epifaunal	low level filter feeder
Cleiothyridina sp.	ovoid	epifaunal	low level filter feeder
Chonetes sp.	strophomenoid	epifaunal	low level filter feeder
Brachipods continued			
Linoproductus sp.	productoid	epifaunal	low level filter feeder
Dictyoclostus sp.	productoid	epifaunal	low level filter feeder
Schizophoria sp.	ovoid	epifaunal	low level filter feeder
Torynifer sp.	spiriferoid	epifaunal	low level filter feeder
Composita sp.	ovoid	epifaunal	low level filter feeder
Dielasma sp.	ovoid	epifaunal	low level filter feeder
Leptaena sp.	spirferoid	epifaunal	low level filter feeder
Schellwienella sp.	strophomenoid	epifaunal	low level filter feeder
? *Atrypa* sp.	spiriferoid	epifaunal	low level filter feeder
Eumetria sp.	spiriferoid	epifaunal	low level filter feeder
Schuchertella sp.	strophomenoid	epifaunal	low level filter feeder
Bivalves			
Grammysia sp.	round clam-shaped	infaunal	low level filter feeder
Edmondia sp.	bean shaped	infaunal	low level filter feeder
Gastropods			
Spraparallus sp.	planospiral	epifaunal	scavenger/ herbivore
Euomphalus sp.	planospiral	epifaunal	scavenger/ herbivore
Platyceras sp.	slipper-like	epifaunal	scavenger/ commensal
Loxonema sp.	high spired	epifaunal	preditor?
Arthropods			
Exochops sp.		epifaunal	scavenger
Echinoderms			
Pentremites sp.		epifaunal	high level filter feeder
All crinoids		epifaunal	high level filter feeder
Fish		pelagic	carnivore
Trace fossils		infaunal	deposit feeders

Community II

Community II occurs in the upper part of the Mixed Light Wackestone/Grainstone and the lower part of the Bryozoan-Crinozoan Grainstone Facies (Figure 14). Fossils are extremely abundant and more diverse than in Community I (Table 2 and Figure 15). Fifty taxa are present, representing eight phyla. Brachiopod diversity exceeds all other organisms, but numerically fenestrellate bryozoans dominate. Low level filter feeders make up the bulk of the community, but other groups such as burrowers, scavengers and preditors are also represented (Figure 16).

Community III

Community III contains colonial rugose corals and bryozoans. It is identified in the buildup facies, particularly in the Bryozoan Light Wackestone and Coral Framestone/Wackestone Facies (Figure 14). Diversity in this community is low with only five taxa present. All fossils were intermediate level filter feeders. Many corals appear in growth position.

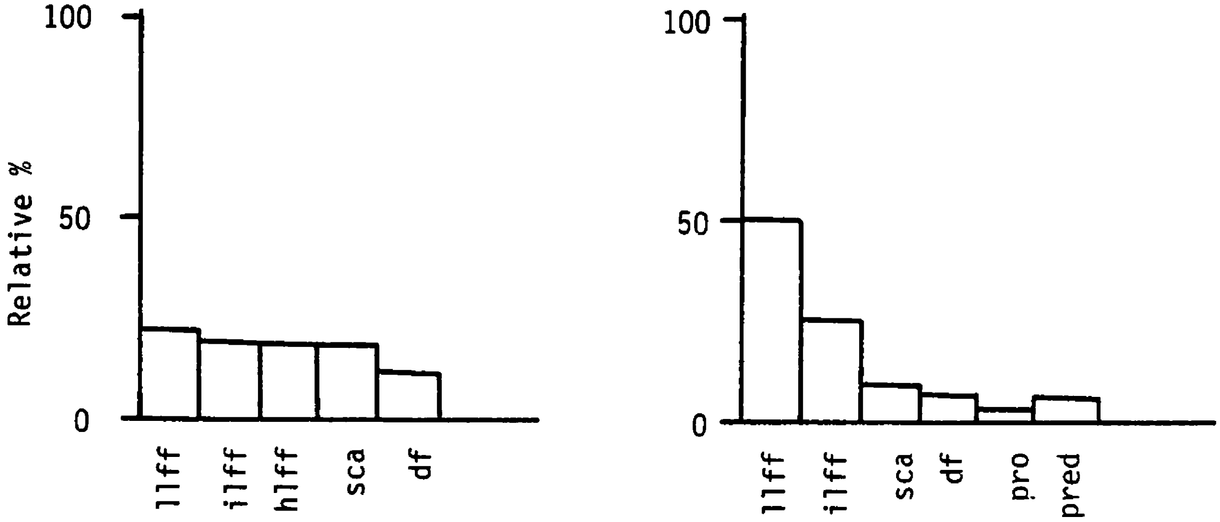
Community IV

The final community occurs in the poorly exposed strata of the Dark Mudstone Facies (Figure 14). Fossils are relatively diverse with twenty-nine taxa identified (Table 2 and Figure 15). Stratigraphic control is poorest in this community. Composition of this community is suspect, as many of the fossils were deposited by mass wasting processes described in Chapter III. The trophic structure of Community IV resembles Community I and they are believed to represent similar conditions of depth. Seventeen articulated crinoid calices were collected, all assignable to the genus Platycrinus. An unusual, but classic paleoecologic, association between the crinoid Platycrinus and the attached snail Platyceras was found in this community. The snail is believed to be a commensel on crinoids, living attached to the anal area feeding on fecal material. Bowsher (1955) reviewed this relationship and provides an excellent bibliography. Crinoid-platycerid snail relationships are common in Devonian and Carboniferous age rocks of the central United States. The Bandbox Mountain specimen is the first occurrence of this relationship in the Rocky Mountain region (A. Boucot, personal communication, 1984). Additional specimens have been reported from Europe (Ager, 1963) and the Soviet Union (Yakovlev, 1926).

Each of the four communities was subjected to trophic analysis following Walker (1972). The results appear in Figure 16. As seen, the communities are dominated by low level filter feeders. Ninety percent of the fauna is composed of epifaunal organisms.

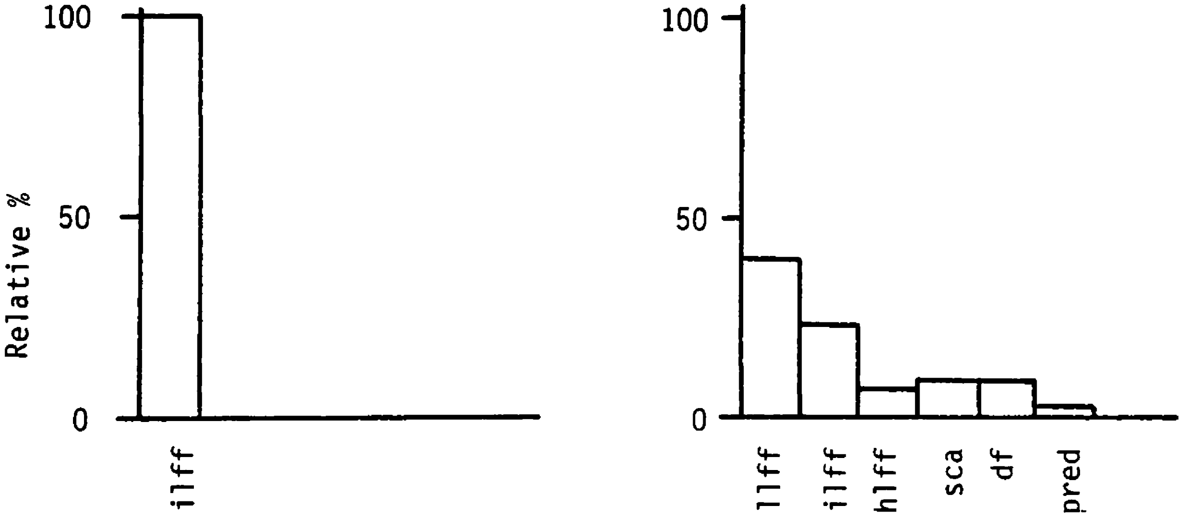
Low diversity can be an indication of harsh environmental conditions. Modern environments where conditions of sunlight, food, and protection produce diverse faunas. Examples such as the tropical rain forest and coral reef are well documented. In such environments intricate relationships develop and complex

Figure 16. Trophic analysis of the four communities on Bandbox Mountain.



