Permian Phosphoria bioherms and related facies southeastern Idaho

Marvin Del Brittenham

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PERMIAN PHOSPHORIA BIOHERMS
AND RELATED FACIES, SOUTHEASTERN IDAHO

by

Marvin D. Brittenham

B. A., University of Montana, 1968

Presented in partial fulfillment
of the requirements for the degree of

Master of Science

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1973

Approved by:

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Chairman, Board of Examiners

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Dean, Graduate School

Date: Mar. 7, 1973
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CHAPTER 1

INTRODUCTION

Carbonate lenses in the Rex Chert Member of the Phosphoria Formation were first noted by geologists of the United States Geological Survey in the early 1900's when the importance of the phosphates of the Phosphoria was realized and mapping of the phosphate reserves was initiated by Mansfield and Richards (Mansfield, 1927; Richards and Mansfield, 1912). At that time several localities of occurrence of the lenses were noted, but no detailed description was made, although some of the fossils collected were described by Girty (Mansfield, 1927).

After World War II the importance of the Phosphoria, not only as a source of phosphates but also as a suspected source of radioactive minerals, influenced the Geological Survey to initiate further study of the stratigraphy, paleontology, petrology, and geochemistry of the Phosphoria Formation, as well as more detailed mapping of the phosphate reserves (McKelvey, et al, 1959). Most of the detailed mapping was concentrated in the southeast Idaho area which is the area of maximum phosphate occurrence. In this mapping project the carbonate lenses of the Rex Chert Member were again noted. Fossils were collected from the lenses and described by E. L. Yochelson (1968), whose data have formed a basis for most of the paleontological aspects of this
study and also provided a listing of most of the localities of lens occurrence. W. C. Gere initially suggested a study of the lenses and located many of them for me.

Most of the field work for the project was completed in the summer of 1969 and a brief portion of the spring of 1970. The study included the stratigraphic analysis of eight localities with thirty-five stratigraphic sections. Detailed petrographic collections including approximately 1000 specimens and a smaller paleontological collection were also accumulated. Lateral and vertical limits of the carbonate lenses were determined wherever possible and the relationship of the lenses to the enclosing chert was closely scrutinized. Other routine field observations, including sedimentary structures, the nature of the contacts, and brief lithologic descriptions, were noted to aid in the laboratory analysis of the samples.

Laboratory analysis included the preparation and description of thin sections, stained thin sections, acetate peels, as well as identification and description of a few of the more significant paleontological specimens. Detailed petrologic logs and subsequent stratigraphic cross sections were plotted for localities in which there was sufficient control, whereas samples from other localities were used for comparison with the major localities.

The area of study (Figure 1) was extreme southeast Idaho near the Idaho-Wyoming and Idaho-Utah borders. Figure
2 shows the location of the major collecting localities; in addition, detailed descriptions of the locations of stratigraphic sections are given in the appendix and more detailed map locations are shown on Plate I.

High rolling ridges and broad valleys, formed as subsequent drainage patterns accentuated the north-south trending fold and thrust patterns, dominate the topography of the area. Almost all outcrops trend generally north-south (see Plate I) and this, coupled with the usual magnitude of the folds, precluded detailed east-west stratigraphic control at any one of the locations of the carbonate lenses. However, some general control in that direction was gained where:

1. Outcrops were formed where the Phosphoria Formation was breached near the axis of a fold;
2. Minor folds or faults yielded closer spaced outcrops;
3. Deeply cut transverse stream valleys yielded outcrops oblique to the normal north-south orientation.

However, in all but the last instance outcrop quality was poor because of structural complications or intense fracturing which affected the normally resistive nature of the dense carbonate and chert.

Outcrops of the massive carbonate lenses normally form bold ridges or cliffs, even more so than the enclosing chert.
EXPLANATION FIGURE 2

Localities Studied with Regional

Cross Section Lines (Figures 6 and 7)

Localities with measured sections (see Appendix A, pages 176 - 187, for description of locations)

3. Hot Springs Locality, Idaho
8. Wood Canyon Locality, Idaho
10. South Sage Creek Locality, Idaho
14. Deer Creek Locality, Idaho
15. Sage Creek Locality, Idaho
16. Timber Creek Locality, Idaho
17. Stewart Canyon Locality, Idaho
18. Dry Valley Locality, Idaho

Other localities studied (see McKelvey, et al., 1959)

1. Little Sheep Creek, Montana: SW¼ Sec. 34, T. 14 S., R. 9 W., Beaverhead County
13. Little Sheep Creek, Montana: SW¼ Sec. 34, T. 14 S., R. 9 W., Beaverhead County
11. Fall Creek, Idaho: SW¼ Sec. 18, T. 1 N., R. 43 E., Bonneville County

Measured sections from literature (McKelvey, et al., 1959)

1. Poison Creek, Wyoming: W½ Sec. 24, T. 30 N., R. 117 W., Lincoln County
2. Montpelier Canyon, Idaho: Sec. 31, T. 12 S., R. 45 E., Bear Lake County
4. Paris Canyon, Idaho: Sec. 8, T. 14 S., R. 43 E., Bear Lake County
5. Mud Spring, Idaho: Sec. 7, T. 12 S., R. 29 E., Cassia County
6. Fort Hall, Idaho: Sec. 22, T. 4 S., R. 37 E., Bingham County
7. Rock Canyon, Idaho: NE¼ Sec. 1, T. 6 S., R. 38 E., Bannock County
9. Snowdrift Mountain, Idaho: NW¼NE¼ Sec. 8, T. 10 S., R. 45 E., Caribou County
12. Teton Pass, Wyoming: Sec. 23, T. 41 N., R. 117 W., Teton County
which can easily be recognized by its ridge-forming nature. The chert's resistance to erosion is accentuated by the fact that it overlies and is overlain by nonresistant swale or valley forming shales (Figure 3). An exception to the usual mode of outcrop occurs when the carbonate or chert is highly fractured, thus reducing its resistive nature.

Figure 3: Exposure of Permian System at Hot Springs, Idaho. Section is overturned and faulted.

The purpose of this study was threefold:

1. Definition of carbonate lens occurrence - The first major objective was to locate the areas of occurrence of the carbonate lenses of the Rex Chert Member and to define their
lateral extent and geometry.

2. Determination of the stratigraphic relationships of the carbonate and enclosing chert — This facet of the study involved the use of outcrop and laboratory data to determine the stratigraphic relationships, petrology, and biostratigraphy of both the carbonate and the chert.

3. Explanation of the relationships of carbonate and chert depositional and post-depositional processes — From the definitive aspects of the study I hoped to explain local relationships of carbonate and chert deposition to gain a better understanding of regional relationships and general hypotheses of the origin of the Rox Chert Member.
Permian Stratigraphic Nomenclature

The basic regional stratigraphic relationships of the Phosphoria Formation are well known as a result of the definitive work of the United States Geological Survey (McKevy, et al, 1963; Sheldon, 1963; Cressman and Swanson, 1964; and McKee, et al, 1967). The complex intertonguing nature within the unit, although it is fairly well defined, adds difficulty to any discussion of regional stratigraphy because of the resultant problems of stratigraphic nomenclature.

For the purpose of clarity in this brief discussion, the nomenclature diagrammed in Figure 4 will be used. The use of the term, Phosphoria Formation, in this manner is widespread in the petroleum and mining industries. This figure illustrates the stratigraphic relationships of rock units in the study area to those in western Wyoming. A similar scheme was used by Cole (1969) in central Wyoming where the Phosphoria shelf carbonates (Park City lacies) intertongue with equivalent continental sediments.

The complex of intertonguing units will be referred to collectively as the Phosphoria Formation, with each separate unit referred to as member, tongue, or lentil, wherever applicable (Figure 4). The eastern Idaho units, dominated
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**Phosphoria Formation**

**Phosphoria facies**  **Park City facies**  **Shedhorn facies**

- FLINTY SHALE
- CHERT
- PHOSPHORITE-MUDSTONE
- CARBONATE
- SANDSTONE
- SANDY CHERTY DOLOMITE

**Figure 4: Schematic Diagram Showing the Stratigraphic Terminology of the Permian in the Area of Study**
by shales, cherts, and phosphorites, will be informally referred to as the Phosphoria facies: the Meade Peak, lower chert, Rex Chert, Retort, Tosi Chert, and cherty shale members. The western and central Wyoming units, dominated by carbonates, will be informally referred to as the Park City facies: the Grandeur, Franson, and Ervay Members. The units in southern Montana and eastern Wyoming, dominated by redbeds, sandstone, and evaporites, will be informally referred to as the Shedhorn-Goose Egg facies: the Shedhorn, Opeche, Glendo, and Freezeout Members.

**Permian Sedimentary Cycles**

The sequence of lithostratigraphic units in the Phosphoria Formation represents shifting sedimentary environments in response to three major transgressions and regressions of the Permian Sea. These cycles are best recorded in the sediments deposited on the gently sloping Permian shelf of central and western Wyoming where fluctuations of sea level caused rapid migration of environments yielding a sedimentary record which clearly indicates the nature of the fluctuations.

In the area of central Wyoming studied by Cole (1969), for instance, fluctuating sea level resulted in the migration of shorelines across the area (Figure 5). In contrast most of southeast Idaho was near or beyond the shelf edge throughout Permian time so that less direct or definitive evidence of these cycles is present. For this reason, the
S.E. IDAHO | C. WYOMING

Cherty Sh. Mbr. | Ervay & Tosi Mbrs.
Retort & Cherty Sh. Mbrs. | Retort Mbr.
Rex Chert Mbr. w/ Franson lentils | Franson & Glendo Mbrs.

(Cole, 1969)

W ———— Regressive ———— E

Transgressive

Forello Tng.

Mean low sea level

FIGURE 5

Permian Sedimentary Cycles
Wyoming & Idaho
events for this area will be considered in a regional context along with those on the shelf to the east (Figure 5).

The regional stratigraphic sections, Figures 6 and 7, illustrate in more detail the relationships shown in Figure 4. The carbonate lentils studied are equivalent to the Franson Member carbonates of western Wyoming as evidenced by: their stratigraphic position, their lithology, and their fauna. They are an integral part of the second major transgressive Permian cycle (Figure 5) which will be termed the Franson cycle.

The area of study is very near the western limit of the Franson Member carbonates as they intertongue with the cherts of the Rex Chert Member on the west (Figures 6 and 7). Westward from the area of study near the Fort Hall Indian Reservation, the Rex Chert Member grades laterally and vertically into the siliceous shale of the cherty shale member. The cherty shale member, in turn, grades laterally to the southwest in the Sublette Range of south-central Idaho to a thick section dominated by chert (Figure 6) (McKelvey, 1959; Mansfield, 1927; Warner, 1956).

In the area of the Lost River Range in central Idaho (Figure 1) Dostwick (1955) reports sandstones of lower Permian age, but all of the younger Permian and Mesozoic rocks are eroded. In north-central Idaho volcanic rocks of Permo-Triassic age (Seven Devils Volcanics) are exposed (Bissel, 1959; McKee, et al, 1967).
FIGURE 6 — STRATIGRAPHIC CROSS SECTION 1-5
See Figure 2 for location of sections
See Figure 4 for stratigraphic terminology

Sources for Sections:
1, 2, 4, 5 — McKelvey, 1959
3 — Personal Observation
FIGURE 7
STRATIGRAPHIC CROSS SECTION 1-6
See Figure 2 for location of cross section and Figure 6 for legend.
Figure 8 is a schematic representation of the paleogeography at the time of deposition of the Franson cycle sediments as interpreted from the data discussed above. The following genetic relationships within the Franson cycle may be interpreted from the regional stratigraphic evidence as diagrammed in Figure 8.

Permian Depositional Environments

Clastic Shelf Sediments

The Shedhorn Sandstone in southwestern Montana and northwestern Wyoming represents the littoral sediments of the north margin of the Franson Sea. The sands were derived from older sandstones in the uplifted area to the north in Montana and were transported southward into the northwest portion of the diagram.

The shoreline to the east in Wyoming (Cole, 1969) consisted of a more gradual change from subtidal and tidal-flat carbonates to restricted marine and continental red beds and evaporites of the Goose Egg facies.

Farther to the southeast of the study area the shoreward equivalents of the Franson are eroded but may have originally consisted of the littoral and aeolian sandstones of the White Rim Sandstone and the continental redbed-feldspathic sandstone sequence of the Cutler Formation on the flanks of the Ancestral Rockies and Uncompahgre Uplift (McKee, et al, 1967).
FIGURE 8: SCHEMATIC DIAGRAM SHOWING THE PALEOGEOGRAPHY OF THE PHOSPHORIA SEA (FRANSON CYCLE) IN THE AREA OF STUDY
**Inner Shelf Carbonates**

Most of the Franson Member carbonates were deposited offshore in shoal conditions resulting in deposition of biostromes and bioherms. Both local and regional paleo-topography probably affected the position of the bioherms relative to the more normal biostromal nature of the carbonates. Locally sponge spicular cherts were deposited in topographic lows laterally from carbonate bioherms.

**Outer Shelf Chert and Carbonates**

Carbonate deposition was largely restricted to the shallow shelf areas of western to central Wyoming and southwestern Montana, while deposition of spicular cherts of the Rex Chert Member dominated the lower portions of the shelf in the study area. However, lentils of Franson equivalent carbonate bioherms occur westward from the main body of the Franson up to the edge of the shelf representing local shoals on paleotopographic highs.

**Shelf Slope and Basinal Cherts and Shales**

The nature of the slope and basinal sediments of the Phosphoria Formation is very poorly known. From what is known to date (Mansfield, 1927; McKelvey, 1959; Warner, 1956; McKee, et al, 1967) the change from slope to basin is represented only by a facies change from chert on the east to siliceous shales basinward. It may not have represented a sharp topographic boundary but rather the outer limits of
the average depth at which siliceous sponges were no longer present to form the sediment supply for the cherts. The thick section of chert present in the Sublette Range (Figure 6) presumably near the Phosphoria basinal axis is nonspicular. Therefore, a different genesis is implied for these cherts as opposed to the shelf and eastern shelf slope cherts.

Orogenic Belt: Clastics and Volcanics

The presence of an orogenic belt through central to western Idaho is assumed from scattered localities in which Permian rocks outcrop. Present distributions of the clastics and volcanics of the Permian System in western Idaho, relative to marine limestones and shales in northwestern Washington (McKee, et al, 1967), indicate that this was a narrow orogenic belt.
LOCAL STRATIGRAPHY

Details of the Permian stratigraphy of southeast Idaho are somewhat incompletely described in the geologic literature. Most of what is known is a result of the geologic mapping of the U. S. Geological Survey by Richards and Mansfield in the early 1900's (Mansfield, 1927) and in more detailed quadrangle mapping in the 1950's by various members of the Survey (Cressman and Gulbransen, 1955; Cressman, 1964; Gulbransen, et al, 1956; Cheney and Montgomery, 1967; and McKelvey, et al, 1959). Stratigraphic sections of parts of the Phosphoria Formation were published as circulars in the early 1950's but generally included detailed descriptions of the Meade Peak Member only.

Figure 9 is a generalized stratigraphic section for the area of study. Complete Permian sections are exposed in many localities in the area, where phosphate exploration trenches add greatly to the quality of exposure. The following is a description of the Permian System as well as the immediately subjacent and superjacent strata in the thesis area.

Pennsylvanian-Lower Permian Wells Formation (Upper Member)

The Wells Formation of Pennsylvanian and Lower Permian age was named by Richards and Mansfield (1912) in the Snow-
Generalized Stratigraphic Section
Southeast Idaho

FIGURE 9
drift Mountain area of southeast Idaho. The type locality is in Wells Canyon, T. 10 S. - R. 45 E., Caribou County, Idaho. As defined by Richards and Mansfield, the upper Wells included the Grandeur carbonates, but was later restricted to exclude that unit (McKelvey, et al, 1959).

The upper portion of the unit consists of fine grained, grey and buff dolomitic sandstone and grey dolomite and limestone. The unit is conformably overlain by the Grandeur Member throughout the area and is thought to range into the Lower Permian (Wolfcamp) on the basis of fusulinids identified by R. C. Douglass (Cressman, 1964).

**Permian Phosphoria Formation**

As previously mentioned, all the units of the Phosphoria Formation as originally defined by Richards and Mansfield (1912) in Phosphoria Gulch near Georgetown Canyon in Caribou County, Idaho and those of the Park City Formation as defined by Bottwell (1912) in Utah will be referred to the Phosphoria Formation for the area of study. This is necessary because of the predominance of Phosphoria lithologies in the complex intertonguing of Phosphoria and Park City facies. By rules of the Code of Stratigraphic Nomenclature (American Commission of Stratigraphic Nomenclature, 1961) the marked predominance of Phosphoria lithology is more than sufficient justification for reference of these units to the Phosphoria Formation.
The informal terms appearing in Figure 3 will be used when it is necessary to denote a "Phosphoria" or "Park City" lithofacies. Cole (1969) lists various reasons for using the term Phosphoria Formation exclusively in preference to Park City. However, in the type area of the Phosphoria Formation I see no reason for extended discussion over the preference of terms.

**Grandeur Member**

When Richards and Mansfield defined the Wells and Phosphoria Formations (Richards and Mansfield, 1912) they originally included the Grandeur Member in the upper member of the Wells Formation. The Grandeur Member was later included as a tongue of the Park City Formation when it was redefined by the U. S. Geological Survey (McKelvey, et al, 1959). In quadrangle mapping, however, the unit was included with good reason with the upper member of the Wells Formation as it was by Richards and Mansfield since the contact is extremely gradational and usually obscured.

The Grandeur Member in the area of study consists of ten to one hundred feet of finely crystalline grey dolomite and dolomitic limestone. It commonly contains blue-grey chert nodules and is silty with interbedded very fine grained sandstone near the base. In places it is fossiliferous, often with a fine grained bioclastic texture. From the few thin sections observed, the fossils are in
part bryozoa fragments, but the unit may also contain microfossils. Brachiopods in the Grandeur Member are similar to those found in Leonardian rocks in West Texas (Williams, 1959; Yochelson, 1968).

The fossils are characteristically silicified and because of the general siliceous nature of the unit it forms a prominent ridge underlying the nonresistant Meade Peak Member. The contact with the Meade Peak Member is conformable and probably gradational since a few phosphate beds have been noted below the top of the unit within the area of study (Cressman, 1964). Immediately east of the study area the Grandeur and Meade Peak Members are separated by a thin chert referred to as the lower chert member (Figure 3).

Meade Peak Member

The Meade Peak Member of the Phosphoria Formation was formally designated by McKelvey, et al (1956). The type section is near Meade Peak east of Georgetown, Idaho (Figure 1) in Section 8, T. 10 S. - R. 45 E. The unit consists of approximately 200 feet of carbonaceous, phosphatic, highly organic shales and mudstones, as well as phosphate rocks. There are minor amounts of dark grey aphanitic carbonate beds and lenses.

There are few natural outcrops of the unit in the area, as it normally forms topographically low areas with much soil cover and vegetation. However, phosphate mining and
exploration activities have created excellent fresh exposures in the form of bulldozer trenches and mines. In the absence of man-made exposures the thickness of the Meade Peak Member may be closely approximated by measuring the distance between the two resistant ridges formed by the Grandeur and Rex Chert Members.

Fossils from the unit are inconclusive as far as correlation with the West Texas Permian section. The molluscs indicate a Leonardian age and the brachiopods a Wordian age (sensu Yochelson, 1968). The Meade Peak is conformably overlain by the Rex Chert Member and in places the contact appears gradational. Specifically, thin beds of oolitic phosphate rock were observed in the lower part of the Rex Chert at Timber Creek (Plate I).

Rex Chert Member

The Rex Chert Member is one of the most unique lithologic units within the Rocky Mountain area. It consists of a seemingly ubiquitous succession of bedded chert 130 to 200 feet thick. The unit was first described by Richards and Mansfield (1912) and was named by Gale for Rex Peak in Utah. The type section designated by Richards and Mansfield in Georgetown Canyon included an upper unit of cherty shale which McKelvey, et al (1959) referred to the cherty shale member of the Phosphoria Formation.

The resistant cherts normally form prominent ridges
and outcrops relatively barren of vegetation. The massive bedded carbonate lentils form even more prominent outcrops, often with broad talus slopes. The contact with the overlying unit is conformable and most often gradational consisting of interbedded thin beds of chert and dark grey siliceous shale.

Fossils in the Rex Chert Member include sponge spicules, fish remains, and inarticulate brachiopods, which are generally not usable for correlation. An abundant and varied fauna, however, has been noted from the carbonate lentils enclosed in the chert. Yochelson (1958) studied a collection from South Sage Creek (Plate I) which contained, among other fossils, a brachiopod that Cooper (1957) described from lower Guadalupe rocks in Oregon. On the basis of this indirect correlation Yochelson tentatively assigned the Rex Chert to the lower Guadalupe. In addition, Yochelson felt that the Franson Member in western Wyoming (Figure 3) is equivalent to some part of the lower Guadalupe. Since the Franson is a facies and time equivalent of the lentils within the Rex Chert, Yochelson's correlation of both as lower Guadalupe seems reasonable.

Cherty Shale Member

The cherty shale member, as mentioned before, was originally considered by Richards and Mansfield (1912) as part of the Rex Chert Member but was later separated from that
unit by McKelvey, et al (1959). The type section is the same as that of the Rex Chert Member.

The cherty shale member in the area of study consists of 100 to 150 feet of dark grey and black siliceous shales and mudstone with minor amounts of chert, phosphatic shale, and phosphate rock. The contact with the overlying Triassic Dinwoody Formation appears to be conformable (Richards and Mansfield, 1912; McKelvey, et al, 1959; McKee, Oriel, et al, 1967; Yochelson, 1968; Cheney and Montgomery, 1967) within the area of study.

The Retort Member to the east (Figure 4) is in part a lateral equivalent of the cherty shale member as evidenced by the presence of phosphatic rocks within the unit as well as physical stratigraphic correlations (McKee, 1959). Evidence in the area of the northwest Chesterfield Range (Figures 1 and 6) to the west of the study area indicates that the cherty shale member may in that area be equivalent to part of the Rex Chert Member as well as the Retort Member as illustrated in Figure 5.

There are no fossil collections from the unit which would establish a correlation with the West Texas section. However, since it is conformable with both the Rex Chert Member and the overlying Triassic Dinwoody Formation it may be logical to assume that it is at least equivalent to the Retort, Tosi and Ervay Members (Figure 4) of Wyoming and therefore is probably Upper Guadalupe in the area of study.
and ranges lower into the Guadalupe to the west.
CHAPTER 4

DISTRIBUTION AND STRATIGRAPHY OF CARBONATE LENTILS

The first major objective of this study was to locate the areas of occurrence of the Franson carbonate lentils within the Rex Chert Member and to define their lateral extent and geometry. Several of the localities were noted from the literature (Mansfield, 1923; Cheney and Montgomery, 1967; Gulbranssen, 1968) while other and more detailed locations were provided by Frank Armstrong and W. C. Gere of the United States Geological Survey.

The following is a brief discussion of field observations of each locality studied. Details of the locations and descriptions of the measured sections are given in the appendix (page 176). The areas of lens occurrence are shown on Plate I.

**Wood Canyon Locality**

The carbonate lentils at Wood Canyon (Plate I) are the westernmost of all the known occurrences. The best outcrops are on the south side of Wood Canyon where the carbonates form bold cliffs visible from the canyon below (Figure 10). Because of the loss of massive carbonates laterally to the south the rocks are poorly exposed. Generally the more normal grass covered slopes and ridge typical of the Rex Chert Member persist.
Figure 10. Exposure of carbonate lentil south of Wood Canyon (view from Wood Canyon).

North of the canyon the exposures are of poorer quality with much of the carbonate cropping out on dip slopes. Farther to the north along the divide between Trail and Wood Canyons the section becomes gradually more cherty, but thick vegetative cover and poor outcrops obscure the lateral stratigraphic relationships of the chert and carbonate. In Trail Canyon there is an excellent outcrop and road cut exposure of the full Permian section (Figure 11) including the cherty shale member which is seldom well exposed. At the top of the divide between Trail and Wood Canyons there are also good partial exposures of the section in the form
GEOLOGIC MAP - Wood Canyon Locality

(Gulbrandson, et al, 1936)

R42E R43E

EXPLANATION

Q - Qal QUATERNARY

TRIASSIC

 Rw Woodside Tongue
 Rd Dinwoody Formation

PERMIAN

Phosphoria Formation

Ppc Cherty shale member

Ppr Rex Chert Member

Ppm Meade Peak Member

PERMO-PENNYSYLVANIAN

Phosphoria Formation - Grandeur Member

& Wells Formation

Measured Section

Observed Outcrop

SCALE

0 1/2 1 Mi.

1/2

0
of bulldozer trenches.

The stratigraphic relationships at the Wood Canyon locality are shown in generalized form in the cross section on Figure 11. The vertical contacts of the Rex Chert Member with the suprajacent and subjacent members are gradational as determined from the exposure at Trail Canyon. The vertical relationships of the carbonate lentil and the chert are also gradational with a typical vertical sequence of lithologies as follows:

**TOP**

C. Chert as in A below, in inverted sequence.

B. Limestone, dark grey, fetid, thin to medium bedded, coarsely bioclastic with some interbeds and lenses of fossiliferous chert.

A. Chert, dark grey, thin irregular bedded, spicular, increasing amounts of limestone, dark grey, aphanitic and some limestone, dark grey, bioclastic near top.

**BASE**

All exposures include a medial chert member which reflects the same sequence discussed above with an increased amount of carbonate bioclasts.

The limestone is very fossiliferous with abundant spirocerid and productid brachiopod fragments, less abundant crinoid columnals or plates and bryozoans and rare rugose corals. The chert contains both carbonate bioclasts and
siliceous spicules, but ten feet or more away from the contact with the lentil it is predominantly spicular. A high organic carbon content of both lithologies is probably responsible for the dark color and fetid odor of freshly broken hand specimens.

Laterally (north to south) the contacts of the carbonate and chert do not continuously crop out, as one might surmise from the previous discussion of the quality of exposure. However, because of the thin interbedded bioclastic limestones in the Trail Canyon section, which is predominantly chert, the lateral relationships are thought to be gradational.

Approximately one-half mile to the west on the downthrown block of a normal fault there are outcrops which, where observed, contain no carbonates. However, the exposures are poor because of dense overgrowth and were only observed on the immediate south side of Wood Canyon and on the divide between Trail and Wood Canyons. U. S. Geological Survey mapping in the area revealed the presence of carbonates at only the locality described above (Gulbransden, et al, 1956). Thus, it is doubtful that the carbonate lentil extends more than one-half mile west of the outcrop discussed.

To the east the closest outcrops are three and one-half miles, where the Rex Chert is quarried for road metal, and there is no evidence of carbonate lenses in the section.
With such poor east-west control it is difficult to define the stratigraphic relationships in those directions; however, the lateral carbonate to chert contact is felt to be abrupt but gradational to the west. The only positive evidence for this facies change is the minor amount of carbonate bioclasts in the chert outcrop to the west.

Further discussion concerning the significance of the stratigraphic evidence presented for this and the rest of the localities will follow the section on carbonate petrology.

**Dry Valley Locality**

The exposure at lower Dry Valley Creek is an excellent single outcrop of the Permian section from the base of the Grandeur Member to the cherty shale member. The carbonates and chert of the Rex Chert Member again form a prominent ridge with most of the carbonate exposed on the dip slope. The rest of the section is transversed by numerous phosphate exploration trenches.

Lack of other good outcrops in this area precluded detailed study of the lateral carbonate-chert relationships; however, the one excellent outcrop was described and sampled in some detail. The measured section (Figure 12) is located at the southern end of the outcrop.

The lower contact of the Rex Chert Member with the Meade Peak Member is conformable. It consists of a dark grey to black bedded chert overlying dark phosphorite and brown mudstone. The upper contact with the cherty shale
Covered on dip slope
Chert, pink, spicular, massive bedded.
Limestone, grey, fossiliferous, medium bedded, medium to coarse, sparry matrix. Abundant crinoid debris & product-tid brachiopods-minor bryozoans
Chert, dark grey to black, massive bedded, with pods of bryozoan limestone
Chert, dark to light grey, massive bedded

Covered
Chert, black, med. to thin irregular bedded, with thin inter-heds of buff mudstone
Chert, grey to black, medium bedded

Mudstone, brown, silty, phosphatic
member is poorly exposed but presumed to be gradational as at all other localities.

The lower contact of the carbonate lentil is gradational and consists of medium to massive bedded black chert with interbeds of dark aphanitic limestone and pods of bioclastic limestone. The limestone pods were found to be almost exclusively made up of ramose bryozoa in a micrite matrix and were sampled in detail to determine their nature petrographically. The chert immediately surrounding the lentil and the above mentioned pods contains abundant carbonate bioclasts substantiating the gradational nature of the lower contact.

The contact of the upper chert unit and the carbonate lentil is sharp but probably conformable. The upper unit is a massive bedded pink to white highly spicular chert. The spicules appear in hand specimens to be oriented. The light color of the upper chert unit contrasts with the dark color and fetid nature of the chert unit below the carbonate.

The carbonate in the lentil is predominantly a coarse crinoid bioclastic medium grey limestone with large productid brachiopods and subordinate amounts of bryozoan and brachiopod clasts. The crinoid particles are largely stem plates with some articulated stems up to several centimeters in diameter. Exposed dip slopes reveal highly bored abraded productid brachiopod shells.
Stewart Canyon Locality

A section of the carbonate lentil at Stewart Canyon was measured and described by the U. S. Geological Survey (Cheney and Montgomery, 1967) and is illustrated as Section B in the cross-section (Figure 13). The lentil is exposed in a series of tight folds on Dry Ridge between Stewart Canyon and South Stewart Canyon (Plate I). Hillslope debris, steep topography, and heavy vegetation preclude laterally continuous outcrops, but road cuts and phosphate exploration trenches provide fresh exposures.

The contact of the Rex Chert Member with the Meade Peak Member in the Stewart Canyon area is conformable where exposed. It consists of black thin bedded chert with interbedded dark grey aphanitic limestone overlying dark phosphatic brown mudstone. In some sections the base of the chert is argillaceous and contains thin interbedded dark shales.

The contact of the Rex Chert Member with the overlying cherty shale member is gradational, consisting of interbedded dark siliceous mudstone or shale and thin irregular beds of chert. In many cases the chert is noticeably spicular and often the siliceous mudstone also contains large siliceous sponge spicules.

The vertical stratigraphic relationships of the chert and carbonate are very similar to those at the previously discussed localities except that in the lower portions of
Geologic Map
Stewart Canyon Locality
(Cheney & Montgomery, 1967)
R 45 E

See Figure 11 for explanation.
FIGURE 13
Stratigraphic Cross Section
Stewart Canyon, Idaho

NW

Sec.DR
cherty shale mbr.
datum - top Rex Chert Mbr.
Grey, specular chert
Rex Chert Mbr.

Sec.A

Sec.B

Sec.E

Sec.D

Sec.C

Franson lentils

Grey, specular chert

DX grey chert
6 beds of dkc
dense limestone
Exposed

Meade Peak Mbr.

20'
Scale
1/4 Mi.

Cherty limestone
Breviocrinus
Acrothrella

Gray limestone
Breviocrinus
Acrothrella

Remora

a Faunal collection from
Cheney & Montgomery (1947)
the lentil, where the carbonates and cherts are interbedded, there is some evidence of scour of chert beds and infill by carbonate clasts. Further, some large vertical burrows in the carbonate are infilled with chert (Figure 14). The upper contact again is sharp and sometimes irregular with a corroded appearance. There are often carbonate bioclasts in the overlying chert unit.

Figure 14: Scour and fill (A) and burrows (B) near base of Section C, Stewart Canyon. Lithology of A is bioclastic limestone partially silicified (arrows). B is a dark grey chert. Note more resistant siliceous limestone below B (arrow). Scale at left is 6 inches.
In all of the sections there is a medial chert unit of varying thickness dividing the carbonate, except in the southernmost section where interbedded chert consists of twenty percent of the carbonate unit.

Although there are no continuous lateral exposures the stratigraphic relationship again appears to be a gradational facies change. Section A in Stewart Canyon at the northern limit of the occurrence of the lentil contains abundant interbeds, pods, and lenses of dark bioturbated finely crystalline limestone and a few carbonate bioclasts within the chert. The Dry Ridge section farther to the north contains less limestone with only a few lenses of finely bioclastic limestone.

The carbonate lentils are composed primarily of a dark grey, often fetid, bioclastic limestone with abundant crinoid columnals or plates and productid brachiopods, with minor amounts of spiriferid brachiopods and ramose bryozoa. The fine grained carbonate interbeds and some of the cherts near the chert to carbonate contact contain abundant small ramose bryozoa. Montgomery and Cheney (1967) list fossils collected from Section B (Figure 13) as shown in the cross section. The cherts, especially the upper unit, are noticeably spicular. Generally the lower unit is black to dark brown with a very fetid odor.
Timber Creek Locality

Examination of the Timber Creek locality (Plate I) gave the first insight to the lateral facies changes within the carbonate lentils as well as closely spaced control regarding the horizontal relationships of the chert and carbonate. The locality consists of a breached anticline plunging northward with very continuous outcrops of the Rex Chert Member as well as many bulldozer trenches.