Community I

Community II



Community III

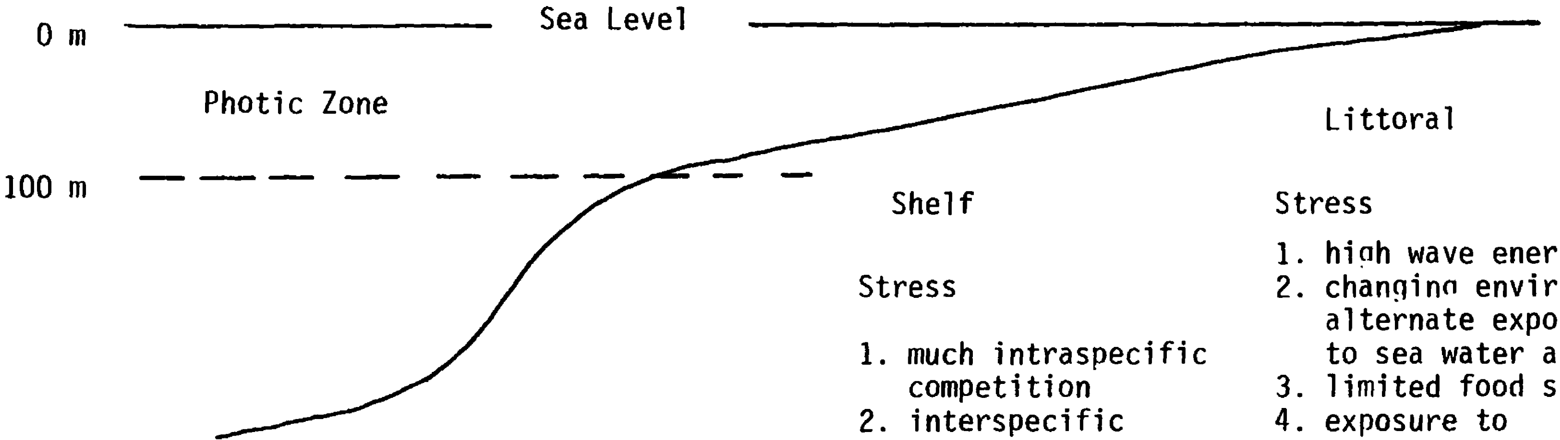
Community IV

llff=low level filter feeders, ilff=intermediate level filter feeders, hlff=high level filter feeders, sca=scavenger, df= deposit feeder, pro=producer, pred=preditor.

food chains develop (Boucot, 1981). In the "normal" marine environment, that is one in which there is open circulation, all environments are not equally suited for life. Figure 17 depicts a cross section of the "normal" marine setting in which there is a littoral zone, shelf zone and deep water zone. As summarized, each of these environments has various stress factors that limit the structure and composition of the community. In the littoral and deep water zones, these factors are physical stresses such as exposure, pressure and changing salinity. In environments where physical stress is reduced, biological stress is increased.

The four graphs in Figure 16 show the various trophic groups and diversity of feeding types. I believe Community I, III, and IV must have existed under more physical stress than Community II. Due to the type of organisms, I believe they represent communities below normal wave base. The dominate food is microparticulate material that filters down from above. The substrate is mud and richly organic. The large number of trace fossils in Community IV, represent the burrowing, sediment feeding element of the community. Community II contains greater diversity of organisms and trophic groups. Algae coated grainstone fragments suggest this zone was not only agitated, but also received abundant light. Modern oceans would produce such sediment at depths of 15 to 60 m.

Figure 17. Environmental stress in the modern marine environment.



Littoral

Stress

1. high wave energy
2. changing environment alternate exposure to sea water and air
3. limited food supply
4. exposure to dessication

Shelf

Stress

1. much intraspecific competition
2. interspecific competition
3. large number of preditors
4. parasitism

Deep

Stress

1. pressure
2. darkness
3. limited food supply
4. possible low oxygen supply

The results of community analysis plus information provided from stratigraphy allow construction of models of various times (Figure 18).

Other Lodgepole Faunas

Other faunal studies, of the Lodgepole, include a detailed systematic study of the Big Snowy Mountain buildup (Merriam, 1958), a faunal list from the Sun River Canyon Area (Mudge, Sando & Dutro, 1962), a faunal list from the type locality near Three Forks, Montana (Holland, 1952) and a faunal list from the Gravelly Range, Montana (Mann, 1954). Taxonomic studies of crinoids (Laudon & Severson, 1953), brachiopods (Shaw, 1962), (Rodriguez and Gutschick, 1968, 1969) and corals (Sando, 1960) complete the knowledge of Lodgepole faunas.

A comparison of the fauna from Bandbox Mountain to others described in the Lodgepole Formation is found in Table 3. Sixteen taxa occur on Bandbox Mountain that have not been found in other localities. Of particular interest is the abundance and diversity of bryozoans, crinoid and trilobites (Plate V & VI). Trilobite fragments are reported from Sun River Canyon, but none are identified (Mudge, et. al., 1962). All crinoids found at Bandbox Mountain occur in the Bridger Range (Laudon & Severson, 1953). The great abundance of bryozoan types is unreported at other localities.

In other areas of Lodgepole outcrop, the fauna has rather low diversity. The faunal list from the Big Snowy Mountains

Figure 18. Community reconstructions. A. Community I. Sparse fauna of crinoids, brachiopods and bryozoans, rare trace fossils. B. Community II. Diverse fauna of bryozoans, brachiopods, corals, trilobites, cephalopods, bivalves and fish. C. Community III. Buildup community of colonial corals and fenestrellate bryozoans. D. Community IV. Sparse fauna of crinoids, bryozoans, gastropods and brachiopods, crinoid thicket located a short distance away.

Wave base refers to fair weather wave base in all diagrams.

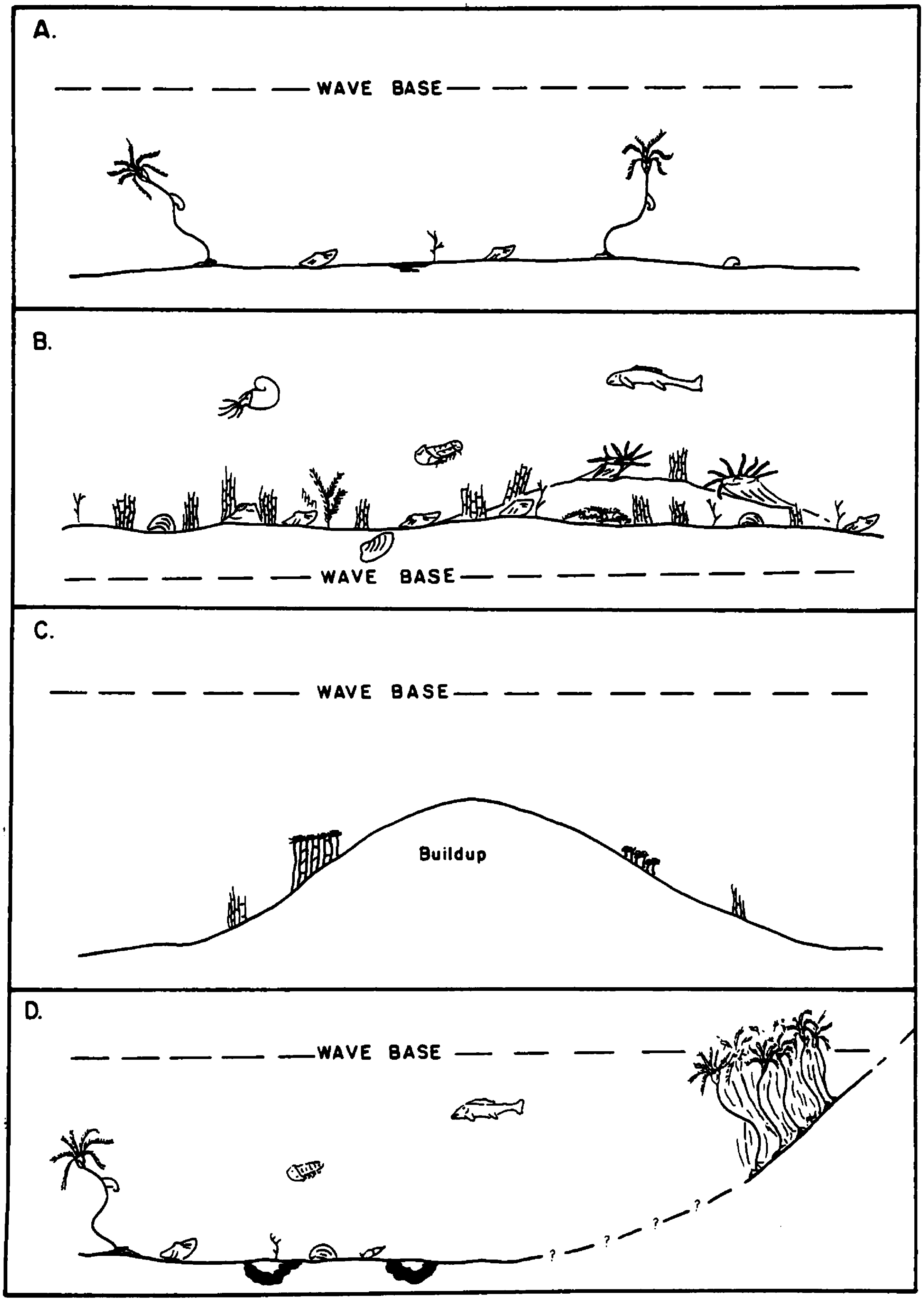

A.
WAVE BASE
B.
WAVE BASE
C.
WAVE BASE
Buildup
D.
WAVE BASE
?
?
?
?

TABLE 4. Comparison of the Bandbox Mountain Fauna with other Faunal Lists from the Lodgepole Formation. 1. Sun River Canyon (Mudge et. al., 1962). 2. Swimming Woman Canyon, Big Snowy Mountains (Merriam, 1958). 3. Type locality near Three Forks (Holland, 1952). 4. Gravelly Range (Mann, 1954).