The stratigraphic cross sections (Figures 15 and 16) illustrate the general lateral relations at the locality. The carbonate exposures are restricted to the east limb of the anticline which, unfortunately, is faulted resulting in a loss of the lower portion of the member in many of the outcrops.

The vertical stratigraphic relationships of the Rex Chert, Meade Peak, and cherty shale members at Timber Creek are similar to those at the other localities. At the southernmost section (Section A Figure 15) in a bulldozer trench the lower part of the Rex Chert Member contains some phosphatic chert and limestone and the upper part of the Meade Peak contains thin beds of phosphorite and chert. The cherty shale member is poorly exposed but from a trench between Sections A and G appears to be conformable and gradational with the Rex Chert Member.

The carbonate is exposed on the east side of the ridge from just north of the trench at Section A northward to
FIGURE 16
Stratigraphic Cross Section
Timber Creek, Idaho
Section L. Exposures are poor from there to Section H one-half mile to the north where the carbonate is very thin and near the base of the member. To the west on the opposite limb of the anticline (Section J) no carbonate is present. West to east across the plunge of the anticline an increasing amount of carbonate bioclasts are present in the chert. In fact, very near the area of massive carbonate at Section K the chert includes thin to medium beds of silicified bioclastic limestone. The lateral chert to carbonate facies change, then, is gradational, but more abrupt to the west and south and very gradual to the north. The stratigraphic position of the bioclastic carbonate appears to be more variable than at the other localities.

The lithology of the carbonates at this locality is quite variable. The greatest thickness of carbonate is exposed at Section K (Figure 15) which consists of two units, the lower unit being a light grey to brown bioclastic limestone. The major fossil constituents are large productid brachiopods with some clams and crinoid stem plates. There are some discontinuous lenticular beds with abundant brachiopod hash including brachiopods up to two inches in width. The lower unit is approximately fifty feet thick. The upper carbonate unit at this section is a dark grey fetid bioclastic limestone with crinoid stem plates as the main fossil constituent. Rugose corals and brachiopods are also found within this unit. The total thickness of carbonate at
Section K is approximately seventy-five feet with the lower part of the section cut out by a normal fault so that this thickness is minimal.

To the south at Section G there is only a very thin unit of bioclastic limestone. It is black, fetid, has a micrite matrix and includes abundant ramose and fenestrate bryozoa as well as brachiopods and some small pelecypods. Immediately south of this locality at Section A there is no carbonate in the exposure. However, the lower chert unit does include some bryozoan bioclasts.

To the north of the major carbonate occurrence at Section K there is another relatively poorly exposed section of approximately forty feet of bioclastic carbonate with a very fetid almost petroliferous odor. Crinoid stem plates are the major fossil constituent with rare rugose corals.

Much farther to the north at Section H there is a very thin limestone unit at the base of the section which is in part bioclastic limestone and in part dense aphanitic limestone with the major fossil constituent being bryozoan material.

The chert units of this locality are also quite variable with the most noted variance from the other localities being a ten foot bed of dark siliceous shale within the lower middle portion of the section. This shale is present only in the sections where the thick massive carbonates are not present. The cherts in the lower part of the section
are thin and irregularly bedded with thin interbeds and lenses of dense aphanitic limestone. The cherts are quite typically very dark at the base of the section. The middle and upper parts of the section are more massive bedded spicular cherts. They are generally lighter in color, ranging from light grey to tan and are more obviously spicular. Near the margins, both laterally and vertically, of the carbonate lentils the chert contains carbonate bioclasts and grades to replaced bioclastic limestone.

**Sage Creek Locality**

The carbonates at Sage Creek (Plate I) crop out on the east limb of Freeman Ridge which is a topographic expression of the Snowdrift anticline (Figure 17). It is about three miles south of the Timber Creek locality on the limb of the same fold but is separated from Timber Creek by outcrops in which the Rex Chert Member is entirely chert. The stratigraphic cross section (Figure 17) of this locality illustrates the lateral dimensions of carbonate exposure. The carbonates are exposed for approximately one-half mile until they are covered on the southern margin by the Quaternary alluvium of Sage Creek. One-half mile to the south of the last exposure of the carbonates is a section (Section A, Figure 17) of the Rex Chert Member which is entirely chert.

Stratigraphic relationships of the Rex Chert Member and the units above and below are similar in this locality
to those of the other localities previously described. The lower contact is well exposed at Section E where it is conformable. The upper contact is probably gradational. The contacts of the carbonate lentil with the chert units above and below are also similar to those described in the other localities. The contact of the carbonate on the lower chert unit is gradational with carbonate bioclasts, especially ramose bryozoan, occurring in the chert beds directly below the carbonate. The contact of the upper chert unit with the carbonate is sharp and irregular and appears to be corroded. At least one section, however, this is suspected of being a scoured surface and at Section E a chert breccia unit occurs approximately at this interval.

The lateral stratigraphic variations within the Rex Chert Member at this locality are well known in three directions as shown in the cross section (Figure 17). On the north and south, at Sections E and A respectively, the carbonate lentil is bounded by sections comprised entirely of chert. At Section E especially, however, there are some thin lenses of bioclastic limestone and some bioclastic inclusions within the chert to suggest a gradational facies change in that direction. Section A contains much less evidence of gradation and it appears that the facies change to the south again is quite abrupt. The section observed on the west limb of the same anticline approximately one mile to the west is also entirely comprised of chert (Freeman
FIGURE 17
Stratigraphic Cross Section
Sage Creek, Idaho

South
Sec.A

Sec.B
Sec.C
Sec.D
Sec.E

North

Cherty shale mbr.

Light brown spicular chert

Rex Chert Mbr.

Fransonintil

Biolastic

Chert

Dark grey spicular chert

Gray crinoid laminated limestone

Covered by Quaternary Alluvium

Brown-grey spicular chert

Covered

Gray crinoid-bryozoan bioclastic limestone

Dr. grey spicular chert & lens of dense bryozoan limestone

Datum base of Rex Chert Mbr.

datum base of Rex Chert Mbr.

Scale

0 1/6 Mi.
Ridge, Plate I). The closest control to the east are exposures at South Sage Creek which contain a major occurrence of carbonate within the Rex Chert Member.

The carbonates at Sage Creek are much thicker than those previously discussed, with the thickest section being Section B where there is over 120 feet of carbonate exposed. The dominant lithology in the carbonate lentil in exposures at the south end of the outcrop, Sections B and C, is a light to medium grey bioclastic limestone with the major fossil constituents being crinoid columnals or plates and brachiopods. There are lenses of coarse brachiopod hash material that are discontinuous throughout the sections. Laterally to the north within the carbonate lentil in Sections C and D the lithology is dominantly a light to medium grey bioclastic limestone with chert nodules and the major fossil constituent being brachiopods, crinoid columnals, and bryozoa. In the lower portion of the carbonate unit are several discontinuous lenses, two and one-half to three feet thick, of silicified coarse brachiopod hash. The lateral extent of the hash units is five feet or less. The bases of the lenses probably represent a scour surface. Farther to the north at Section E, which is predominantly chert, there are thin interbeds of dark grey aphanitic limestone which contain fossils, mostly bryozoon clasts.

The upper and lower chert units at this locality are also quite similar to other localities. The lower unit is
a black thin irregular to medium bedded chert with thin dark aphanitic limestone interbeds and lenses while the upper unit is a light grey to brown medium bedded chert, noticeably spicular. There are several interbeds of chert within the limestone lentils which generally contain a large amount of carbonate bioclasts. On the north margin of the locality at Section E in the poorly exposed part of the section there is some evidence of angular lithoclasts of chert.

**South Sage Creek Locality**

The exposures at the South Sage Creek locality are by far the best observed. The carbonates and cherts of the Rex Chert Member are exposed in almost continuous outcrop for approximately three and one-half miles. The carbonates form very prominent outcrops as ridges and cliffs with long talus slopes below (Figure 18). The locality is on the east limb of the Webster syncline approximately two and one-half miles due east of the Sage Creek locality previously discussed. The excellent exposures and evidence of lateral variation within the carbonates and chert at this locality make it best suited for a detailed petrologic study. Most of the stratigraphic relationships at this locality are very well known because of the nature and quality of the exposures. The outcrop was examined for lateral variations and stratigraphic relationships of the chert to carbonate. The continuity of the exposure provided much valuable insight to
Figure 18: Typical carbonate outcrop at South Sage Creek, Idaho. Note the extensive vertical fracturing and resultant blocky talus slope below the outcrop.

The vertical relationship of the Rex Chert Member to the overlying cherty shale member at this locality is quite similar to the other localities. It is both conformable and gradational. The contact with the Meade Peak Member is not exposed at the locality largely because of the large talus slopes from the carbonate outcrops. However, based on the relationships at all the other localities it is
thought to be conformable. Although a total section is not exposed at this locality, the total thickness of the Rex Chert Member probably ranges from 200 to 240 feet. This is several ten's of feet thicker than the other localities and represents expansion of the section due to the thick carbonate lentil present at this locality. The carbonate exposed at Section B (Figure 19) is the thickest occurrence of carbonate within the study area.

The thickest carbonate section exposed at Section B (Figure 19) grades laterally to the north at the expense of the lower part of the section into chert. Beds of carbonate can actually be followed for several feet laterally to the north until they grade to chert with horizontal aphanitic limestone lenses and finally to pure chert. The facies change from carbonate to chert in a northward direction as can be seen in the stratigraphic cross-section (Figure 19) is very gradual. In contrast, the facies change from carbonate to chert to the south, beyond Section C, is quite abrupt and may actually be much less gradational, although the exposures are poor south of Section C. In the transition of carbonate to chert at the base and the margins of the carbonate lentil the carbonates are often severely silicified. Some of the chert tongues within the carbonate unit, for example the five foot tongue near the middle of the carbonate unit at Section A, are actually silicified bioclastic limestones.
The contact of the lentil on the lower chert unit is conformable and gradational and is very similar to the contact at other localities. The vertical succession includes (Figures 20 and 21):

TOP
D. Medium to coarse bioclastic limestone.
C. Thin interbedded chert and ramose bryozoa bioclastic limestone.
B. Dark, irregular bedded chert with thin beds and lenses of black aphanitic limestone.
A. Dark irregular bedded chert.

BASE
The contact of the upper chert unit on the carbonate lentil is sharp but conformable. Irregularities in the bedding surfaces of this contact probably represent corrosion. Replaced carbonate bioclasts are present in the lower part of the upper chert unit but no lithoclasts have been observed. Also, no scour and fill structures were observed at this contact. At Section B the cherty shale member almost directly overlies the carbonate lentil. Although exposures are poor within the cherty shale member, lenses of bioclastic phosphatic fetid limestones are thought to be present within the unit at Section B.

Lithologically the carbonate and the chert units are extremely variable both laterally and vertically. Details of the variations involved are better discussed with the
Figures 20 and 21: Contact of carbonate lentil and underlying chert. Dark color and irregular bedding is typical of the lower chert (Figure 21). Contact is gradational consisting of interbedded irregular bedded chert and bryozoan bioclastic limestone (Figure 20). South Sage Creek, Section F.
section on carbonate petrology and paleontology. However, some observable field relationships will be discussed at this time.

The carbonate at Section C on the southern margin of the locality is a massive-bedded apparently ubiquitous light grey bioclastic limestone. Spiriferid brachiopods are abundant along with moderate amounts of crinoid debris and many smaller bioclasts. At Section B, 150 feet of massive-bedded bioclastic limestone is exposed (Figure 22). Because of the blocky weathering due to the intense fracturing of the carbonate and because of the massive nature of the bedding it is difficult to discern sedimentary structures on the outcrop. However, highly weathered material on the talus slopes below the outcrop indicate the presence of fairly low-angle tabular crossbedding. The direction and quantitative degree of dip of this crossbedding is indeterminate on the outcrop.

At Section A crinoidal debris is much more apparent than in the previously discussed sections. The limestone is typically a dark grey coarse bioclastic limestone with a very fetid odor and is possibly petrolierous. Crinoid stem pieces appear to be the dominant bioclast constituent. Articulated crinoid stems range up to six inches in length. At the base of the carbonate section and to some extent interbedded with the cherts directly underlying it there are thin beds of dark grey bioclastic limestone packed with
Figure 22: Thickest carbonate exposure in the study area. Note overall massive nature of the outcrop and extensive vertical fracturing making bedding difficult to discern. Trees (center and left) are ten to fifteen feet. South Sage Creek, Section B.
small ramose bryozoan fronds. At this section small mounds and lenses of crinoidal bioclastic limestones are apparent throughout the section. Crossbedding is not discernible within the lenses but the geometry of the lenses suggest very low angle crossbeds. Fragmented blocks in the talus slope below the outcrop which are highly weathered display some small scale crossbedding.

To the north between Sections A and D the lateral facies change from carbonate to chert is very well exposed. The thirty feet of dark grey irregularly bedded chert with lenses of aphanitic limestone at the base of Section B is laterally equivalent to the lower part of the bottom carbonate unit at Section A. The main carbonate unit at Section D consists of grey bioclastic limestone which is massive bedded and contains large amounts of productid brachiopods and crinoid debris. At Sections E and F the carbonate is also a grey bioclastic crinoidal limestone. The basal contact of the chert again is gradational with discontinuous beds and pods of grey bryozoan bioclastic limestone and dark grey aphanitic limestone occurring within the chert. Section G to the northeast is a light grey crinoidal bioclastic limestone which consists almost entirely of crinoidal debris with very large stemplates and articulated stems several inches in length with the exception of the upper-middle part of the section which contains abundant productid brachiopods.

The East Sage Creek and East Sage Creek North Section
three-fourths of a mile to the north (Figure 20, Sections ES and ESN) are on the northern margin of the carbonate lentil. At the East Sage Section the carbonates are almost entirely composed of bryozoan bioclastic limestone with varying amounts of carbonate mud matrix. Coarse brachiopod bioclastic limestones occur in discontinuous lenses several feet thick in both this Section and the East Sage Creek North Section. Many of the bryozoan specimens are fully articulated on bedding plains with branching fronds up to several feet in length. North of Section ESN approximately one-fourth mile is a section comprised completely of chert with thin lenses of aphanitic and bryozoan limestones and east one-fourth mile across a small fault the section is again completely chert.

The occurrence of chert lithologies at this Section is again very similar to those discussed for other localities. Chert units below the carbonate lentil are typically irregularly bedded very dark grey chert and interbedded dark aphanitic limestone. The presence of spicules is not obvious from hand specimens. The section above the carbonate lentil is more typically spicular and grades from a light grey, almost white or light red-brown spicular chert with replaced carbonate bioclasts upward to a very dark fetid spicular chert. The relationship of these two lithologies is very gradational and it is difficult in the field to define unit boundaries based on this lithologic criteria.
However, the light spicular cherts appear to be thickest at Sections A and D and very prominent at Section 0 and Section C.

**Other Localities**

Carbonate lenses are known to exist at other localities in the study area and were briefly observed in the field. The Deer Creek Locality (Plate I) is fairly well exposed but less accessible than the localities previously discussed. The occurrence of the lens in the axis of a syncline also makes measurement, description, and collection of stratigraphic sections difficult.

The carbonate at Hot Springs (Plate I) is very thin, maximum of seven feet, and although the lens is well exposed (Figures 23 and 24) it would be difficult to interpret the genetic significance of the occurrence. This locality is the southernmost outcrop of carbonate lenses within the Rex Chert Member.

Observable field data at the South Sage Creek Locality suggest definite lithofacies and biofacies variations and all of the above described sections were sampled at one and one-half foot intervals for a detailed petrologic study of the outcrop. Relationships observed in the field provided sufficient criteria to conclude that the carbonate lentils at this locality are bihermal in nature. Using the South Sage Creek locality as a model, it may be concluded that
the rest of the localities previously discussed also consist of varying cross sections of carbonate bioherms. The discussions which follow on the paleontology, carbonate petrology and chert petrology of the Sage Creek and South Sage Creek localities relative to the other areas in which the bioherms occur will provide further evidence to substantiate this thesis.

Figure 23: Exposure of small lens of carbonate in massive Rex Chert Member, Hot Springs, Idaho. Carbonate is seven feet thick. Section is overturned. The Pennsylvanian-Permian Wells Formation is visible on the skyline.
FIGURE 24
Stratigraphic Section—Rex Chert Mbr.
Hot Springs, Idaho
The preceding discussions of the regional and local Permian stratigraphy in or adjacent to the study area is presented as background for the following discussion of the paleontology, petrology, and genesis of the Rex Chert Member and the carbonate bioherms contained within it. Lithologic and faunal descriptions contained within the discussion of regional stratigraphy are brief, but may be easily supplemented by the references cited in the text or listed in the selected bibliography (pages 167-175). Time-stratigraphic relationships discussed are those which have been suggested by the U. S. Geological Survey and are strictly based on megafaunal correlations. A further discussion of the age of the Rex Chert Member will be attempted in the following section on the paleontology of the carbonate bioherms.
A detailed paleontologic study of the carbonate bioherms was one of the original objectives of this study. However, after some time in the field, it was apparent that such a study was not practical in the amount of time available. In fact, it is doubtful that such a study would ever lead to much more meaningful results than obtained by the methods used in this study, for the following reasons:

A. Poorly preserved fossils - mostly due to abrasion or silicification.

B. Transport from site of origin - the above factor (A) is suggestive of some degree of transport. The results of this study indicate that the degree of transport on a generalized scale is small, but in a detailed study this factor would be much more damaging. Very little evidence could be gathered in the field relative to the life style of individual genera or species other than the few generalizations made. Indirect determination of life processes or environments for specific individuals of the fauna from morphologic characteristics would be greatly hampered by the poor preservation of specimens.
C. Lack of quantity of identifiable material - very few identifiable specimens may be found at any one locality. Quite often the only specimens are found in highly weathered blocks in talus slopes, which destroys the ability to reconstruct the vertical array of the fauna. The chance of statistically reliable results of such a detailed study would be low because of the lack of a suitable number of specimens.

D. Lack of models for comparison - few of the fossils involved have modern analogues with which to compare either life processes or environments. Most of the fossils involved are poorly studied with regard to specific environments in ancient rocks which could yield a basis for comparison. Publications by both Yochelson (1963) and Wilkinson (1967), however, have made excellent conclusions regarding regional paleoecology of Phosphoria carbonates, much of which added greatly to this discussion of paleontology and paleoecology.

In most areas of shelf carbonate sedimentation the amount of sediment supplied is directly proportional to the organic productivity of carbonate particles. The amount of sediment supplied, then, is related to the organisms' ability to live and thrive in a specific environment. Totally disregarding transport of that sediment, one could determine
the distribution of fauna within a carbonate province by defining the nature and distribution of carbonate particles.

Total absence of transportation within a system which resulted in winnowed abraded carbonate clasts, such as the bioherms studied is, of course, inconceivable. However, evidence from the study of the carbonate petrology of the bioherms indicates that in all but exceptional cases lateral transport of carbonate clasts was minimal on a general scale. As an after-the-fact observation, then, the best method for determination of biofacies distribution and interpretation of depositional environments and paleoecologic aspects of faunal distribution in this particular carbonate system was through petrologic methods.

The biota from the Rex Chert Member and enclosed bioherms within the study area are summarized in Table 1. Most of the specific and generic identifications are from Yochelson (1968) who described specimens from U. S. Geological Survey collections from the area, especially from the South Sage Creek locality. Many of the genera listed are confirmed by personal observations, but not all those listed by Yochelson were present in my collection. Cheney and Montgomery (1967) list the fauna identified from the bioherm at Stewart Canyon and these are also included in Table 1.

Most of the additions to Table 1 are microfossils or fossils identified from thin section analysis, since Yochelson only described the megafauna. The one other exception
TABLE 1 - BIOTA OF THE REX CHERT MEMBER AND ENCLOSED BIOHERMS, SOUTHEAST IDAHO
(After Yochelson, 1968, and from personal observations)

<table>
<thead>
<tr>
<th>Algae</th>
<th>Gastropods</th>
</tr>
</thead>
<tbody>
<tr>
<td>?Schizophyte (Blue-green)</td>
<td>Babylonites sp. indet.</td>
</tr>
<tr>
<td>Dasyclad (Green)</td>
<td></td>
</tr>
<tr>
<td>Epimastapora</td>
<td></td>
</tr>
<tr>
<td>Vermiporella?</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Foraminifera</th>
<th>Scaphopods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Textularid indet.</td>
<td></td>
</tr>
<tr>
<td>Globivalvulina</td>
<td></td>
</tr>
<tr>
<td>Encrusting foram</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Porifera</th>
<th>Pelecypods</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Monaxial siliceous spicules</td>
<td>Nuculopsis sp. indet.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coelenterates</th>
<th>Echinodermes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rugose corals</td>
<td>Echinoid spines and fragments</td>
</tr>
<tr>
<td>Rugose coral indet.</td>
<td>Crinoid stem plates and fragments</td>
</tr>
<tr>
<td>Bradyphyllum idahoensis</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bryozoa</th>
<th>Arthropods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramose bryozoa (Cryptostomes)</td>
<td>Ostracodes</td>
</tr>
<tr>
<td>Fenestrate bryozoa (Trepostomes)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Brachiopods</th>
<th>Incerte sedis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inarticulate</td>
<td>*Organic walled micro-fossils</td>
</tr>
<tr>
<td>*Orciculoidea sp. indet.</td>
<td>Spindle-shaped borings</td>
</tr>
<tr>
<td>Rhynchonellids</td>
<td>Burrows</td>
</tr>
<tr>
<td>Leiorhynchus sp. indet.</td>
<td></td>
</tr>
<tr>
<td>Rhynchonidea sp. indet.</td>
<td></td>
</tr>
<tr>
<td>Strophomenid</td>
<td></td>
</tr>
<tr>
<td>Derbyia sp. indet.</td>
<td></td>
</tr>
<tr>
<td>Productids</td>
<td></td>
</tr>
<tr>
<td>Echinauria sp. indet.</td>
<td></td>
</tr>
<tr>
<td>&quot;Lioestella&quot; sp. indet.</td>
<td></td>
</tr>
<tr>
<td>Kochirproductus c.f. K. longus</td>
<td></td>
</tr>
<tr>
<td>Bathymyonia c.f. nevadensis</td>
<td></td>
</tr>
<tr>
<td>Antiquatonia c.f. A. sulcatus</td>
<td></td>
</tr>
<tr>
<td>Anidanthus eucharis</td>
<td></td>
</tr>
<tr>
<td>Cancriellia sp.</td>
<td></td>
</tr>
<tr>
<td>Muirwoodia multistratiatus</td>
<td></td>
</tr>
<tr>
<td>Sphenosteges sp. indet.</td>
<td></td>
</tr>
<tr>
<td>dicytoclostid indet.</td>
<td></td>
</tr>
</tbody>
</table>

| Spiriferids                   |                                   |
| Composita sp. indet.          |                                   |
| Spiriferina sp. indet.        |                                   |

*Biotic elements occurring primarily in a chert matrix.
is the identification and description of a rugose coral which is the only systematic description attempted herein. Since this is, at this time, the only identifiable coral reported from the Phosphoria Formation, its identification and description were considered an important facet of the study.

The following discussion of the faunal distributions interpreted for the Sage Creek and South Sage Creek localities precede a more involved discussion of the individual faunal elements within the study area.

**Distribution of Biota - South Sage Creek Bioherm**

Upon analyzing the observed field data and a preliminary scan of thin sections from all localities I determined that the Sage Creek and South Sage Creek localities were best suited for detailed petrologic study. In addition to the normal lithologic descriptions from thin sections as described in the section on petrology, fossil constituents were all identified in thin section and an estimate was made of relative abundance. Samples from these localities were taken at intervals of three per each five feet from which over 400 thin sections were made and analyzed in addition to all of the hand specimens, thereby defining a fairly dense vertical array of control. The lateral control at both localities consists of stratigraphic sections which are for the most part one-quarter mile or less apart.
It would be difficult because of the size differential involved in the fossil clasts and because of mechanical sorting involved in deposition to quantify the abundance of fossil clasts in each thin-section. The results, therefore, are highly dependent on my ability to visually estimate the relative abundance of the fossil constituents within each thin-section and my ability to recognize each constituent. Thin-sections were spot checked, however, and identifications and relative abundances appeared to have a high reproducibility. With this consideration in mind, the number of samples involved probably represent a statistically reliable distribution.

Bioclast distributions at the two localities are summarized in Plates II and III. The histograms at the top of the plates show the average relative abundance of each fossil element for the total section. This averaging of the total section eliminates details of vertical variations of the faunal elements which will be discussed later. What each histogram represents, then, is an average of the faunal elements which were stably located at a single position and those which migrated laterally with time throughout the locality. This should yield a generalized biofacies distribution for the total bioherm. The following is a brief description of the distribution of each faunal element and the significance of that distribution.
Productid Spines

Productid spines are, of course, not a faunal entity but a skeletal particle abraded from a productid shell. The distribution of productid spines within the bioherms, however, is considered to be significant. The productid spines are by far the smallest of the particles listed and when they occur in thin-section they usually occur in great abundance and appear to be oriented. The distribution is shown on Plates II and III and is essentially ubiquitous at both localities which indicates a high degree of sediment transport and equal dispersion from the area of productivity of productid spines. Such a distribution could be expected for a small bioclast in a well winnowed sediment.

Ramose Bryozoa

Increased abundance of ramose bryozoa is noticeable from south to north at South Sage Creek with the greatest abundance occurring in Sections ES and ESN (Plate II). The histogram for Section ES shows the almost total dominance of ramose bryozoa at that section. Other faunal elements at this section probably represent transport from another area, specifically the crinoid and brachiopod fossil debris. Field evidence supports this interpretation since most of the brachiopod debris occurs as lenticular discontinuous hash beds probably representing current channel deposits. The apparent ubiquitous distribution of ramose bryozoa
throughout the rest of the sections actually represents occurrences at the base of each carbonate section where the carbonates grade laterally and vertically into chert. This distribution, then, represents the lateral migration of the ramose bryozoa biofacies from south to north with time. Sections ES and ESN represent the areas in which the ramose bryozoa were persistently dominant. Some ramose bryozoa do occur, however, mixed with crinoid debris.

**Fenestrate Bryozoa**

The distribution of fenestrate bryozoa appears to be laterally consistent with several very small peaks at various sections (Sections A, F, and ES–ESN, Plate II). The fenestrate bryozoa appear to be much more restricted than the ramose bryozoa as they occur almost exclusively with the ramose bryozoa near the base of the bioherm and at the lateral facies change of chert to carbonate (for instance Sections ES and ESN, Plate II). Fenestrate bryozoan material is almost totally lacking in the rest of the bioherm. This may in part, represent destruction in higher energy zones but more likely represents restriction to an aerated, but low energy, back-bank environment.

**Pelecypods**

The distribution of pelecypod fossil clasts at the South Sage Creek parallels the distribution of fenestrate bryozoa and suggests the same environmental restrictions as
those of the bryozoa. Unabraded pelecypod fossils, indicating a very low degree of transport, are specifically distributed as described above; are never found within the interbedded cherts and are seldom found within the more coarse bioclastic material. Again the pelecypods at this locality were probably restricted to a low energy environment.

**Crinoids**

Crinoidal material increases to a peak at Section D and decreases gradually from there to the north. Crinoid stem plates are found quite consistently with most of the coarse bioclastic material. However, considering the field evidence for occurrence of many articulated crinoid stems in Sections A through G as well as the small mounds and lenses of almost pure crinoid bioclastic limestone at these sections this likely represents a subtle, but real, biofacies distribution.

**Brachiopods, General**

This category is used for index of the abundance of both productid and non-productid brachiopods within the biherm (Plate II). At South Sage Creek there is a bimodal distribution of brachiopod material with one peak at Sections C and B and one at Section G. Note that peak distributions with the productid and non-productid brachiopod categories occur in the same sections as the peak distribution for
the brachiopod, general. Intuitively, the total of the abundance of productid brachiopods and non-productid brachiopods at any one section should be equivalent to the abundance of general brachiopods at that particular section. However, one of the reasons for having a category general brachiopod was that some brachiopod material was not distinguishable, usually because of diagenetic effects, as either productid or non-productid material, so that the relationship mentioned above is not necessarily true. The three distributions were estimated independently. The fact that it appears that distribution of the productid brachiopod could be added to the non-productid brachiopod distribution, resulting in a histogram quite similar to that of the general brachiopod category, attests to the reproducibility of the data.

Productid Brachiopods

The distribution of productid brachiopods within the bioherm (Plate I) is again fairly consistent from north to south with a peak at Section G. Field evidence indicates that productid brachiopod fossils are most abundant at Sections D through G, supporting peak distribution in this area. Other productid bioclasts at Section ES, as discussed previously, may be explained by transportation into the area by current channels. The degree of clasticity in Sections C through A may also indicate transport into that area. How-
ever, it should be noted that the variability of fauna at the generic level is highest within the productid brachiopods (Table 1). It is certainly conceivable that the productid brachiopods occupied many diverse environments.

Non-Productid Brachiopods

One might expect from this title quite a variety of genera in this category. However, it actually includes five genera, only three of which are known to occur at the South Sage Creek locality (Composita, Spiriferina, and Derbyia). Of these the spiriferids, Composita and Spiriferina, are by far the most abundant in hand specimens. Thin-sections are also found to include mostly spiriferids. Therefore, the non-productid brachiopods may generally be considered spiriferid brachiopods. Distribution of the spiriferid brachiopods appears to be limited to Sections A through D (Plate II) as substantiated by field evidence. The distribution is important, not only in delineating a specific biofacies, but also as evidence for the general low degree of sediment dispersion within the bioherms. From this data it would appear that the spiriferid brachiopods have been transported from the area of greatest sediment productivity to the area of deposition for no more than one-half mile. It is quite possible that the degree of transport is much less than that.

Most of the above descriptions of faunal distribution were from the South Sage Creek locality (Plate II). The
South Sage Creek locality (as described on pages 49-59) is by far the best exposure of all the localities observed and is the largest bioherm exposed in terms of vertical and lateral dimensions, displays the most evident variations in lithology and fauna in the field, and was studied in greatest detail in terms of carbonate petrology. For this reason it is certainly the best understood of all biohermal occurrences within the study area.

Bioclast distribution analysis of exposures at Sage Creek, Idaho (Plate III) involved less samples from outcrops which are much more poorly exposed both vertically and laterally, so that the data may be somewhat less reliable than at South Sage Creek. Certainly much more interpretation is needed at this locality to establish an understandable biofacies distribution. The southern end of the bioherm at Sage Creek is completely obscured by alluvium (Figure 18) and is suspected of being the area of thickest carbonate accumulation as in the South Sage Creek exposure. The most obvious evidence for this supposition is that the amount of carbonate in the exposure increases greatly from north to south and that the total Rex Chert Member increases in thickness from north to south (Figure 18, Plate III).

At Sage Creek the bioherm appears to be more prominently divided into two units, with a medial chert unit. The bimodal distribution of ramose bryozoa, then, is probably related to the separate distribution within each of
these units as is the abundance of fenestrate bryozoans at Section B. Pelecypod material again is rare. Productid spines are distributed equally throughout the exposure and again probably represent complete dispersion of that type of sediment. The same may be true for crinoidal material, although it should be pointed out that without an exposure of the major carbonate occurrence, distribution of crinoidal material at Sage Creek is very similar to the northern end (Sections G, ES, and ESN) of the distribution chart at South Sage Creek (Plate II). Again the distribution of general brachiopod clasts appears fairly consistent although they are more abundant at this locality than at South Sage Creek. The same methods of determination were made at this locality for the general brachiopod, productid brachiopod, and non-productid brachiopod abundances. The addition of the abundance of the two separate brachiopod categories approximately equals the general brachiopod category. Again this is a test of the reproducibility of the data. The degree of transport of the productid brachiopods at this locality may be quite high, as field evidence indicates the presence of brachiopod hash lenses which may represent current transport and deposition within channels.

**Biotic Elements**

The following discussions and photo plates (Plates I - XII) provide further details of the occurrence and methods
of identification of the biotic elements listed in Table 1.

Algae

Algae and/or algal structures are represented mostly in the upper part of Section B and throughout Section C at South Sage Creek, although algal coatings appear on grains farther northward at Section F. The presence of blue-green algae may indicate fairly shallow water depths (60 ft.), at least within the photic zone (Heckel, 1972). All forms encountered, however, are most likely subtidal. The Dasy­

clad algae present are difficult to interpret in terms of environment but their close association with the blue-green algae at this locality suggests similar environments. Recognition in thin-section was based primarily on knowledge of gross morphology (Photo Plate I)(Johnson, 1963).

Foraminifera

Forams are also especially abundant at Section C, South Sage Creek. Several varieties of foraminifera were encountered. The globose forms, Globivalvulina, and the textularids have a fairly ubiquitous distribution. There is some evidence that Globivalvulina was a relatively mobile form since it is found even within the chert. The one encrusting specimen identified suggests a very stable if not hard substrate in a fairly well aerated environment. The presence of foraminifera within the bioherms is in itself anomalous since few have been described from equivalent
shelf sediments to the east. Thin-section identification was based on knowledge of gross morphology (Plate III).