	1	2	3	4
Chlorophyta				
Garwoodia sp.		X		
Protozoa				
unident foraminifera				
Cnidaria				
Rylstonia cf. *R. teres* (Girty)	sp*			
Vesciulophyllum sp.	X			
Aulopora sp.	X			
Cleistopora placenta (White)				
? *Lithostrotion* sp.				
Syringopora sp.	X	X		
Lithostrotionella microstylum				
Bryozoa				
Fenestrella sp.	X			
? *Fenestrellina* sp.			X	
Ptylopora sp.				
? *Fenestralia* sp.				
Pennireptepora sp.				
Rhombopora sp.				
? *Cheilotrypa* sp.		X		
Sulcoretepora sp.				
Brachiopoda				
Camarotoechia cf. *C. chouteauensis*			X	
Camarotoechia cf. *C. inaequa* Shaw	sp*			
Reticularia sp.		X		X
Spirifer cf. *S. centronatus* Winchell	X	X		X
Spirifer cf. *S. grimesi* Hall	X			
Spirifer grimesi	X	X		
Spirifer mundulus Rowley		X		
Delthyris sp.				
Cleiothyridina sublamellosa (Hall)		X		
Chonetes sp.	X	X	X	
Linoproductus ovatus (Hall)	sp*	X	X	
Dictyoclostus cf. *D. inflatus*				
Dictyoclostus cf. *D. fernglenensis* (Weller)		X		
Dictyoclostus sp.	X		X	
Schizophoria chouteauensis Weller	sp*	X	sp*	
Schizophoria swalleri (Hall)		X		
Torynifer montanus Shaw	sp*			
Composita humilis (Girty)	sp*		X	
Brachiopoda continued				
Dielasma sp.	X	X	X	
Leptaena analoga (Girty)	X	X		X
Schellwienella cf. *S. inflata* (Hall)		X	X	X
? *Leptagonia* sp.				
? *Atrypa* sp.				
Eumetria sp.			X	
Schuchertella sp.	X			
Schellwienella sp.			X	X
Mollusca				
Bivalves				
Grammysia cf. *G. welleri*		X		
Edmondia cf. *E. marionensis*				
Gastropoda				
Spraparallus sp.	X			
Euomphalus sp.		X	X	
Platyceras sp.	X	X	X	
(*Platyceras*) cf. *P. niagarense* (Hall)				
Loxonema sp.	X	X		
Cephalopoda				
unident nautiloid				
Arthropoda				
Trilobites				
Exochops sp.				
unident. fragments	X			
Echinoderms				
Blastoids				
Pentremites sp.				
Crinoids				
? *Cactocrinus* sp.				
Dinotocrinus sp.				X
Culmicrinus cf. *C. jeffersonensis* Laudon and Severson				
Platycrinus incomptus White				
Platycrinus bozemanensis Miller & Gurley			sp*	
Chordata				
unident fish				
Trace fossils				

sp*-- genus present but species not identified, may not correspond to the Bandbox Mountain species of this study.

most resembles the Bandbox Mountains (Merriam, 1958). Major differences occur in the number of trilobites, crinoids and bivalves. Merriam (1958) believed the buildup contained a unique fauna different from a nonbuildup fauna. From Bandbox Mountain this seems less true, with eighteen taxa in common. The similar fauna occurs below the buildup at Bandbox Mountain and the similarities may relate to general age equivalence.

The number of species in common with Sun River Canyon is surprising. The rocks of this locality are allothonous and have been transported eastward (Mudge, 1974). The rocks of Sun River Canyon were deposited on the lower shelf margin (Rose, 1977). The similarity of the two faunas suggests similar environments.

PLATE V

A. *Platycrinus bozemanensis*, Community IV, x1, MI 5750.

B. *Eumetria* sp., Community IV, x1, MI 5620.

C. *Schizophoria swalleri*, Community IV, x1, MI 5757.

D. *Platycrinus* cf. *P. incomptus*, Community IV, x1, MI 5484.

E. *Ptylopora* sp., Community II, x1, MI 5754.

F. *Leptaena* sp., Community IV, x1, MI 5648.

G. *Fenestrella* sp., Community II, x1, MI 5653.

H. ? *Cheilofrypa* sp. encrusting on *Spirifer* sp., Community II, x1, MI 5487.

I. *Platycrinus* sp., Community IV, x1, MI 5651.

J. *Dinotocrinus* sp., Community I, x1, MI 5646.

K. *Lithostrotionella microstylum*, Community III, x1, MI 5652.

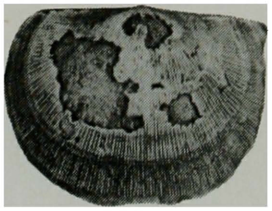
L. Unident. proetaean, Community II, x1, MI 5755.

M. *Edmondia* cf. *E. marionensis*, Community II, x1, MI 5485.

MI ----= University of Montana museum numbers.

A

B



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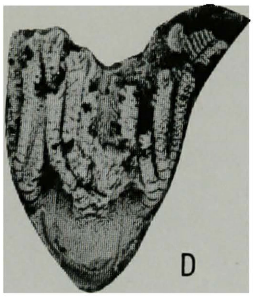

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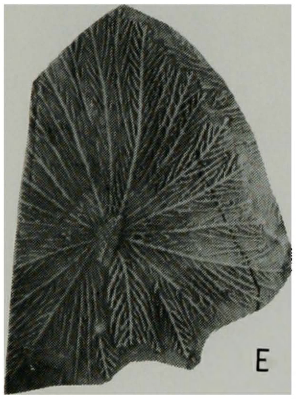

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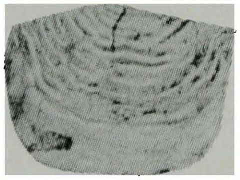

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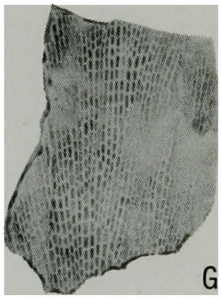

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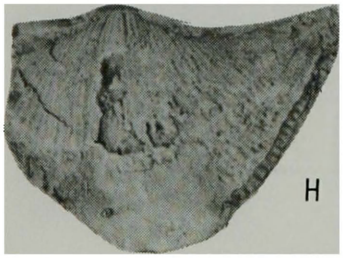

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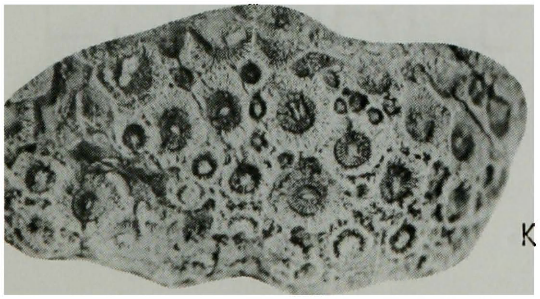

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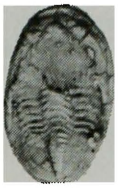

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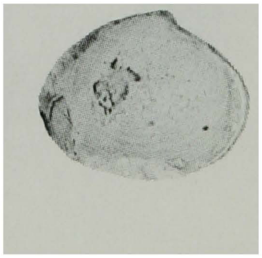


M

PLATE IV

A. Spirifer mundulus, Community II, x1, MI 5647.

B. Pentremites sp., Community II, x1, MI 5486.

C. Euomphalus sp., Community II, x1, MI 5642.

D. Leptaena analoga, Community II, x1, MI 5648.

E. Dinotcrinus sp., Community I, x1, MI 5654.

F. Cleistopora placenta with Fenestrella sp., Community II, x1, MI 5655.

G. Platycrinus sp., Community IV, x1, MI 5656.

H. Aulopora sp., Community II, x1, MI 5489.

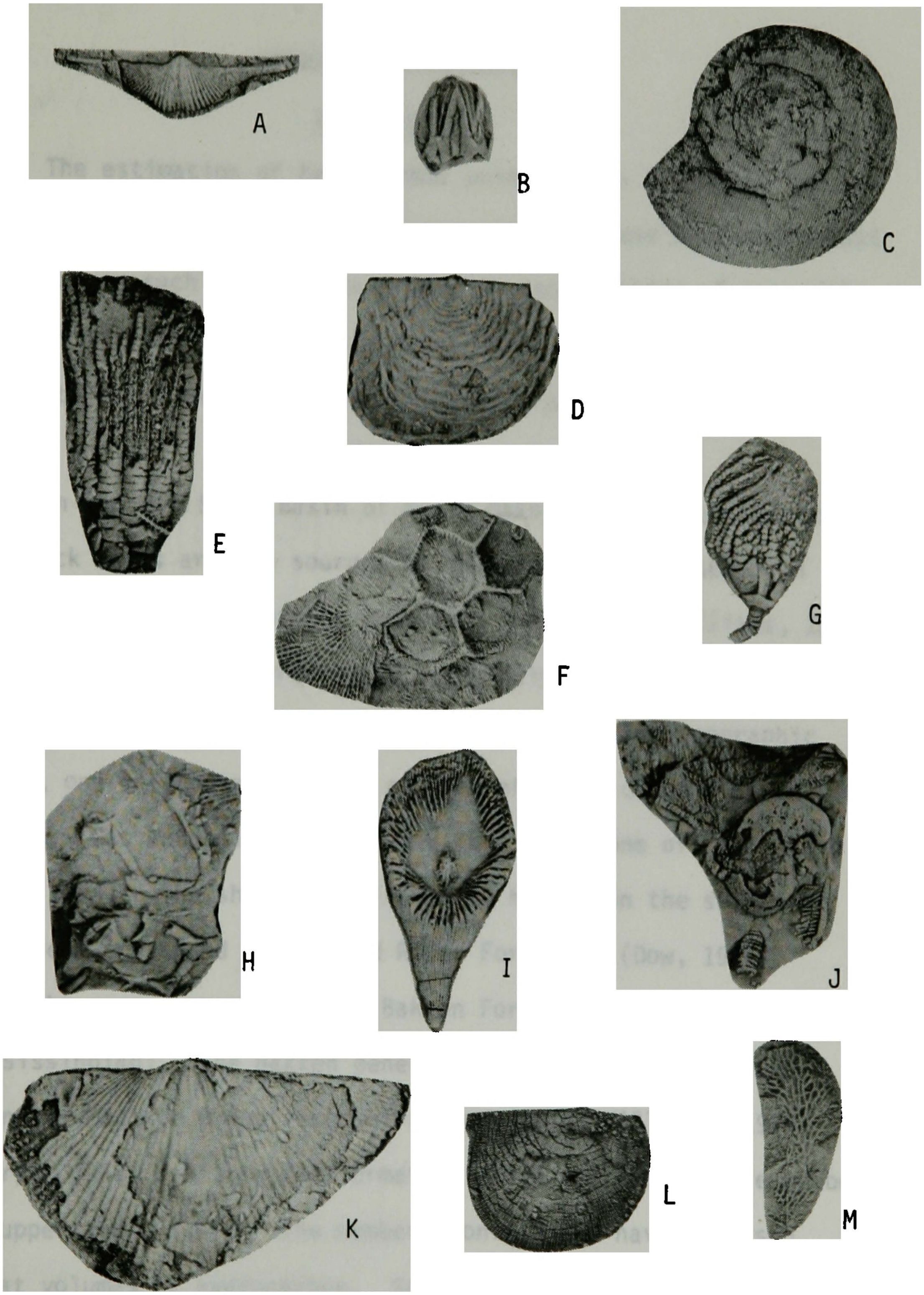
I. Rylstonia sp., Community II, x1, MI 5657.

J. Platycrinus sp. and Platyceras sp., commensal relationship, Community IV, x1, MI 5658.

K. Spirifer grimesi, Community II, x1, MI 5728.

L. Schellweinella sp., Community IV, x1, MI 5649.

M. Fenestrellina sp., Community II, x1, MI 5700.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CHAPTER VI

HYDROCARBON POTENTIAL

Introduction

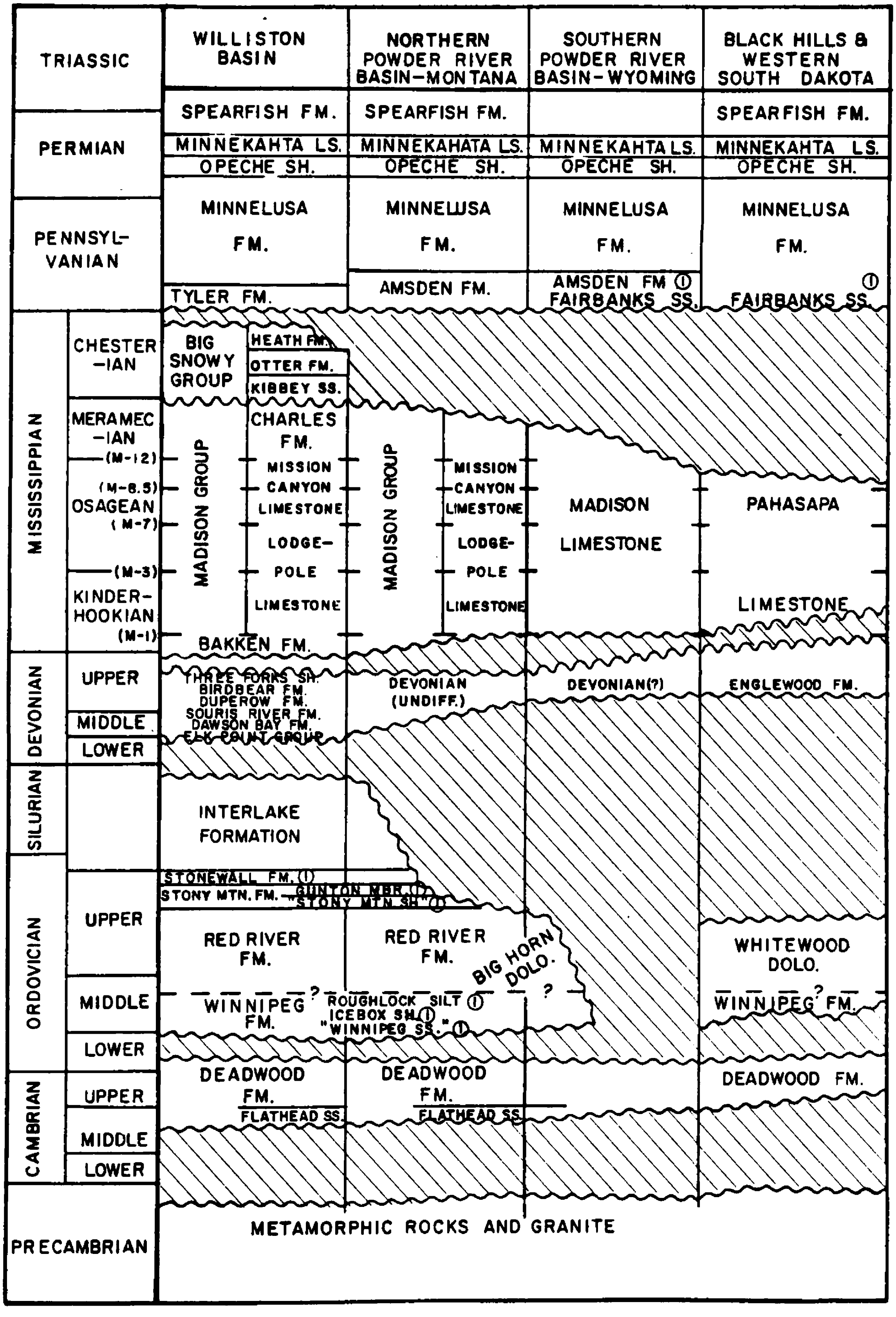
The estimation of hydrocarbon potential is a complex task. Factors of source rock, maturation, migration and entrapment must interact in such a way as to create an accumulation of gas, oil or both of sufficient size to be economic. Based on the analysis given below, I do not believe entrapment occurred on Bandbox Mountain.

Source Rocks

In the Williston Basin of North Dakota and eastern Montana two rock units are the sources of the gas and oil trapped in lower and middle Paleozoic reservoirs (Dow, 1974; Williams, 1974). The lowermost is the Ordovician age Winnipeg Formation (see Figure 19). Organic carbon is concentrated in two geographic areas, one in eastern Montana and the other in central South Dakota. Gas and oil are generated in a 30 m zone of dark shale (Dow, 1974). The shale is believed to have been the source of petroleum entrapped in the Red River Formation (Dow, 1974).

The second source is the Bakken Formation (lowermost Mississippian). The Bakken generates much of the petroleum found in Madison Group reservoirs (Dow, 1974; Williams, 1974; Thorpe, 1981). Within the formation there are black shale members, an upper and a lower. The members contain and have released great volumes of hydrocarbon. Schmaker and Hester (1983)

Figure 19. Stratigraphic column of the Williston Basin, Powder River Basin and Black Hills area. From Peterson, 1978.



① NAME NOT ADOPTED BY U.S.G.S.

estimate a volume of 132 billion barrels in the U. S. The Bakken Formation thins westward and does not extend out of the Williston Basin (Meissner, 1978).