**Porifera**

Monaxial spicules are restricted to and very abundant in the intermound cherts. No evidence for any calcareous spicules was found. All spicules are now, and are assumed to have always been, siliceous. The spicules are thought to represent the siliceous framework of demosponges. Sponges are sedentary and occupy a diverse spectrum of modern environments (deLaubenfels, 1954, 1957) but have some very specific fundamental requirements (deLaubenfels, 1954):

a. Clean water – sponges are not tolerant to excessive amounts of silt or sediments which would smother them.

b. Moving water – currents of two to three kilometers, but not in excess.

c. Oxygen and other nutrients – sponges thrive in abundance of phosphate and silica.

d. Depth – sponges as a group have wide ranges of tolerances but each species has specific restrictions. The demosponges live in water depths of 600 feet up to intertidal depths.

e. Symbionts – sponges often contain symbionts.

f. Salinity – sponges live in delicate osmotic balance with their environment and are not tolerant to marked salinity changes.
g. Substrate - modern sponges require a fairly stable substrate.

All of the above factors suggest that sponges are hardy within a specific delicately balanced environment and are not very tolerant to changes. Certainly the thick (up to 200 feet) section of Rex Chert within the study area is suggestive of a very optimum set of conditions.

The upwelling current hypothesis for formation of phosphorites within this area (McKelvey, et al, 1959) would also explain the abundance of siliceous sponges by providing clean moving water, abundant nutrients (silica and phosphate), stable salinity, and fairly stable temperatures. The high productivity of both spicular siliceous and carbonate bioclastic sediments could certainly be related to this unique set of circumstances.

The siliceous sponges thrived in unrestricted topographic low areas between bioherms, laterally to the east until currents, wave energy and clastic supply became intolerable and to the west to the shelf edge where depths and basin clastics (cherty shale member) were prohibitive. The sponges were disarticulated to form spicular siliceous muds, eventually enclosing the bioherms in chert. Spicules are easily identifiable in thin-section because of their uniform small size, presence of a central canal, and siliceous nature (Photo Plate V).
Corals

Rugose corals are another anomalous element in Phosphoria carbonates. They are not found in the Franson equivalent shelf carbonates to the east (Duncan, 1961), but are found to be moderately abundant in four exposures of the bioherms within the study area.

The following systematic description of the specimens found is attempted because of the significance of the corals in establishing the relationships of the study area to regional Permian paleogeology. It is also hoped that further work may help define a basis for correlation with at least the European Standard section to better define a basis for time-stratigraphic correlation of the Phosphoria carbonates.

**SYSTEMATIC DESCRIPTION**

**Phylum** COELENTERATA

**Class** ANTHOZOA

**Order** RUGOSA

**Family** METRIOPHYLLIDAE Hill, 1939

**Genus** BRADYPHYLLUM Grabau, 1928

**Bradyphyllum Idahoensis**, n.sp.

Plates VI & VII 6 Figures
Description -
External features:

Solitary straight cylindrical to ceratoid corallites (all specimens are fragments). External surface rugose with slight to moderate septal grooves. Holotype 2.5 cm. in diameter and 3.0 cm. in length (fragment). Paratypes 1.5 - 3.0 cm. in diameter and 1.0 - 3.6 cm. in length (fragments).

Transverse section: Holotype UM 6591

Strong calicular pit in mature stage. Septa reach axis in immature stage, are moderately farther from the axis in the intermediate stage. Septa dilate toward the axial region to join, with the exception of the cardinal septum which is withdrawn creating a cardinal fossula. No cardinal fossula in immature form. An alar fossula develops in the moderately mature portions of the corallite. Counter septum is slightly withdrawn but still in contact with other septa. Holotype contains 38 septa. Septa are of slightly unequal length (.8 - 1.0 cm.). Mature specimens exhibit prominent minor septa which are missing in the immature stage. There are two to three orders of dissepiments not forming a distinct dissepimentarium. Thin epitheca in all forms with thin to moderate marginarium (2 mm) in mature forms. Few dissepiments in mature and immature form, slightly concave to exterior.
Longitudinal section: Paratype UM 6592

Septa are simple and continuous. Tabula are present in immature to intermediate stages. Mature stage not observable. Massive concave upward tabulae in immature stage. Narrow tabularum. From the transverse sections of the holotype the tabula do not appear to be well developed in the mature stage.

Discussion:

All specimens, holotype and three paratypes, are partial specimens. Holotype (UM 6591) appears to be intermediately mature, paratype (UM 6592) is mature with calyx almost preserved, paratype (UM 6593) is intermediately mature, paratype (UM 6594) is immature. Twelve acetate peels of the holotype and four acetate peels and eight polished surfaces of the paratypes were examined.

Occurrence - known from three localities, Wood Canyon, Timber Creek, and Sage Creek, Idaho (see appendix for location) and suspected of being present at South Sage Creek, Idaho. Holotype and paratypes are from Timber Creek, Section K, paratype from Wood Canyon, Section C.

Repository - University of Montana, Department of Geology: Holotype UM 6591, paratypes UM 6592, UM 6593, UM 6594.

Hoare (1964) described the first North American species of the genus, Bradyphyllum gracilium, from a Wolfcamp? carbonate in northern Nevada. The genotype, B. bellicostatum (Grabau, 1928) and all previously described species were
found only in Eurasia, presumably as a member of the Tethys fauna.

The genotype is a very simple form much like *B. idahoensis* with the exception of the presence of tabulae in the latter. Grabau (1928) in his discussion of the genotype does not directly exclude tabulae as a criterion for the genus. Also, there are insufficient longitudinal sections of the genotype to definitely exclude the presence of tabulae. For this reason, as well as the very close similarities of other features, the specimens described were assigned to the genus *Bradyphyllum*.

The genus *Pseudobradyphyllum* as discussed by Dobrolyubova (1940) may actually be a synonym for the genus *Bradyphyllum* as the critical difference was stated to be the presence or absence of tabulae. However, at the present time there is insufficient data to warrant placing *Pseudobradyphyllum* into synonymy.

The present range of the genus as indicated from the species listed below is Middle Pennsylvanian, Moscovian (Desmoines) to Upper Permian, Kazanian (Guadalupes):

Genus *Bradyphyllum* (Grabau, 1928)
- **B. bellicostatum** Grabau, 1923
  - Moscovian (M. Penn.): China (Genotype)
- **B. obscurum** Grabau, 1923
  - Moscovian (M. Penn.): Moukou, China
- **B. nordskioldi** Heritsch, 1939
  - L. Permian: Western Spitzbergen
- **B. geinitzi** Heritsch, 1939
  - L. Permian: North fjord, Spitzbergen
- **B. gracilium** Hoare, 1964
  - Wolfcampian: Nevada, U.S.A.
B. *caninoideum* Huang, 1939  
Artinskian? (Leonardian): Chekiang, China

B. *angeli* Heritsch, 1936  
U. Auernig: Carnic Alps

B. *incertum* Heritsch, 1936  
Permian (Guadalupe?): Wesleyo, Timor

B. *indictum* Heritsch, 1937  
Kungurian-Kazanian (U. Leonardian-Guadalupian): Salt Range, India

B. *idahoensis* n. sp.  
U. Leonardian-Guadalupian: Idaho, U.S.A.

There are insufficient specimens described to definitely establish any evolutionary trends. However, it appears that the Lower Permian forms have thinner, more simple, even and straighter septa, while those of the Upper Permian are typified by distally dilated septa. The presence of more prominent tabulae may also be a trait of the older forms.

The specimens described by Hoare (1964) have a closer affinity to *B. nordenskioldi* and *B. geinitzi* (Heritsch, 1939). The Wolfcampian age of the Nevadan rocks also compares favorably with the Sakmarian (Wolfcampian) age of the specimens from the Alps.

*B. idahoensis* has closer affinities with *B. incertum* (Heritsch, 1936) and *B. indictum* (Heritsch, 1937) from the Kungurian-Kazanian (Upper Leonardian-Guadalupian) of India which agrees quite well with the age presumed for the Frank-son and Rex Chert members in the area of study.

The Eurasian (Tethys) affinity of the only identified coral from Phosphoria carbonates suggests that the corals migrated from the west through narrow passages in the orogenic belt in western Idaho (Figure 8, page 16).
Bryozoa

Bryozoa occur in relative abundance within specific portions of the bioherms. A systematic study of the bryozoa would be very difficult since relatively few studies of bryozoa have been attempted for rocks of equivalent age in the Phosphoria Formation (Yochelson, 1968). Duncan (1957) described the life processes of fossil bryozoa as being similar to present bryozoa. The following is a summary of the ecological requirements of modern bryozoa (Duncan, 1957; Wilkinson, 1967; Yochelson, 1968; Heckel, 1972):

a. Depth of water — Bryozoa flourish in water depths of 600 feet to shallow subtidal but are present to even greater depths.

b. Nutrients — Bryozoa are suspension feeders and require moderate bypass of nutrients. Slight currents or suspension fallout in relatively quiet waters would suffice.

c. Turbidity — High amounts of fine clastic sediment would probably be detrimental.

d. Salinity — Normal salinity to slightly brackish or very slightly saline.

e. Substrate — A firm substrate or a stable attachment is best since all forms are sessile, but "rooting" in a stable mud is possible.

f. Life mode — Sessile, benthonic, and colonial; some are encrusting.
g. Temperature - Varied temperatures limit single species but the group occupies diverse temperature regimes.

The presence of bryozoa in the carbonate bioherms of the Rex Chert Member is not unusual, since bryozoa are commonly found in crinoidal rocks (Duncan, 1957). In consideration of ecological requirements of crinoids this most likely represents a preference for the same or similar environments.

Three distinct types of bryozoa were distinguished, fenestrate, ramose, and encrusting (Photo Plates 8-9). The fenestrate are the most restricted in occurrence within the bioherms. No articulated fossils were found, attesting to the delicate nature of the colonies. The fenestrate bryozoa probably coexisted with ramose bryozoa in a relatively quiet water, back bioherm, environment and in deeper waters on locally high firm substrates as a pioneer phase of biothermal development.

Ramose bryozoa are much more widely distributed and abundant and probably occupied several environments. They occur most abundantly in the quiet backbank environment coexistent with the fenestrates and probably served as a slight current baffling mechanism protecting the more delicate fenestrates. Fronds of a foot in length and a half inch in diameter are found aligned, apparently by currents, attesting to the hardier nature of the ramose forms. They
also probably coexisted with crinoids in an environment immediately leeward of the main bank. The crinoids most likely provided the same current baffling service for the ramose bryozoa as the bryozoa do in the previously mentioned case.

The encrusting bryozoa have a more diverse distribution, related mostly to prospective substrate. This form required some relatively stable particle on which to encrust and was eliminated from environments where current energy was not conducive to particle stability.

Bryozoa were recognized in thin section on the basis of knowledge of gross morphology (Majewski, 1971) and relative to hand specimens. A wide variety of forms of the ramose type were noted, with less variety of the fenestrate and encrusting forms (Photo Plate 8).

Brachiopods, General

The most demonstrably diverse group within the bioherm is the brachiopods. With respect to abundance of sediment supplied they rank second only to the crinoids. In terms of numbers of individuals, then, the brachiopods probably outnumbered the crinoids by an order of two to one. Obviously a single crinoid produces a much larger amount of carbonate particles than a single brachiopod. Indeed, if one had to attach a significantly notable biologic element to the formation of the bioherms, they would be classified as brachiopod-crinoid bioherms.
The brachiopods are a large group which likely adopted a wide diversity of environments. A complete discussion of the ecological requirements of the group, therefore, will not be attempted. Faunal associations and paleoecology of most of the genera known to occur in the bioherms (Table 1) have been studied from the Franson and Ervay shelf carbonates to the east (Yochelson, 1963, 1968; Wilkinson, 1967). The faunal associations as determined by Yochelson are summarized in Figure 25.

Distribution of the brachiopod faunas at generic level was not determined in this study so that evidence of correlation with Yochelson's model is not completely conclusive. However, all of the elements of that model are present within the bioherms and the paleoecologic criteria must be similar. Therefore, application of the model (Figure 25) will be assumed to be valid for the few generalizations made.

As previously discussed, evidence of faunal distribution within the bioherms was primarily gained through petrologic analysis. In this analysis two categories of brachiopods were recognized – productid and non-productid. The non-productid brachiopods that occur in abundance at South Sage Creek are Spiriferina, Composita, and Derbyia. The productids described by Yochelson (1968) from South Sage Creek were Kochiproductus, Antiquatonia, and a dictyoclastid. A much greater variety, however, is listed for Stewart Canyon (Cheney and Montgomery, 1967) including "Liostellia", Bathy-
MAXIMUM TRANSGRESSION

FAUNAL ELEMENTS - FRANSON CYCLE
W. WYOMING
(Data from Yochelson, 1963, 1968)

FIGURE 25

MAXIMUM REGRESSION
myonia, Anidanthus, Kochiproductus, Antiquatonia, Fairswoodia, and Sphenosteges.

From the description of Yochelson's section at South Sage Creek (Yochelson, 1968) it would appear that it represents a single section in an area where the biofacies would not include a variety of productids. It is conceivable, and quite probable from field observations, that a more diverse brachiopod fauna would be found laterally from that section, as is the case at Stewart Canyon. The paleontologic collection from South Sage Creek gathered for this study was insufficiently large and contained material too poorly preserved to identify, so that it is impossible at this time to further define the details of distribution of brachiopod faunas at that locality.

Considering the fact that all of the localities studied (Plate I) are no more than chance exposures of relatively random cross sections at varying positions within a bioherm, the use of all the faunal elements listed in Table 1 in relation to the models defined by Yochelson (1963, 1968) and Wilkinson (1967) may ultimately be the best method for defining the paleoecology of the brachiopod fauna. This method, in conjunction with the distributions already defined petrologically, will be used in the discussions of distribution and paleoecology of the brachiopod faunal elements.
Non-productid Brachiopods

Of the non-productid brachiopods listed in Table 1, the three genera, Derbyia, Composita, and Spiriferina are probably the most abundant within the bioherms. The rhynconellids were not observed in the field or from the paleontologic collection while the presence of the other three genera was confirmed.

Derbyia and Spiriferina are typically found in bioclastic limestones within the Franson shelf carbonates to the east (Figure 25) (Yochelson, 1963) associated with ramose bryozoa. From the matrix material described, this association probably represents a fauna adapted to a high energy regime. The morphological characteristics as portrayed in Figure 25, especially the sessile mode of attachment to the substrate or other organisms and the streamlined nature of the valves, supports this conclusion. Composita, although also sessile, is more globose and may have occupied a less turbulent environment.

The non-productid brachiopods at South Sage Creek are more closely associated with crinoids than ramose bryozoa, as described by Yochelson (1963), but from personal observations crinoids may also be an important associate in the shelf carbonates to the east. The distribution of the non-productids at South Sage Creek as determined petrologically (Plate II) substantiates the interpretation of a high energy environment. This is also the area of maximum carbonate
buildup and the non-productid brachiopods were certainly responsible for a large share of the production of carbonate debris which allowed the bioherms to expand both laterally and vertically. Thin-section identification was based on shell structure as described by Majewski (1969), Horowitz and Potter (1971), and on Photo Plate X.

Productid Brachiopods

The relative abundance or lateral variation of productid brachiopod genera is not known for any of the localities studied. Again, the relationships must be interpreted from the petrologically determined distribution (Plate II) and the model presented by Yochelson (1963) (Figure 25). In general, the productid brachiopods may be interpreted to have occupied a diverse spectrum of environments of moderate to low energy regimes. This diversity is exemplified by both the petrologic evidence (Plate II) and Yochelson's model (Figure 25).

Of the genera known from all localities (Table 1) Kochi-productus, Antiquatonia, and a dictyoclastid were described by Yochelson to occur at South Sage Creek. In addition to these, from poorly preserved specimens, Bathymyonia?, "Lic-stella"?, Echinauris?, and Sphenostages? are thought to occur at this locality. From the poor quality of the collection it would be difficult to say that others listed (Table 1) do not exist, even in abundance, at the South Sage Creek locality.
The sessile form *Sphenostega* which was firmly cemented to the substrate was well adapted to an environment with a moderate to high energy regime. Most of the productid material in the bioclastic limestone of the main carbonate buildup and immediately north was probably produced by a member or members of this genus.