Because neither the above mentioned formations extend into the study area, the only way gas and oil could be brought in from this source is lateral migration. Although not impossible, migration seems unlikely due to lack of porous unit pathways. Beds of the Lodgepole could be source rocks. The abundant fossils suggest these sediments were deposited in a well oxygenated environment (see discussion of facies in Chapter III). Burrows suggest a number of bottom feeding organisms. Biological activity does not favor the accumulation of organic material.

Maturation

Two common methods are used to gauge thermal maturity. Kerogen studies, most commonly vitranite reflectance, is a method whereby woody macerals are examined with the oil emersion objective of the reflecting microscope. Reflected colors range from yellow through orange and brown to black (Dow, 1979). The colors darken with increased temperature. The second method is the use of conodont elements in the same way, these show similar color change when subjected to similar temperatures (Claypool, et. al., 1978).

In samples from Bandbox Mountain, no vitranite was found. Rock samples from below the buildup (Mixed Light Wackestone/Grainstone and Bryozoan-Crinozoan Grainstone Facies) dissolved in 5% acetic acid did produce seven fragmental conodonts.

Specimens were so fragmental that identification was not possible. These showed reflected colors of dark brown to black indicating a temperature of greater than 200^{o} C. (Claypool, et. al., 1978). Rough reconstruction of the Big Snowy Trough suggest sediment did not accumulate thick enough to cause this degree of maturity, therefore high maturity is accredited to proximity to igneous intrusions.

Migration

Methods of expulsion and secondary migration of hydrocarbon are discussed by Momper (1978), Cordell (1972) and Waples (1971). Factors necessary for migration are sufficient pore space and interconnection of the space. The lower part of the Lodgepole Formation contains alternating beds of limestone and argillaceous limy mudstone. The mudstone layers forms impermeable barriers to migration of liquids.

Reservoir

Properties essential for a good reservoir are porosity, permeability and an impervious cap. Several systems of porosity classification have been developed (Reeckmann & Friedman, 1982). Porosity is divided into two types, primary and secondary. In carbonate reservoirs, secondary porosity is very important.

Thirty-eight samples from the buildup were checked for porosity amount and type. The results are presented in Appendix I, Table 5. The average porosity is 2 to 2.5%. Thin zones, less than one meter, occur with porosity up to 20%. Scanning a list of producing wells from the Williston

Basin, porosity figures of less than 10% are not common, most have porosity greater than 10% (Montana Geological Soc., 1978). The Bandbox Mountain buildup does not have sufficient porosity to be a reservoir.

Economics

Even if all conditions were excellent, is a buildup the size of the one on Bandbox Mountain a viable exploration target? Dahlberg (1979) provided a model for determining the recoverable oil in a trap. The value of the oil in this small reservoir versus the cost of discovery and production make small targets such as the Bandbox Mountain buildup a dubious financial venture.

CHAPTER VII

CONCLUSIONS

The following are the findings of this study:

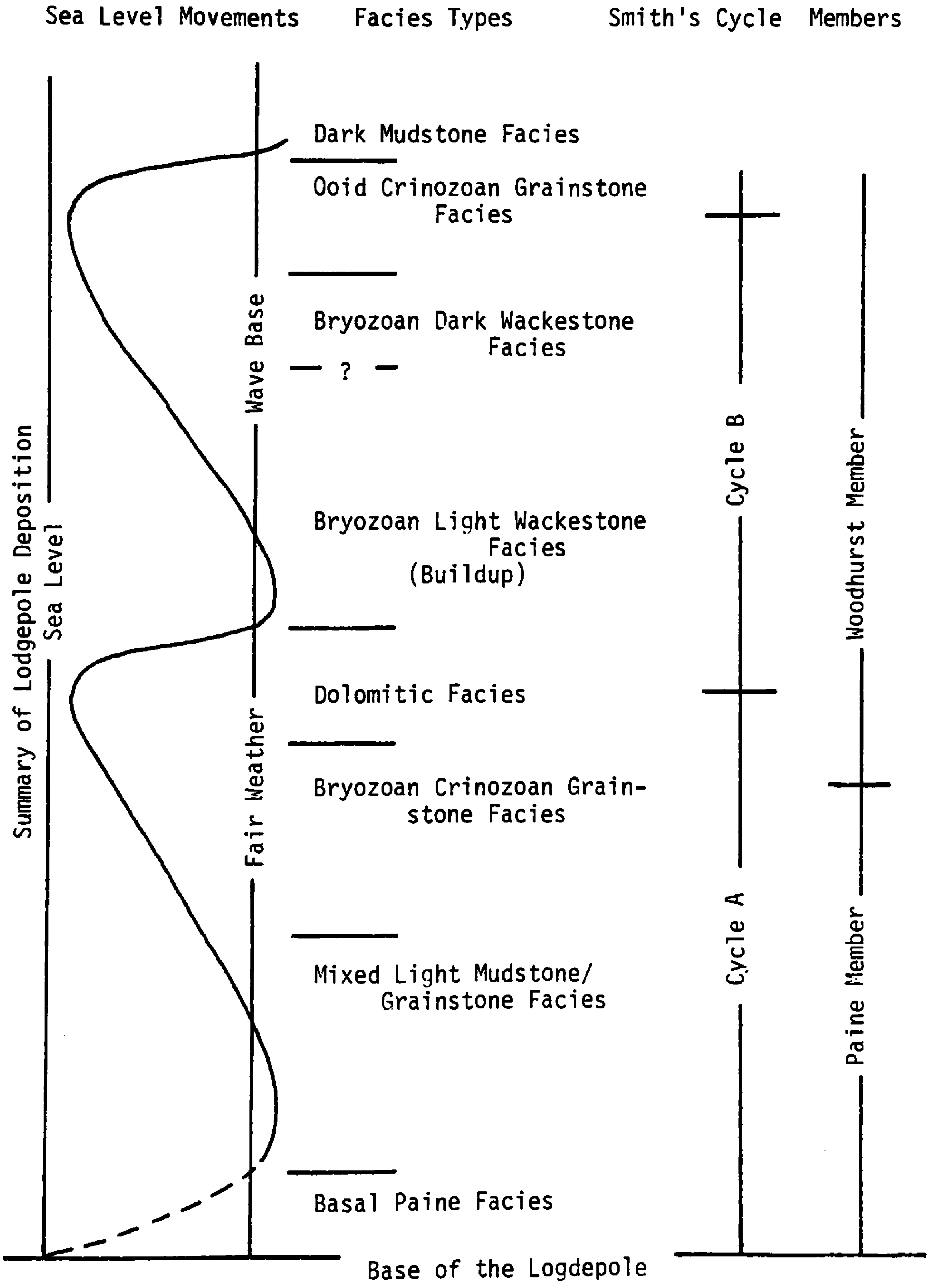
1. A carbonate buildup is recognized in the Lodgepole Formation at Bandbox Mountain approximately 65 m above the basal contact with the underlying Three Forks Formation. No other buildups were identified in the mapped area, however, two concentrations of colonial coral *Syringopora* with similar buildup lithologies exist in poorly exposed areas of Sec. 19 and 20 of T. 14 N., R. 10 E. In both areas cover is dense and outcrops occur only occasionally. The exposure on Bandbox Mountain is on the northern limb of an east-west trending anticline, a structure created by compression between the Dry Wolf Laccolith and the pluton at the south end of Sheep Mountain. The core of the anticline exposes Middle Cambrian Park Shale below the mountain.

2. The general geology of the area is dominated by the Paleozoic section folding around the eastern end of the Little Belt Mountains. Lower and Middle Paleozoic strata exposed range from Middle Cambrian (Park Shale) to Upper Mississippian (Kibbey Formation). Two intrusions occur in the map area, Dry Wolf Laccolith in the north and the Sheep Mountain intrusion in the south. The intrusions formed small scale folds and faults between them. The area is cut by at least two generations of dikes.

3. The Bandbox Mountain exposure is a carbonate buildup, characterized by general thickening of the beds. It has different lithofacies than the enclosing beds and shows evidence of topographic relief. The buildup is not an ecologic reef because it lacks the characteristics, particularly those of modifying the surrounding environments; therefore, the term "bank" is more appropriate. This bank is a "Waulsortian type" composed of an "inner core" of crinozoan grainstone and an "outer core" of bryozoan wackestone. The bank is capped by grainstone facies. This bank is similar to Waulsortian examples described in the Bridger Range by Stone (1972) but the following exceptions are noted: 1) The stratigraphic position of the Bandbox Mountain bank is higher, being located in the Woodhurst Member of the Lodgepole Formation. 2) The "inner core" facies of the bank on Bandbox Mountain is a crinozoan grainstone, whereas in the Bridger Range it is bryozoan grainstone. Finally, the capped beds of the Bandbox Mountain bank are grainstone, whereas mudstone caps the Bridger Range banks.