The genera "Liostella", *Echinauris*, *Bathymyonia*, and *Muirwoodia* were sedentary and stabilized by spines. These four genera were probably adapted to environments with a less firm substrate, and decreasing energy regimes in the order listed. The abundance of productid spines (5-10% of the total bioclasts) at the Sage Creek and South Sage Creek localities attests to the abundance of these genera. The peak distribution of the productid bioclasts at Section G (Plate II) is probably related to the presence of the four sedentary genera.

Thin-section identification of productid brachiopod clasts was based on shell structure and general morphology as described by Majewski (1969) and Horowitz and Potter (1972) and discussed on Photo Plate X.

The interpreted vertical and lateral distribution of faunal elements at South Sage Creek relative to Yochelson's model (Figure 25) is presented in Figure 26, Page 98. The notable difference is the reversal of direction of the models which is caused by the geometry of the bioherms relative to energy regimes, whereas Yochelson's model applies
more adequately to a normal shelf biostrome sequence. The lack of the more normal down slope sequence in front (south-west) of the bioherms is likely due to the inhibitive environment of the intermound areas.

**Molluscs**

Molluscs are relatively rare in the bioherms and a limited variety have been noted (Table 1). Most of these may be related directly or indirectly to the Franson shelf carbonate model (Figure 25). Again, only a few generalized interpretations based on that model, some field observations, and petrologic analysis will be attempted.

Gastropods, probably *Babylonites* or some related form, were recognized only in thin-section. The gastropods appear to be restricted to a very shallow, high energy regime, carbonate shoal condition of the bioherm at South Sage Creek (Section C, Plate II). Scaphopods are restricted to the cherts and were probably free-swimming forms feeding on organic matter on the sea floor but not living within the toxic siliceous interbank muds.

Pelecypods are only slightly more abundant than other molluscs and all may be referred to the model (Figure 25) directly for paleoecologic interpretation. Ciriacks (1963), Yochelson (1963, 1968), and Wilkinson (1967) all discuss the details of morphology and paleoecology of the genera found within the bioherms.
Petrologic determination suggests several modes of occurrence of pelecypod material within the South Sage Creek locality (Plate II) and is verified by field observations. The nuculoid pelecypods at South Sage Creek (*Nuculopsis, Polidevica*, Table 1) are associated with the ramose and fenestrate bryozoa near the base of the carbonate unit and to the north in Sections ES and ESN (Plate II). This is interpreted to represent a protected lower energy regime environment where bottom conditions were suited for burrowing organisms (Figure 25) since both genera are small mobile infauna.

Burrowing organisms or burrows are, however, rarely noted within the bioherms or the interbioherm areas. This lack of infauna probably resulted from competitive pressure of siliceous sponges restricting the necessary ecologic conditions. Also, the interbioherm siliceous muds were a highly toxic environment for any infauna. It may be noted that the inarticulate orbiculoid brachiopods normally associated with the nuculoid pelecypods (Figure 25) are found primarily within the chert facies (Table 1).

The pectinoid pelecypods *Aviculopectin, Girtypectin*, and *Streblochondria* were probably a mobile epifaunal group and, as suggested by the model (Figure 25), are commonly associated with the non-productid brachiopods, *Derbyia* and *Spiriferina* (and crinoids) in a bioclastic limestone. The presence of pelecypod fragments within the bioclastic lime-
stones of Sections A and B, South Sage Creek, probably represent pectinoid forms. The pectinoids were adapted, then, for life among the sessile organisms of the high energy regime bank environment. The molluscs were identified in thin-section on the basis of general morphology and shell structure (Majewski, 1969) as illustrated in Photo Plate XI.

**Echinoderms**

Crinoid particles (Photo Plate XII) are by far the most abundant sediment constituent of the bioherms. Since the only material found consisted of columns, calyx plates, and a few articulated stems it is difficult to estimate the diversity of forms represented by this group. All the remaining debris appears to be quite similar, suggesting a low order of diversity. However, crinoids are felt to have occupied a wide range of environments within the bioherms.

The paleoecological restrictions of fossil crinoids is very poorly known (Laudon, 1957). They are mostly sessile suspension feeders and thereby dependent on at least slight wave or current action. They are found most abundantly as disarticulated debris in bioclastic limestone, again suggesting at least a moderate energy regime. Most modern echinoderms have severe restrictions involving normal salinity but occupy quite diverse water depths (Heckel, 1972).

Depending on the type of holdfast, crinoids could prob-
ably anchor themselves on substrates varying from soft to hard surfaces but most likely preferred a firm, stable substrate. One poorly preserved holdfast was observed and appeared to have agglutinated to bioclasts, mostly crinoid debris.

As previously discussed, it is difficult to determine the area of abundant crinoid growth from distribution of crinoid bioclasts (Plate II). Crinoid stem plates would be readily dispersed with only moderate current or wave activity (Laudon, 1957). However, the peak distribution at Section D, South Sage Creek (Plate II) may indicate highest productivity of clasts in this area. The crinoids then would be most abundant in an environment just north of the main carbonate buildup. The presence of articulated stems at other localities is interpreted to indicate active presence of crinoids in most of the more aerated environments of the bioherms.

The general paucity of echinoid fossils within the Franson carbonates is described by Yochelson (1968). Echinoid material, however, has been found by Ahlstrand (1970) to be moderately abundant as determined through thin-section examination. Echinoid plates and spines (Photo Plate XII) are generally associated with a late phase shallow bioclastic carbonate shoal at South Sage Creek. The main ecologic requirements were probably a sandy substrate, normal salinity, and relatively high energy regime.
Other Faunal Elements

Other identified faunal elements, such as ostracodes (Photo Plates X and XI), occur very rarely and it would be difficult to place any ecologic significance on their presence. Many of the fossils observed are highly bored especially in areas behind the main carbonate buildup. This is probably due to the action of sponges or algae on disarticulated shells or fragments. The interiors of the shells appear to be as highly bored as the exteriors. All the above evidence supports the theory that deposited particles were relatively stable over long periods of time (Yochelson, 1968). This also supports the theory that the energy involved in winnowing the sediments was mostly in the form of moderate currents active over a long period of time.

Organic walled microfossils of the order of several microns in diameter and some chain-like organic walled microfossils are present within the cherts. These may be acri-tarchs or possibly even small symbionts which originally lived within the framework of the demosponges (Photo Plate III).

Paleontology - Synthesis

Complete interpretation of the paleoecology of the carbonate bioherms is not possible without regarding evidence involving physical characteristics of the environment. However, a brief synthesis of the evidence involving the
paleoecology of the bioherms will be attempted at this time with a reminder that many of the details relating to environments of deposition will be presented in the section on carbonate petrology.

Up to this point the term bioherm as defined by Nelson, Brown and Brindman (1961) has been used as a descriptive term to define the carbonate lens occurrences within the Rex Chert Member. Since few of the organisms described exhibit the ecologic potential to erect a rigid wave or current resistant structure and since most of the organic productivity involved in creating the bioherms was related to brachiopods and crinoids the genetic term bank will be used in preference to the term reef (Nelson, Brown, and Brindman, 1961). It is fairly unlikely that the few rugose corals present within the bioherms could have contributed to building a rigid wave resistant structure.

The faunal associations interpreted in the exposure of the carbonate bank at South Sage Creek are summarized in Figure 26 for comparison with the faunal elements of a normal Franson cycle in western Wyoming as described by Yochelson (1963, 1968) shown in Figure 26. Only the lateral sequence is shown in Figure 26 since a cyclic sequence comparable to Yochelson's model does not occur within the bank. Yochelson's model involves a biostromal sequence where faunas and lithologies migrated in response to transgressions and regressions of the Franson Sea.
FIGURE 26
INTERPRETED FAUNAL ASSOCIATIONS
S. SAGE CRK, IDA.

Increasing Depth
High Energy Zone

Decreasing energy regime

Increasing depth

S.W.  N.E.

Siliceous Sponges
Orbiculoid Branchiopods
Crinoids
Componentia
Sphenoscelididae
Dendroidea
Ramosa Bryozoa
Siliceous Pelagic forams
Sphenostygus
Crinoids
"Liozetta"
Echinus
Baliuniera
Ramosa Bryozoa
Fenestrate Bryozoa
Siliceous Sponges
Nuculoid Pelecypods
Orbiculoid Echinoderms

Reference Depth

1 Correlative Faunal associations - Figure 25
The southeast Idaho banks, on the other hand, were initiated on and restricted to topographic highs surrounded by a toxic, siliceous mud. The paleoenvironments, then, in terms of both the fauna and lithology within these banks were relatively stably located. In response to the transgression of the Franson Sea the bank grew vertically with increasing productivity and gradually spread laterally to the north. At the point of maximum transgression the lateral sequence was as shown in Figure 26. This sequence is the same as the model (Figure 25) except that the area of decreasing energy regime and increasing depth occurs behind the bank or high energy zone. The deeper, low energy regime environment in front of the bank was occupied by siliceous sponges living on a substrate of siliceous mud which was toxic to the fauna living within the bank.

A more detailed discussion of the response of the South Sage Creek bank to the major Franson transgressive-regressive cycle and biofacies distributions within the bank will be given in the sections on carbonate petrology and facies distribution.
CHAPTER 6

PETROLOGY

Methods and Terminology.

The South Sage Creek locality, because of the quality of its exposures, the number of closely-spaced measured sections, the quantity and quality of petrologic specimens collected, and the lateral and vertical lithofacies and biofacies changes throughout the outcrop, was chosen for a detailed petrologic study. The Sage Creek locality directly to the west was also studied in detail since there was no field evidence that the carbonates of the two localities were unrelated. The petrologic analysis of South Sage Creek is summarized in the cross section, Plate IV. A similar cross section was not made for the Sage Creek locality since the major portion of the bioherm at that locality is covered. Petrologic descriptions, however, are generalized in Figure 32, Page 145.

Field descriptions of lithology and the brief descriptions presented in the discussion of the stratigraphy of the bioherms were simple, descriptive, and self-explanatory. Description and classification of the lithologies for the more detailed petrologic study involved the scheme presented on Table 2. This classification, following that of Dunham (1962), is descriptive and stresses texture, with prefixes and modifiers added where necessary. The same classification
TABLE 2

Lithologic Classification (After Dunham, 1962)

I. TYPES WITH GREATER THAN 10% CLASTS
A. Texture (See chart below)

<table>
<thead>
<tr>
<th>TEXTURES</th>
<th>MATRIX</th>
</tr>
</thead>
<tbody>
<tr>
<td>MUD (&gt;4 μ)</td>
<td>SPAR</td>
</tr>
<tr>
<td>Mudstone - (Ms)* 10% grains</td>
<td>Crystalline types (Cry)* 10% grains</td>
</tr>
<tr>
<td>Wackestone - (Ws)* mud support 10% grains</td>
<td>Grainstone (Gs)* grain support 10% grains</td>
</tr>
<tr>
<td>Packstone - (Ps)* grain support</td>
<td></td>
</tr>
</tbody>
</table>

B. Prefixes
1. Mineralogy
   a. Lime - Limestone (L)*
   b. Dolo - Dolomite (D)*
   c. Chert - Chert (C)*
2. Clast type-major constituent as prefix; others as modifiers
   a. Bio ->10% bioclasts (Bc)*
   b. Intra ->10% intraclasts (Ic)*
   c. Pel ->10% pellets (P)*
   d. Oo ->10% oolites (Oo)*
   e. Litho ->10% lithoclasts (Lc)*
3. Fossil types
4. Clast grain-size
   a. Coarse -> 50% 2mm
   b. Medium -> 50% 1/16 - 2mm
   c. Fine -> 50% 4μ- 1/16 mm
5. Clast sorting (qualitative)
   a. Unsorted
   b. Moderately sorted (if not mentioned)
   c. Sorted
6. Rounding or angularity
7. Terrigenous clasts
8. Other modifiers - porosity, diagenesis, organic bitumen content, minor constituents, lamination, structures, etc.

II. CRYSTALLINE TYPES
A. Crystalline limestone (CryL)*
B. Crystalline dolomite (CryD)*
C. Crystalline chert (CryC)*

* Abbreviations used on Plate IV.
was used for both of the major lithologic types, the cherts as well as the carbonates, within the study area.

The primary objective of this classification was distinction of lithologic types with a mud matrix as opposed to those with a spar matrix, the term "mud" referring to small carbonate particles (> 4 microns, after Folk, 1962) and "spar" referring to a crystalline matrix. Of the types with a mud matrix the term "mudstone" was used for rocks with less than 10% grains, the term "wackestone" for rocks with greater than 10% grains supported in a mud matrix, and the term "packstone" for rocks with grain support. Of the types with a spar matrix the term "crystalline" was used for grain-supported rocks. In the case of the presence of microspar in the matrix the term "subgrainstone" was used to denote a parallel for wackestone, or a sparry matrix rock with a matrix support of microspar. The prefix "limo" was used in cases where calcite was the major mineralogic constituent of the rock (e.g., lime packstone). The prefix "dolo" was used where the primary mineral constituent of the rock was found to be dolomite (e.g., dolo packstone). The term "chert" was used as a prefix where either crystalline or microcrystalline quartz was the major mineralogic constituent of the rock (e.g., chert packstone). The remaining prefixes are self-explanatory, following Folk (1962).

The lithologic classification used emphasizes texture which is, in this case, the best parameter for definition of
the physical processes involved in deposition. The presence or absence of the mud matrix or degree to which it is present is a measure of the energy regime of the environment of deposition or at least a degree of winnowing of the sediment. Sedimentary structures are also an important method for interpreting the processes active in the depositional environment. However, sedimentary structures, other than very small ones, are very seldom observed in thin-section or hand specimen analysis. The few sedimentary structures observed in the field will be considered in discussions of the various lithotypes within the bioherms.

Within this particular carbonate system, and probably most other carbonate systems, the type of fossil clast deposited greatly affects the resultant texture of the rock. Grain size, sorting, and possibly even the type of matrix in a carbonate or a chert is greatly dependent on the type of fauna available to produce carbonate or siliceous particles. In an area, for instance, where crinoids are the primary faunal constituent and little particle transport is involved, a very high degree of sorting can be displayed within the rock even though it was deposited in a fairly low energy regime or with very little winnowing. Of course the assumption must be made that the crinoids are all the same type, produce columnals of approximately the same size, and that the calyx plates, as in the case of this system, are seldom preserved. These factors will be considered in the
discussion of the carbonate and chert lithofacies.

All of the samples collected from Sage Creek and South Sage Creek were examined as hand specimens, slabbed sections, and in thin-section, but the final description was based primarily on thin-section analysis. Approximately 25% of the thin-sections were stained with alizarin red-s for mineralogical determination. A few crude insoluble residues of the carbonates were made and found to include primarily organic (bituminous) matter.

Descriptions of the thin-sections included notation of the mineralogy, texture, grain, structures, evidence of diagenesis, types of fossil clasts, and pertinent remarks. Details of the description of texture included the percent mud, percent grains, percent spar, type of grain support, grain type, grain size, and a qualitative description of the sorting. Based on the evaluation of this description, a name with modifiers was applied to the specimen in accordance with Table 2. All of the descriptive criteria as well as the classification were then plotted graphically on petrologic logs for each stratigraphic section at South Sage Creek and Sage Creek. With these petrologic logs a visual comparison of the stratigraphic sections within the localities was possible and from them the stratigraphic cross section (Plate IV) of the South Sage Creek locality was constructed. Field observations were also included in the cross section.

Various lithotypes were defined within each strati-
graphic section at the South Sage Creek locality. Correlation of these lithotypes is shown in Plate IV. Admixtures of lithotypes occur and for that reason the correlations shown (Table 2) are somewhat generalized.

From the evidence already presented there would be little reason to conclude that the carbonate and chert systems within the study area acted independently. For this reason the dual classification scheme, Table 2, was used in preference to a separate classification for the carbonate lithologies and the chert lithologies. The following sections on carbonate petrology and chert petrology are separated for convenience only, with no lack of interaction of the lithologies implied.

**Carbonate Petrology**

The lithotypes designated in the petrologic cross section of South Sage Creek (Plate IV) are illustrated in Photo Plates XIII - XVIII and types of sedimentary structures are illustrated as Photo Plates XIX and XX.

**Limestone Lithotype 2A**

Limestone lithotype 2A is a medium to massive bedded, fine to medium, moderate to well-sorted, rounded, brachiopod lime biograinstone. It is restricted in occurrence to Sections B and C at the south end of the South Sage Creek bioherm. Bioclast constituents are predominantly non-productid brachiopod clasts with abundant amounts of ramose bryozoan
fronds and less abundantly productid spines, algal, foraminiferal, echinoid, fenestrate bryozoan, encrusting bryozoan, crinoid, and pelecypod clasts. Algal-coated lithoclasts are also a minor grain constituent.

A high degree of maturity of the sediment is interpreted from the fine to medium grain size, nature of the sorting and rounding, and the lack of mud matrix. This indicates a high degree of winnowing, or transportation to the site of deposition. Of the grain constituents noted, non-productid brachiopods and ramose bryozoa appear to exhibit the lowest order of elasticiticy. Other bioclast constituents including the algae, foraminifera, encrusting bryozoa, gastropods, echinoids, and to some extent the pelecypods are rarely found within the rest of the locality. The degree of elasticiticy of these bioclasts is also low to moderate.

These two lines of evidence suggest that the faunas which produce the above mentioned carbonate particles were produced within the depositional environment of limestone lithotype 2A. Other bioclast types, especially the crinoid and productid spine bioclasts, exhibit a higher degree of elasticiticy as well as sorting and rounding and may have been transported to the site of deposition. The presence of algal-coated lithoclasts, or more specifically the lithoclasts themselves, also imply a moderate degree of erosion and transportation of carbonate particles to the site of
deposition of this lithotype.

Lithotypes designated as is the lithotype 2A-2B in Section C (also lithotype 2B-2C and lithotype 2H-2B, Section B) indicate a lithology which has constituents of both lithotypes. In all cases the dominant lithotype is listed first. Lithotype 2A-2B indicates a gradation of lithotype 2A towards lithotype 2B with a dominance of lithotype 2A. Lithotype 2A is interpreted to change facies directly to the south of Section C to chert lithotype 1A or 1C. To the north of Section C lithotype 2A is interpreted to grade vertically downstream to lithotypes 2B and 2C; laterally northward of Section B it is interpreted to change facies to chert lithotype 1B.

**Limestone Lithotype 2B**

Limestone lithotype 2B is a medium to massive bedded, bituminous, coarse, poorly sorted, unrounded, brachiopod lime bioclasts. This lithotype is restricted in occurrence to Section B (Plate IV) but occurs as an admixture with lithotype 2A, Section C. To the north of Section B at Section A, lithotype 2B is interpreted to change facies to lithotypes 2D and 2I. To the south of Section B this lithotype changes facies to lithotype 2A in part and to chert lithotypes 1A and 1C.

The main bioclastic constituents of the lithotype are spiriferid brachiopod clasts with moderate amounts of ramose
bryozoan and productid brachiopod clasts. Crinoid particles and productid spines are also present. The major whole fossil constituents of this lithotype are spiriferid brachiopods. The low degree of plasticity or rounding of the spiriferid brachiopod particles in this rock type supports the hypothesis that these fossils are indigenous to the depositional environment. Large productid clasts are moderate to rare and highly abraded. Because of the nature and lack of abundance of productid bioclasts, they are not interpreted to be indigenous to the depositional environment. The ramose bryozoan, crinoid, and productid spine bioclasts are also interpreted to have been transported to the site of deposition. The ramose bryozoan material occurs mainly as very fine particles in the matrix. The productid spines (Plate II) are ubiquitously distributed through all the sections at South Sage Creek and also occur in most of the lithotypes, indicating a very high degree of dispersion.

In view of the description of this lithotype one would be tempted to think of it as a moderately immature carbonate sediment. However, this is a good example of control of the particle sorting by the type of particle produced within the sedimentary environment as opposed to those particles transported into that environment. In this case the spiriferid brachiopods are considered to be indigenous to the depositional environment. They were well-suited to the environment and produced a large volume of coarse angular carbonate
debris, whereas the particles which were transported to the depositional environment were much smaller and exhibit a much higher degree of plasticity. The lack of a carbonate mud matrix in this lithotype supports the moderate degree of maturity interpreted for the sediment.

Comparison of limestone lithotypes 2B and 2A (Photo Plate XIII) illustrates the differences in textural maturity of the two sediments. Lithotype 2A is the most mature carbonate lithotype within the South Sage Creek bank. Lithotype 2B, then, was probably deposited in a moderate energy regime. The currents which winnowed the sediment within this depositional environment also provided oxygen and nutrients which contributed to the prolific organic productivity and produced the thick section of bioclastic carbonate at Section B.

**Limestone Lithotype 2C**

Limestone lithotype 2C is a medium to massive bedded, medium to coarse, poorly sorted, moderately rounded, crinoid-brachiopod, lime biograiningstone. It also occurs only at Section B (Plate IV). North at Section C this lithotype is interpreted to grade to carbonate lithotypes 2G and 2E predominantly. South of Section B lithotype 2C probably grades laterally to lithotype 2B. In talus slopes below the outcrop at Section B and in some highly-weathered blocks within the outcrop low angle cross-bedding is exhibited. The lith-
ology is slightly more resistant than lithotype 2B but is very difficult to distinguish from that lithotype on the basis of differential weathering alone.

The main fossil constituents of this lithotype are crinoids and spiriferid brachiopod particles. There are minor amounts of productid brachiopod and ramose bryozoan clasts along with the usual productid spines. The moderate degree of rounding attributed to this lithotype is mostly due to the inherent roundness of the crinoid particles. The spiriferid brachiopod debris is much more angular. Both constituents are interpreted to be indigenous to the depositional environment. The ramose bryozoan fragments again are mostly restricted to the matrix material as very fine particles. The productid debris in this lithotype also exhibits a very high degree of clasticity. Most of the minor particle types were probably transported to the site of deposition.

The textural maturity of this lithotype is intermediate to the two previously discussed (Photo Plate XII). The energy regime of this depositional environment was probably also intermediate to the two previously discussed. This moderate to high energy regime again was responsible for a very high degree of organic productivity, contributing to the thick section of bioclastic carbonate at Section B.
Limestone Lithotype 2D

Limestone lithotype 2D is a medium-bedded, bituminous, medium to coarse, poorly sorted, moderately rounded, productid brachiopod, lime biograins. This lithotype has a relatively wide lateral distribution at the South Sage Creek locality (Plate IV). It is present in Sections A, D, F, and G respectively northward and at Section ES is present as discontinuous lenses in scour channels. The lithotype is best developed at Section D. As previously described lithotype 2D is one of the northward lateral facies equivalents of lithotype 2B. From Section A to the north throughout the South Sage Creek locality lithotype 2D is in lateral facies relationship with types 2E and 2F predominantly and to a minor extent with types 2I and 2H.

Major bioclastic constituents of this lithotype are productid brachiopod clasts. Crinoid particles also occur in moderate abundance along with minor amounts of spiriferid brachiopod and ramose bryozoan particles. Again, the usual presence of productid brachiopod spines is noted, although they may be slightly more abundant within this lithotype.

Productid brachiopod clasts mostly consist of large angular particles of whole fossil clasts that are often moderate to highly bored on both surfaces. The degree of rounding of the sediment is mostly due to the presence of crinoid stem plates. The spiriferid brachiopod material is minor in abundance in comparison to the productid brachiopod and
crinoid bioclasts. The particles usually occur as small but angular bioclasts. Ramose bryozoan material again occurs as very small particles in the matrix.

Because of the angular nature of the productid bioclasts and the presence of whole fossil productids, the productid brachiopods are considered to be indigenous to this lithotype. The moderate abundance of crinoidal debris with the occurrence of articulated crinoid stems in the sections in which this lithotype occurs indicates at least a close proximity of crinoid growth. Ramose bryozoan particles because of their degree of plasticity again are most probably transported into the environment of deposition.

Limestone lithotype 2D ranks lower in terms of texture maturity than any of the previously discussed lithotypes (Photo Plate XIV). The lower degree of maturity is evidenced by the much more abundant ramose bryozoan bioclastic particles in the matrix as well as the high degree of boring of the productid shells which might indicate a long period of exposure to boring organisms prior to deposition. However, again the lack of carbonate mud as well as the above mentioned evidence for long term exposure prior to deposition would require at least a low to moderate energy regime.

Note that, in terms of the total amount of bioclastic carbonate sediment, less was produced (Plate IV) in the areas of best development of this lithotype resulting in a much thinner total section of carbonate. This is also suggestive of
a lower energy regime with less aeration and low organic productivity.

**Limestone Lithotype 2E**

Limestone lithotype 2E is a massive-bedded, coarse, poorly sorted, rounded, crinoid lime biograinsstone. This lithology is best developed at Sections F and G (Plate IV) but is also well developed at Sections A and D. In the outcrop, rocks of this lithology exhibit a slight lensoidal or pinch and swell nature with small mounds of up to five feet thick and several ten's of feet in lateral dimension. This lithotype as well as lithotypes 2F and 2G exhibits very subtle crossbedding in highly weathered blocks. Between Sections A and B lithotype 2E changes facies to carbonate lithotype 2C. It is present from Section A to the north to Section G where it changes facies to lithotype 2I. The most dominant lateral facies change of lithotype 2E (Sections A, D, F, and G) is to lithotype 2D or as an admixture with lithotype 2G.

The dominant bioclast constituent of lithotype 2E is crinoidal debris, to the extent that the rock might actually be called an encrinite (Photo Plate XIV). Other bioclasts are rare including very fine ramose bryozoan particles and small abraded productid brachiopod particles as well as a very minor amount of productid brachiopod spines. Crinoids are the only faunal element believed to have existed in abun-
dance in the environment of deposition of lithotype 2E as evidenced by the predominance of coarse crinoidal debris, the presence of articulated crinoid stems and a very poorly preserved crinoid holdfast which was collected from this unit at Section D. Most of the remaining bioclast constituents are interpreted to have been transported to the site of deposition.

The maturity of carbonate lithotype 2E is much more difficult to interpret. The fact that the carbonate particles produced from disarticulation of similar crinoids would be of similar size and shape dictates at least a moderate degree of sorting and rounding for the resultant rock without any further winnowing. The presence of the fine bryozoan clasts within the matrix supports moderate to low energy regimes while the absence of carbonate mud in the matrix suggests at least a low order of winnowing. The field evidence of cross bedding and the lensing nature of this lithotype also supports some degree of winnowing. Lithotype 2E, then, is somewhat more mature than 2D.

**Limestone Lithotype 2F**

Limestone lithotype 2F is a medium to massive bedded, bituminous, coarse, poorly sorted, angular, productid brachiopod-crinoid lime biograinsone. The distribution of this lithotype is generally limited to Sections A and B (Plate IV) although it occurs in other areas as an admixture
or a variation of lithotype 2E. Lithotype 2F might actually be considered to be a variation of lithotype 2E, with the addition of productid brachiopod debris to the extent that the productid bioclasts become the dominant constituent. Lithotype 2F has similar lateral facies relationships to those described for lithotype 2E.

In addition to the dominant crinoid and productid brachiopod bioclasts, fine ramose bryozoan particles again occur in the matrix as well as productid spines and more rarely fine spiriferid brachiopod clasts. The crinoids and brachiopods are considered to be indigenous to the environment of deposition of lithotype 2F.

The textural maturity of this rock type is also difficult to interpret. The presence of coarse productid clasts and moderate to coarse crinoid clasts which are produced within or near the site of deposition along with the finer particles which are transported to the site of deposition predicates any appearance of maturity within the resultant rock (Plate XV). However, the absence of lime mud in the matrix again necessitates some degree of winnowing and a low to moderate energy regime is interpreted for the environment of deposition for lithotype 2F.

**Limestone Lithotype 2G**

Limestone lithotype 2G is a medium-beded, moderate to coarse, moderately sorted to unsorted, unrounded, bryozoan-
crinoid lime biograins. Again, this lithology might be considered a variation of lithotype 2E with the addition of abundant bryozoa to the more normal encrinite lithology. Lithotype 2G is most abundant in Sections A and D (Plate IV) with the dominant facies change to the south to lithotype 2C and to a normal lithotype 2E or in some cases to carbonate lithotype 2I and chert lithotype 1C.

The major bioclast constituents of the lithotype are ramose bryozoan and crinoid particles (Photo Plate XV) with a trend towards the dominance of the ramose bryozoan clasts. There are also minor to moderate amounts of fenestrated bryozoan material and minor amounts of pelecypod, echinoid, foraminifera, and brachiopod clasts in the lithotype. Again the lack of lime mud in the matrix along with the moderate sorting of the lithotype suggests at least a moderate degree of textural maturity and some winnowing of the sediment. Most of the bioclast constituents probably represent faunal elements which inhabited the environment of deposition so most of the particles were produced very near or within the depositional environment of the lithotype as evidenced by a low degree of abrasion of the particles. The brachiopod clasts may have been transported to the area of deposition. The variation of abundance of crinoidal debris might indicate that the site of deposition was marginal to an area of high crinoid productivity.
Limestone Lithotype 2H

Limestone lithotype 2H is a medium-tedded, bituminous, fine to medium grained, poorly sorted, rounded, bryozoan lime biopackstone and/or lime biowackestone. This lithotype is restricted to the basal part of many of the sections (Plate IV). It is probably equivalent to a ramose bryozoan bioclastic limestone found near the base of the carbonate at all the localities studied. The presence of lithotype 2H at Section B as an admixture of lithotype 2B near the base of that section indicates that the covered portion near the base of the section is very near the carbonate-lower chert contact. Lithotype 2H at this section changes facies laterally to the south to lithotype 2B and laterally to the north to chert lithotype 1D or 1C.

The dominant bioclast constituents of lithotype 2H are ramose bryozoan particles and whole fossil clasts. In addition there are moderate amounts of brachiopod and crinoid debris, as well as rare to moderate fenestrate bryozoan clasts. Ramose and fenestrate bryozoan are considered to be indigenous to the depositional environment whereas crinoid and brachiopod debris is probably transported into the environment.

This lithology is one of the most immature of all the carbonate lithologies. The presence of a lime mud matrix in some of the samples observed is indicative of the low energy regime of the depositional environment of lithotype 2H.
Limestone Lithotype 2I

Limestone lithotype 2I is a medium-bedded, fine to medium, poorly sorted bryozoan lime biograins to nite, lime biopackstone. It is also generally limited to the basal part of the carbonate section and is the dominant lithology at Section ES (Plate IV). Similarly to lithotype 2H this lithology grades laterally to the south to the more bioclastic lithologies and laterally to the north to chert lithotype 1C. The lithotype often contains interbeds of chert lithotype 1C.

The major fossil constituents of 2I are ramose and fenestrate bryozoan with minor amounts of pelecypod, foraminifera, and encrusting bryozoan. In addition at Section ES there are lenses of coarse productid brachiopod biograins to nite within the dominant lithology, lithotype 2I, at that section. All of the faunal elements described in lithotype 2I with the exception of the productid brachiopods are interpreted to be indigenous to the depositional environment of the lithotype. Productid brachiopods occur in discontinuous lenses with scoured bases and were undoubtedly transported to the site of deposition. Many articulated bryozoan fronds and small nuculoid pelecypod fossils were collected from this facies.

Lithotype 2I is generally texturally immature as indicated by the presence of lime mud in the matrix. However, in the grainstones of this lithotype there is exhibited a very high degree of abrasion and sorting in addition to the
sparry matrix (Photo Plate XVI). The energy regime of the depositional environment is considered to be normally a very low order with local areas of moderate to high energy regimes as indicated by the cleaner grainstones. The presence of brachiopod hash-filled scour channels and the field evidence of lens shaped bodies of coarse bryozoan grainstone with aligned bryozoan stalks indicates the presence of at least moderate currents.

Crystalline limestones were noted mostly as vertical and horizontal lenses and nodules within the lower chert at the South Sage Creek locality. These carbonates, however, were included with chert lithotype 1C.

**Carbonate Sedimentary Structures**

Sedimentary microstructures are quite rare at the South Sage Creek locality within the carbonate lithologies but are fairly common at several other localities, especially in the Stewart Canyon locality. The only correlary for lithologies which exhibit these microstructures are chert lithotypes 1C and 1D at the South Sage Creek locality.

On the north margin of the exposure of the Stewart Canyon bank lime mudstones which are highly burrowed (Photo Plate XX), rhythmically bedded bryozoan and productid spine packstones and finely crystalline laminated calcareous cherts are quite abundant. Often the laminated calcareous and dolomitic chert in this rhythmically bedded lithology
exhibits burrowing (Photo Plate XX, Figure 4). Also, the siliceous dolomitic lime mudstone is highly burrowed and bioturbated (Photo Plate XX, Figures 1-3). The presence of burrowing infauna at this locality is also evidenced by structures observed in the field (Page 38, Figure 14) where large chert-filled burrows were noted near the base of the carbonate section.

Evidence of burrowing infauna at the South Sage Creek locality, on the other hand, is not present, at least in the form of noticeable burrows or bioturbation. In fact, the only evidence for the existence of a burrowing infauna is the presence of nuculoid pelecypods in facies 2H and 2I. This lack of burrowing infauna is felt to represent an environment below the sediment-water interface which inhibited the normal activity of burrowing organisms in the back bank environment.