4. The Bandbox Mountain section is a portion of a more extensive series of carbonate rocks recording cyclic changes in sea level (Smith, 1972). At least two of these cycles are present on Bandbox Mountain (see Figure 20). The first begins at the contact between the Lodgepole and Three Forks Formations. The Basal Paine Facies is thought to represent the initial transgression phase and a progression into deep water (below fair weather wave base). It is succeeded by a series of interbedded argillaceous

Figure 20. Summary of the depositional environment on Bandbox Mountain, in reference to sea level and the cycles described by Smith, 1972.


Sea Level Movements
Facies Types
Smith's Cycle
Members
Summary of Lodgepole Deposition
Sea Level
Fair Weather Wave Base
Dark Mudstone Facies
Ooid Crinozoan Grainstone Facies
Bryozoan Dark Wackestone Facies
?
Bryozoan Light Wackestone Facies (Buildup)
Dolomitic Facies
Bryozoan Crinozoan Grainstone Facies
Mixed Light Mudstone/ Grainstone Facies
Basal Paine Facies
Base of the Logdepole
Cycle B
Cycle A
Woodhurst Member
Paine Member

limy mudstone and grainstone/wackestone facies. These represent initial deep water deposition followed by a shallowing sequence. The shallowing upward sequence may have resulted from movement on the central Montana high coupled with marine regression (Smith, 1982). The first cycle is capped by crinozoan grainstone beds in the Dolomitic Facies. The second cycle begins below the buildup as a series of laminated to thin bedded dolomitic limestone. The buildup was initiated, apparently, in deep water. Evidence includes lack of algae and predominance of fine-grained mud matrix, as well as thin-bedded enclosing rocks. The grainstone cap is the top of the second cycle. The grainstone developed in a turbulent environment on the topographic high produced by the buildup. Dip on overlying beds suggests that buildup had a maximum relief of 50 m above the sea floor. The buildup is succeeded by a section of poorly exposed rock that may represent other cycles which are not studied in detail.

5. The Bandbox Mountain locality contains a diverse fauna representing eight phyla, consisting of at least seventy-one taxa. These include nine corals, ten bryozoans, twenty-seven brachiopods, two bivalves, one cephalopod, at least two trilobites, one blastoid, five crinoids, at least five trace fossils, one foraminifera and one green alga. Rare elements of the collection include twenty articulated or partially articulated crinoid calices, nearly complete trilobite specimens, and the coprophagous snail _Playceras_ and its host, the crinoid _Platycrinus_.

Well preserved bryozoan zooaria are abundant, many of them nearly complete. Four biotic communities were recognized from the locality. The communities roughly correspond to rock facies types. Communities I & IV have low diversity and correspond to deep water facies at the base of the cycles described above. Fossils in these communities consist of brachiopods, bryozoans and articulated crinoids. As shallowing occurred in the first cycle, Community II developed. This community contains the most diverse fauna with forty-eight taxa present. Brachiopods, bryozoans and corals dominate Community II, but there is a good range of other groups. The last community, Community III, is restricted to the buildup and contains only colonial corals and fenestrellate bryozoans. All communities are dominated by low level filters. The Bandbox Mountain locality contains sixteen species not recorded elsewhere from other Lodgepole localities.

6. Hydrocarbon potential for the area is judged poor based on the following evidence:

   a. Lack of source rocks in this area.
   b. Over maturity of the sediments.
   c. Lack of migration pathways for oil and gas.
   d. Low porosity of the buildup.
   e. Small size of the buildup makes a low cost/benefit ratio.

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APPENDICES

APPENDIX I

Table 5. Porosity of Rock Samples

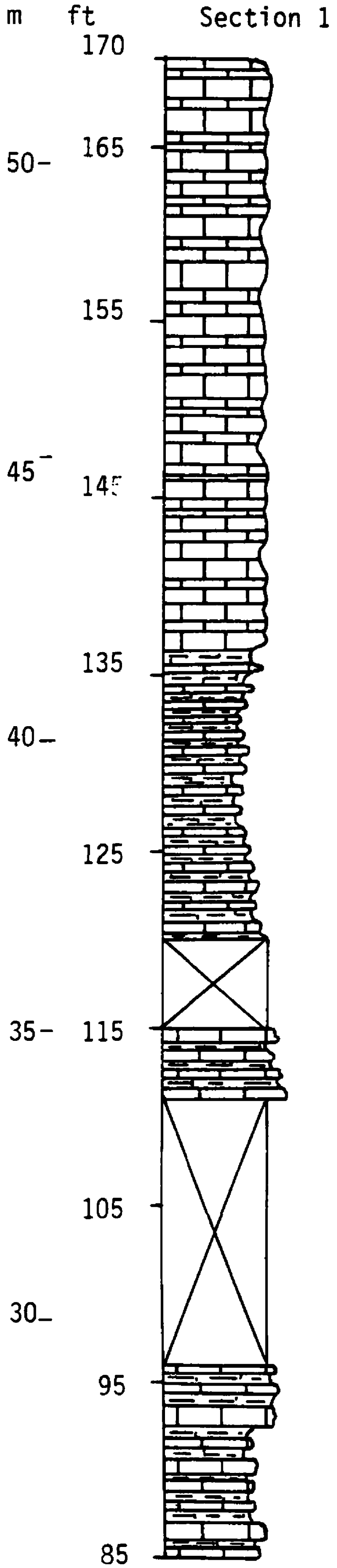
Sample Number	% porosity	Porosity Type*
1-218	0	
1-238a	0	
1-244	2	mesopore vug
1-244a	1-2	micropore vug
1-249	1-2	micropore vug
1-253	0	
1-260	less than 1	micropore vug
1-264	1-2	mesopore vug & channel
1-274	0	
1-278	3	mesopore vug & channel
1-289	2-3	mesopore vug & fracture
2-6	less than 1	micropore vug & fracture
2-13	8-10	mesopore vug & channel
2-17	1-2	mesopore vug & channel
2-31	8-10	growth framework & mesopore vug
3-3	less than 1	micropore vug
3-8	less than 1	micropore vug
3-15	2-3	mesopore vug & channel
3-23	15-20	mesopore vug & channel
3-26	less than 1	fenestral
4-4	1-2	micropore vug
4-9	less than 1	mesopore channel & fracture
4-27	less than 1	micropore vug
4-33	10-15	mesopore vug, channel & fracture
4-37	0	
4-45	8-10	mesopore vug & channel
4-19	less than 1	mesopore channel
5-3	less than 1	micropore vug
5-7	less than 1	micropore vug
5-14	less than 1	micropore channel
5-19	1-2	mesopore vug
5-29	0	
5-32	less than 1	micropore vug
5-33	1-2	mesopore vug & channel
5-38	0	
5-50	0	
6-12	less than 1	micropore vug
6-31	0	

* Classification after Choquette & Pray, 1970.

APPENDIX II

Measured Sections

Six sections were measured on Bandbox Mountain in Sec. 20, T. 14 N., R. 10 E. (see Figure 3). The exact locations of the measured sections are shown in Figure 7. Section 1 was measured from the base of the Lodgepole Formation to the top of Bandbox Mountain. The other sections were measured through the buildup only.



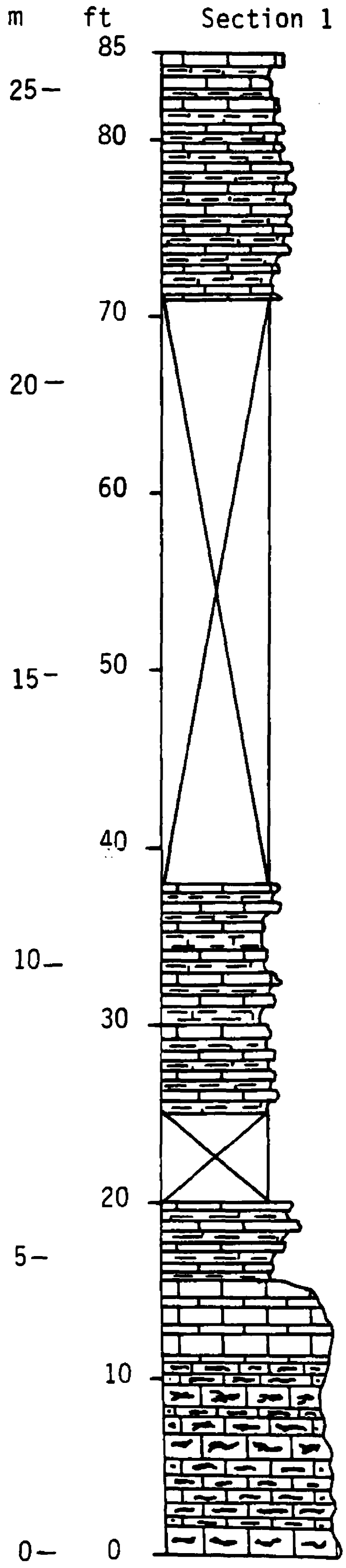
Medium to thin bedded, grainstone/
packstone, med. to dark gray,
weathering lt. gray.

Interbedded grainstone/packstone
with argillaceous limy mudstone
as below.

Interbedded packestone/grainstone with
argillacous limy mudstone as below.

Interbedded packstone/grainstone with
argillacoeus limy mudstone as below.

Section 1



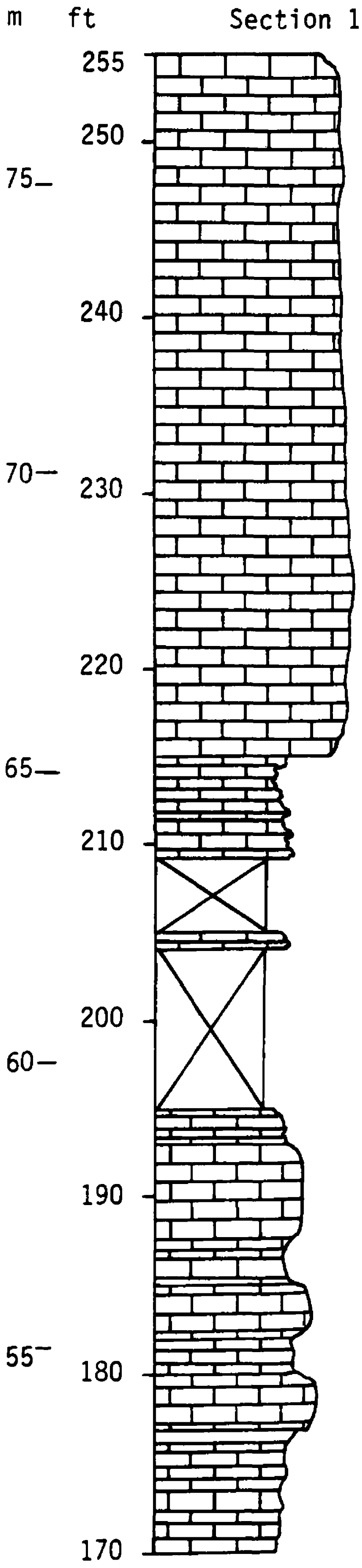
Interbedded, grainstone/packstone and argillaceous limy mudstone as below.

Interbedded grainstone/packstone and argillaceous limy mudstone as below.

Interbedded, thin to medium bedded grainstone/packstone with argillaceous limy mudstone. Weathers light gray, locally yellow brown to red brown.

Massive, packstone to wackestone, med. to dark gray, brownish black bedded and lenses of chert.

Section 1



Light gray, massive, bryozoan wackestone

Light gray, massive, crinoidal grainstone, grades upward into the overlying beds.

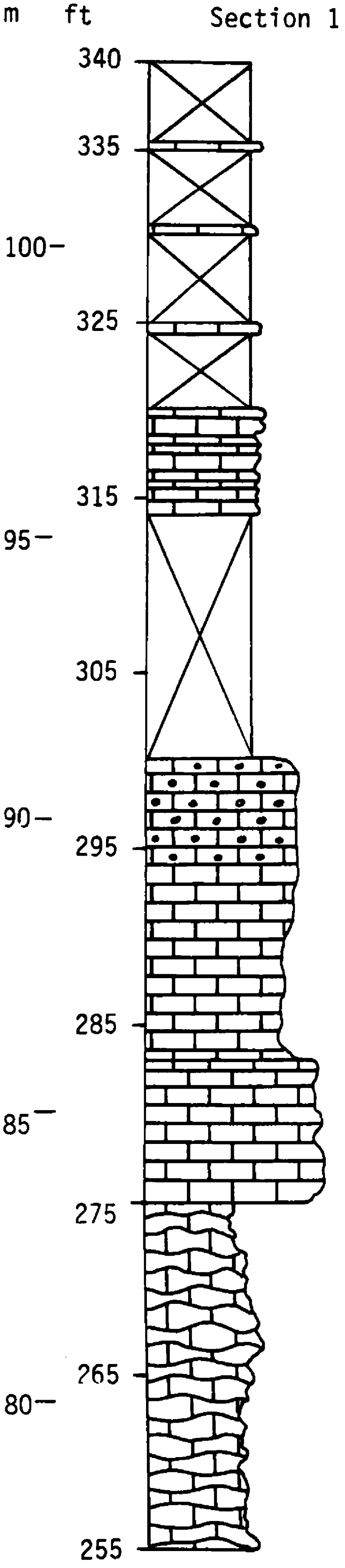
Thin to medium bedded dolomitic wackestone. Medium to dark gray

Crinoidal grainstone

Crinoidal grainstone

Crinoidal grainstone

Medium bedded dolomitic wackestone and packestone, dark gray in color, weathers brownish gray.

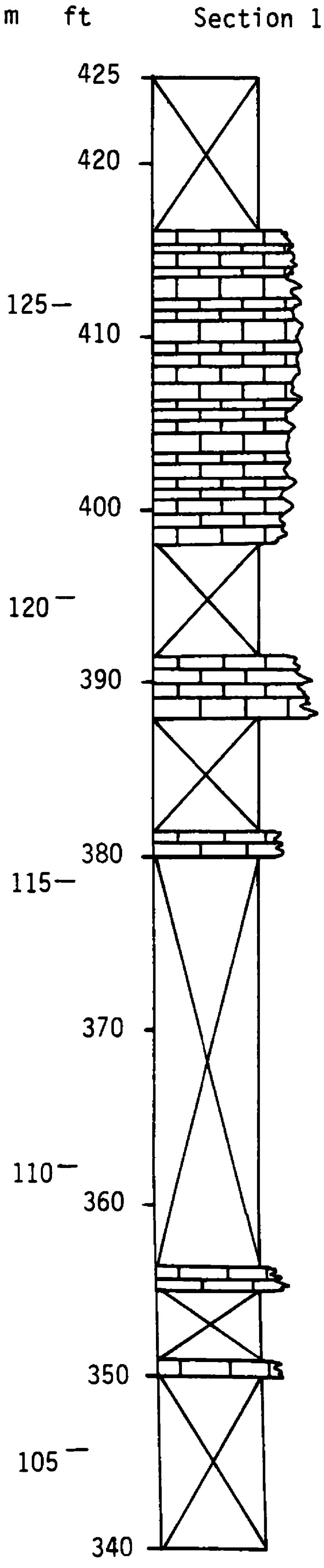


Dark gray mudstone as below.

Thin to medium bedded, dark gray, mudstone.

Massive, medium gray grainstone. Echinoderm columnals common in the base, ooids becoming common near the top.

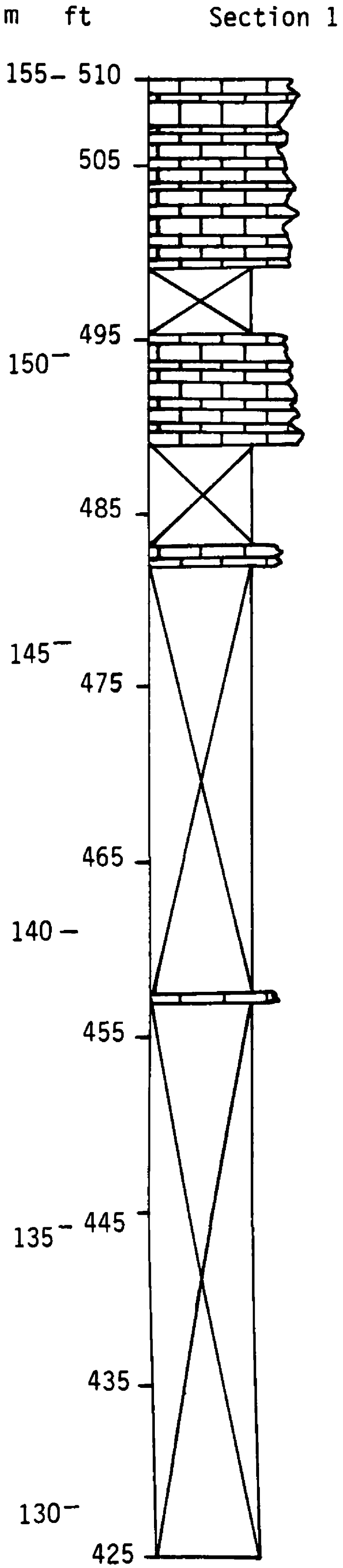
Dark gray, irregular bedded, wackestone.



Crinoidal grainstone near the top.

Medium to thin bedded dark mudstone as below

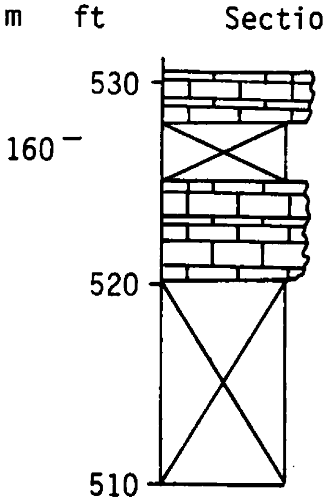
Medium bedded, dark mudstone.



Medium bedded, dark mudstone, as below.

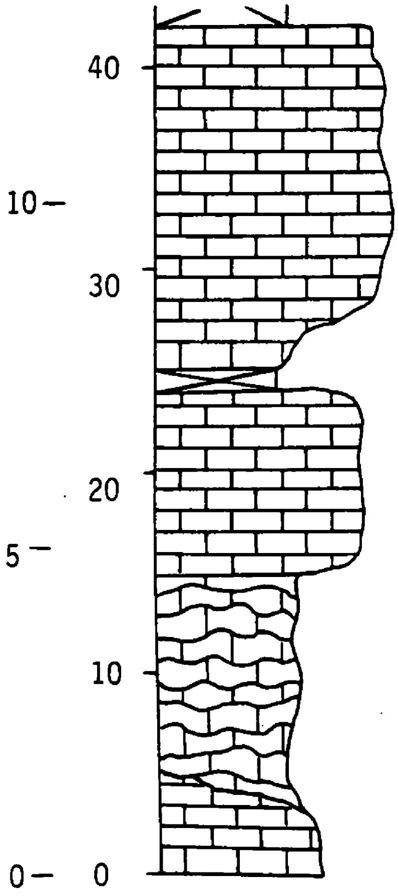
Medium bedded, dark mudstone, as below, becoming crinoidal grainstone near the top.

Section 1



Medium to thin bedded dark mudstone as below, crinoidal at the base of exposure.

Section 3

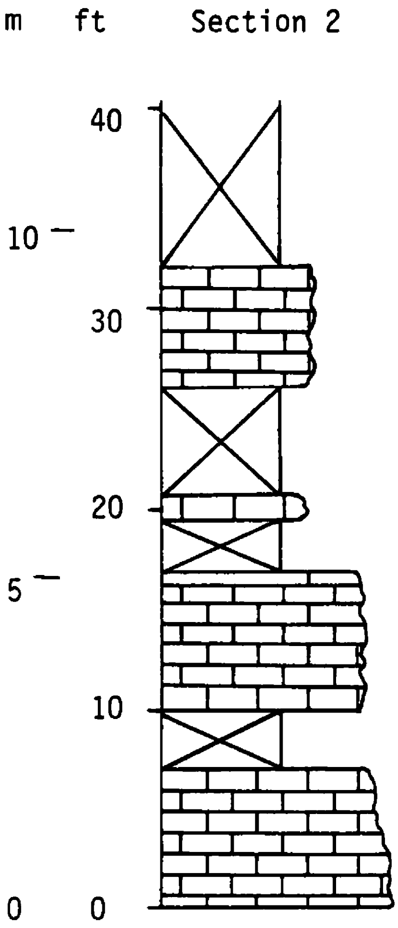


Massive, light gray wackestone.

Massive, light gray wackestone.

Irregular bedded, dark wackestone. broken fossils and toppled coral colonies.

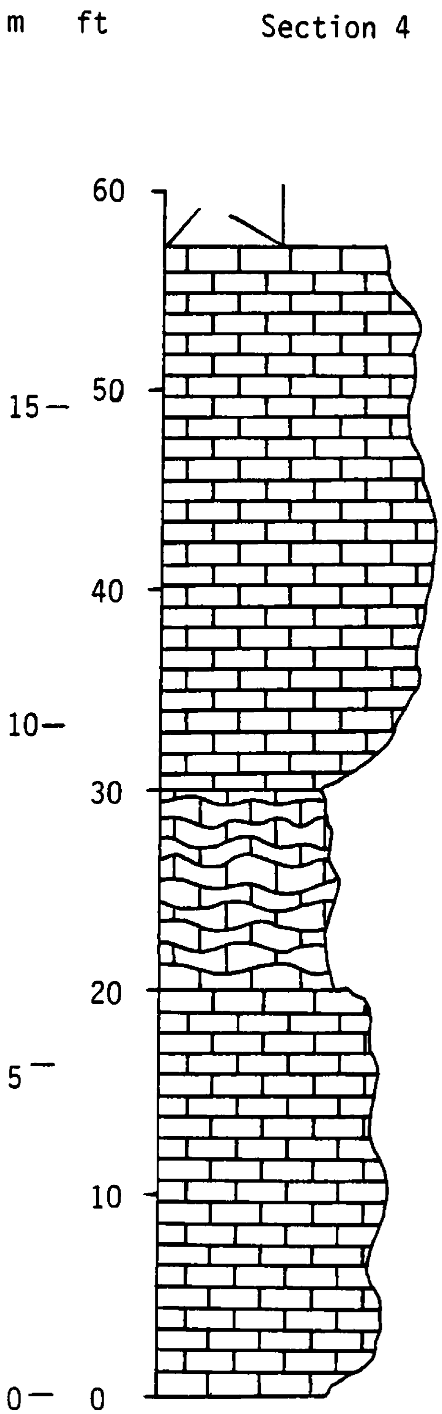
Massive, light gray. crinoidal grainstone.



Light wackestone as below, becoming crinoidal near the top. Grainstone or packstone.

Light wackestone as below.

Light wackestone with numerous Syringopora corals. Massive.



Section 4

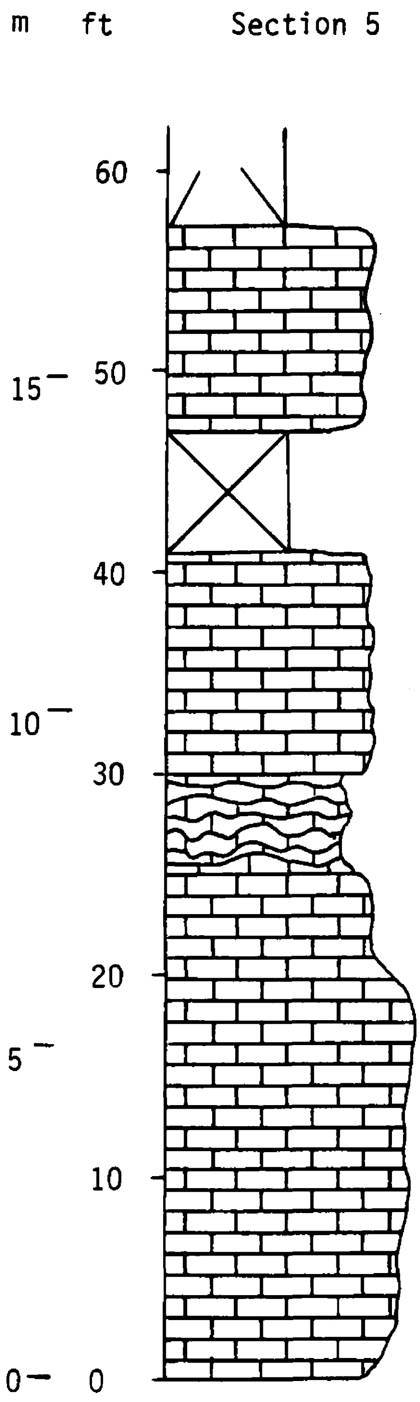
Massive, light gray crinoidal wackestone, grades upward into crinoidal grainstone.

Dark gray, irregular bedded wackestone.

Light gray, massive, wackestone.

Light gray, massive, crinoidal grain-grainstone, grades into the beds above.

Section 5



Light gray, massive, crinoidal grainstone.

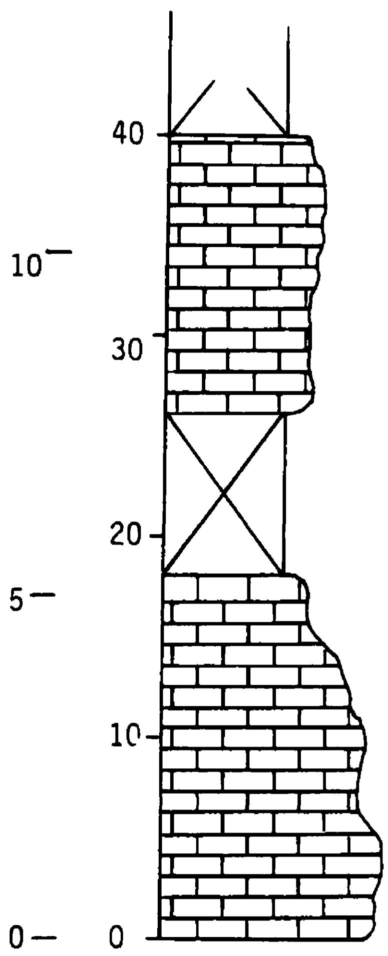
Light gray, massive, wackestone.

Dark gray, irregular bedded, wackestone.

Light gray, massive wackestone.

Light gray, massive, crinoidal grainstone, grades into the beds above.

Section 6



Light gray, massive wackestone,

Light gray, massive, wackestone.
Syringopora coral colonies rare.

Light gray, massive crinoidal grainstone, grades into the beds above.