The exposures at Stewart Canyon, however, illustrate the existence of some more protected perhaps lagoonal areas of the back bank environment where pressures of the siliceous sponge community and the resultant toxic siliceous mud bottom conditions were not as severely inhibitive to the burrowing infauna. The rhythmic bedded structures support the thesis that this was a slightly protected back bank environment in which currents intermediately swept the fine bioclastic particles which formed the bryozoan-productid spine biopackstone and in alternate conditions allowed deposition
of finer grained carbonate particles which formed the siliceous dolomitc crystalline limestone (Plate XIX, Figure 3; Plate XX, Figure 4). Both this rhythmically laminated lithology and the bioturbated lithology contain moderate amounts of cryptocrystalline chert and calcite microspar.

A unique sedimentary structure and lithology was observed at the north end of the Sage Creek locality at Section E in the form of abraded chert lithoclasts (Photo Plate XIX, Figures 1 and 2). The chert lithoclasts are slightly rounded and oriented such as to suggest crossbedding. Lithoclasts are cryptocrystalline chert with abundant to moderate amounts of calcite and dolomite crystals. The matrix material is also cryptocrystalline chert and contains much more calcite and dolomite. This chert breccia lithology probably represents rip up of lithified or semi-lithified chert by currents in a moderate energy regime. Similar evidence of penecontemporaneous scour of at least semi-lithified chert was also observed at Stewart Canyon (Page 38, Figure 14) where small scale scour and fill features were observed at the base of the carbonate section near the contact with the underlying chert.

Larger sedimentary structures representing higher energy regimes were observed in the field and discussed in the section on carbonate petrology under the pertinent lithotype.
Carbonate Diagenesis

The following types of diagenesis of the carbonate lithologies were observed and are illustrated in Photo Plates XXI - XXV:

Cementation - by sparry calcite and drusy quartz cement.

Silicification - by microcrystalline and, to a minor extent, lutecitic quartz.

Dolomitization - in very minor amounts usually associated with quartz cementation or silicification.

Phosphatization - very rarely, in sediments indicative of a lagoonal or protected back bank environment.

The above diagenetic types are listed in order of abundance, cementation and silicification being the most dominant by far. Glauconitization as seen in equivalent (lithologic) Franson carbonates to the north in Montana (personal observation) and to the east in Wyoming (Cole, 1959) is not noted in this area and appears to be indicative of the more normal winnowed shelf biostromal carbonates.

Cementation by sparry calcite is the most common form of diagenesis and lithification as evidenced by the predominance of grainstones in the carbonate lithotypes (Plate IV). The complete degree of calcite cementation resulted in an
almost total lack of porosity in a rock which must have had a moderate to high degree of original porosity.

The original pore fluid within the carbonate sediment, assuming a chemistry similar to that of the sea water in which it was deposited, would not contain sufficient calcium carbonate to precipitate a calcite cement. Yet the petrologic evidence indicates early cementation. The exceptions of grain to grain penetration (Photo Plate IV, Figure 3) which would indicate some compaction are relatively rare and the degree of penetration is moderate.

There is ample evidence of lack of compaction of the carbonates prior to cementation:

A. Grain overgrowths, as opposed to the above mentioned grain to grain penetrations, are much more common (Photo Plate XI, Figure 2; Photo Plate XIII, Figure 1; and Photo Plate XIV, Figures 3 and 4). This type of fabric is more indicative of lack of compaction and early cementation.

B. Floating textures, although only apparent (due to the grain contacts not being visible in the plane of the thin-section) are also very common (Photo Plate X, Figure 2; Photo Plate XIII, Figure 1). These rocks probably had a very high degree of original porosity which was infilled with sparry cement.
C. Calcite-healed fractures cut both the grains and sparry calcite cement. Cementation therefore preceded the fracturing.

D. The presence of a few lithoclasts (Plate I, Figure 2) also could indicate early (penep contemporaneous) cementation.

E. The presence of faunal elements interpreted to have required at least a firm substrate indirectly indicates early cementation.

F. Evidence involving the relationship of carbonate cementation to chert lithification also indirectly supports early, if not penep contemporaneous, cementation.

The problem of lack of suitable calcium carbonate concentration within the original pore fluids still exists. It may be stated as a simple problem of supply and demand. Excess calcium carbonate must be supplied from an external source to meet the demands of an obvious high volume of calcite cement. Formation of dolomite (Bathurst, 1971) would help explain the needed excess calcite but dolomite is very rare in this system and could account for only a very minor amount of calcium carbonate cement.

Silicification, on the other hand, occurs very prominently at the margins of the banks both laterally and vertically. The volume of carbonate silicified would certainly be on the order of the volume of carbonate needed for cemen-
tation of the calcite. This relationship is summarized in Figure 27.

The effect of silicification and carbonate cementation was a resultant loss of the original porosity. Porosity of the limestones is usually very low (~5% or less) the best porosity being interparticle in nature (Photo Plate XIII, Figure 3).

The method of silicification as summarized in Figure 27 resulted in a variety of silicification fabrics which are illustrated in Photo Plates XXI - XXV. All the thin-sections are stained with alizarin red-s to better illustrate the calcite grains (red). The varieties of fabric (terminology after Wilson, 1966) are:

A. Drusy quartz mosaic (Photo Plate XXI, Figures 1 and 3; Photo Plate XXIV, Figures 1 and 2; Photo Plate XXV, Figure 1) - crystallized pore infilling. This fabric exhibits the highest order of crystallinity.

B. Chalcedonic overlays (Photo Plate XXII, Figure 3) - rarely noted, formed as a chalcedonic layer on carbonate grains.

C. Lutecite (Photo Plate XXIII, Figures 1, 2, and 3) - formed as replacement of bioclast which usually is still discernable. The replacing silica displays a slight undulose extinction.
Explanation:

A. Siliceous spicular muds - a pH greater than normal sea water (D) is necessary for mobilization of the silica in the sediments (Krauskopf, 1959 and 1967). A relatively more acidic pH is needed for lithification of the chert. Pore waters probably vary with depth from relatively more basic just below the sediment-water interface to relatively more acidic with depth (Sharma, 1965).

B. Silicified carbonate - (arrows indicate migration of pore fluids). The high pH fluids saturated with respect to silica intermix with the more normal pH pore fluids of the carbonate and the more acidic fluids of the buried siliceous muds resulting in the precipitation of siliceous cement and silicification of carbonate material.

C. Sparry calcite cemented limestone - Fluids migrating from the silicified carbonate zone are overly saturated with respect to calcium carbonate. After mixing of these fluids with the normal pore water of the porous carbonate sediment the sparry calcite cement is precipitated.

D. Sea water - Excess pore waters were probably expelled where the originally porous carbonates were not capped by the less permeable siliceous muds.
D. Microcrystalline quartz (Photo Plate XXI, Figures 2 and 4; Photo Plate XXIII, all figures; Photo Plate XXIII, Figures 1 and 2; Photo Plate XXV, Figures 1, 2, and 4) probably formed as replacement of bioclasts, carbonate matrix and sparry calcite. From Figure 27 it appears that a front of calcium carbonate pore filling might have preceded the front of silicification. Continuous migration of fluids could further cause silicification (replacement by microcrystalline quartz) of the sparry calcite matrix (Plate XXV, Figure 2).

A summary of the descriptive fabrics and their genesis is given in Figure 28 (Wilson, 1966).

Dolomitization, although a very minor form of diagenesis in this system, presents some problems in interpretation. The lack of large scale dolomitization can probably be accounted for by not adding magnesium to the system as is required by most models for dolomitization (Bathurst, 1971; Pray and Murray, 1965). This, of course, precludes using any of these models to explain the occurrence of dolomite in the banks studied.
The dolomite at all the localities studied was closely associated with silicification. Staining of thin-sections and a detailed study of the South Sage Creek samples defined this restriction. Photo Plate XXIV illustrates this occurrence. The dolomite invariably takes the form of cubic, sometimes zoned, rhombs. Often dolomite rhombs increase in abundance near the boundary of silicification (Photo Plate XXIII, Figure 2).

The genetic term silicification residue dolomite is proposed for this type of occurrence. The method of forma-
tion is interpreted to be crystallization of dolomite as a result of a residual concentration of magnesium in the process of silicification of high magnesium calcite particles.

Phosphatization is very rare and appears to be limited in occurrence to the lower energy back bank environment. Phosphatization in such an environment most likely occurs, as described by Pevear (1966), as replacement of calcite in a protected environment with high organic productivity and a resultant high phosphate concentration.

**Carbonate Petrology - Synthesis**

Conclusions and interpretations of biofacies distributions, lithofacies distributions, and depositional environments of the South Sage Creek bank are better considered relative to the evidence presented in the discussion of the chert petrology of the locality. However, at this time a few of the important points regarding the carbonate petrology of the South Sage Creek bioherm will be reviewed.

The lithotypes described, as can be seen from Plate IV, exhibit considerable vertical variation, often appearing to be cyclic in nature. However, most of the lithotypes are stacked in particular areas of the bank and do not appear to have migrated laterally to a very great extent. Therefore, this apparent cyclic nature within the banks is most likely related to progradation and retrogradation of carbonate sediments relative to a fixed point within the bank.
Moreover, the general vertical stacking of both lithotypes and faunal elements suggest that the South Sage Creek bank was very much restricted in an areal sense. The flanking toxic siliceous muds that surrounded the bank were certainly a contributing factor in limiting its occurrence. Also, the stacking could be indicative of paleotopographic control which resulted in initiation of the bank development and was indirectly responsible for the very high degree of organic productivity within the area of the bank.

The relative degree of textural maturity of the carbonate lithotypes described is summarized in Table 3. The general lack of mud matrix in all of the carbonate lithotypes leads to an apparent moderate to high order of textural maturity for most of the lithotypes. It should be pointed out, however, that in many modern environments carbonate muds are mostly formed from the disarticulated aragonite crystals of algae. Although not all carbonate petrologists will agree with the above hypothesis, most do attribute production of shelf carbonate sediment to some type of organic activity.

A review of the relative abundance of fossils known to occur in the South Sage Creek bank (Table 1) shows a general lack of organisms which would produce carbonate particles or tests which could be readily abraded to carbonate particles of mud size. Algae are generally rare and largely limited in distribution to lithotype 2A, Section C (Plate IV).
Ramose and fenestrate bryozoan particles exist as very small clasts in the matrix of many of the coarse biograins. However, it is doubtful that their abrasion could have contributed any large amount of fine grained carbonate mud. For these reasons, the presence or lack of a mud matrix as an indicator of textural maturity within the described lithotypes should be considered only with caution.

**TABLE III  Relative Textural Maturity - Carbonate Lithotypes, South Sage Creek Bank**

<table>
<thead>
<tr>
<th>LITHOTYPES</th>
<th>ENERGY REGIME</th>
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<tbody>
<tr>
<td></td>
<td>HIGH</td>
</tr>
<tr>
<td>2A</td>
<td></td>
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<tr>
<td>2C</td>
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<td>2B</td>
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<td>2G</td>
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<td>2I</td>
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<tr>
<td>2H</td>
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</table>
Chert Petrology

The chert samples were examined and described in the same manner as the carbonate samples following the classification in Table 2. The results of the petrographic study of the cherts are also presented in the stratigraphic cross section of South Sage Creek (Plate IV). Lithotypes were determined on the basis of both petrologic and field evidence.

Chert Lithotype 1A

Chert lithotype 1A is a medium-bedded, bituminous, spicular chert packstone-wackestone. It occurs in float at the base of Section C at South Sage Creek and is abundant in float from there to the south. It is also present on the north margins of the bank at the base of Section E3N and at the top of the upper chert unit, near the contact with the cherty shale member. Lateral relationships of this lithotype generally involve a facies change to one of the lime biograinsstone lithotypes.

The dominant bioclast constituents are sponge spicules, although replaced carbonate bioclasts occur in rare to moderate abundance. The textural maturity of this sediment is quite low. The spicular bioclasts probably represent only disarticulation of the siliceous sponges. When they occur in abundance they may appear to be well sorted but this was probably related to the original consistent size of the
spicules. The depositional environment of lithotype 1A was
dominantly within a low energy regime.

Chert Lithotype 1B

Chert lithotype 1B is a massive-bedded, clean spicular
chert grainstone. It occurs in Sections A, D, F, G, and E3
but not in Sections B and C. It is the first chert unit
above the carbonate section and rests on a sharp corroded
surface. It is interpreted to change facies to the south at
Section B to lithotype 2A-2B and to the north at Section ESN
probably grades to lithotype 1A or 1C.

The dominant bioclast constituents of chert lithotype
1B is also siliceous sponge spicules. However, produktid
brachiopod and other indeterminant bioclasts appear in mod-
erate abundance near the base becoming less abundant near
the top of the unit.

This lithotype is texturally the most mature chert
lithotype within the South Sage Creek carbonate bank complex.
The lack of the usual bituminous matter and fetid nature of
the spicular cherts of lithotype 1A as well as an apparent
orientation of the spicules and the massive-bedded nature
indicate the depositional environment involved a moderate to
high energy regime. It is very improbable, although possible,
that the siliceous sponges actually lived in the environment
of deposition. Lithotype 1B is therefore interpreted to be
a siliceous spicular bar.
Chert Lithotype 1C

Chert lithotype 1C is an irregular, thin bedded, spicular chert packstone with horizontal, bituminous, finely crystalline limestone nodules and partings. Lithotype 1C most often occurs directly below the base of the carbonate section.

The textural maturity of lithotype 1C is of a relatively low order. Again the only evidence of sorting in this lithology is the presence of siliceous spicules of a consistent size which is most likely related to the consistency of the size of the spicules produced by the siliceous sponges. The presence of finely crystalline limestone nodules and partings is interpreted to be lime mud deposited in the back bank environment contributing to the low order of textural maturity. Towards the contact with the carbonate unit the limestone lenses and partings also include a fauna of very small ramose bryozoa. The energy regime of the depositional environment for lithotype 1C is considered to have been low.

Chert Lithotype 1D

Chert lithotype 1D is a thinly laminated, calcareous, finely crystalline chert with vertical and horizontal finely crystalline limestone nodules. This lithotype occurs only at Section A (Plate IV) and because of its calcareous nature, the cryptocrystalline texture of the chert, and the presence of the irregular vertical limestone nodules, this lithotype
is interpreted to be replacement chert after lime mudstone. The textural maturity and energy regime of the environment, then, are very low.

**Chert Lithotype 1E**

Chert lithotype 1E is a silicified biograinsstone-biopackstone-biowackestone. An excellent example of this lithotype is present in the medial chert unit of Section A (Plate IV) as a silicified carbonate lithotype 2D. This lithotype was designated for cherts which have a texture indicating an obvious original bioclastic limestone nature.

**Chert Lithotype 1F**

Chert lithotype 1F is a thin to medium bedded, laminated silty chert wackestone. It has microsedimentary structure suggestive of micro-scour and slight cross lamination. It often contains aligned siliceous spicules. The dominant grain constituent is quartz silt. The chert is very calcareous and dolomitic and may be a replacement feature of carbonate mud. The textural maturity of the sediment is low. A small amount of winnowing in a low energy regime environment is interpreted from the structures. This lithotype is extremely restricted in occurrence.

**Siliceous Shale Lithotype 3**

Lithotype 3 is a silty siliceous shale which occurs only in the cherty shale member above the Rex Chert Member
in the South Sage Creek locality. However, at the Timber Creek locality a thin but discontinuous unit of silty siliceous shale occurs about in the upper middle part of the Rex Chert section in the absence of the bioclastic carbonate. This lithology represents the lowest level of textural maturity of all the sediments discussed and certainly represents a very low energy regime. Siliceous spicules are found only rarely within this lithotype.

Most of the chert lithotypes discussed are illustrated in Photo Plates XVII and XVIII.

**Chert Cementation and Diagenesis**

In the area of study the origin of the siliceous material from which the Rex cherts were lithified is not difficult to establish. The extreme volume of siliceous spicules indicates that biotic processes mainly of demosponges were primarily responsible for the initial precipitation of the silica from sea water. Only normal amounts of silica concentrations would be needed for precipitation but in an area where upwelling currents are thought to have existed (Page 77) conditions would certainly have been optimum for the high volumes of silica deposited in the Rex Chert Member.

Actual lithification of that sediment under conditions of normal (marine pH) pore water is somewhat more difficult to explain. Silica solubility increases with increasing pH (Kauskopf, 1959, 1967) and at normal marine pH and tempera-
ture would be soluble. Lithification of the Rex Cherts in the area of study must have involved a change in pore fluid geochemistry and/or temperature.

The presence of differing geochemical environments below the sediment-water interface is known to exist in modern sediments (Winston, 1969, personal communication; and Sharma, 1965). Also, the petrologic evidence of silicified or corroded carbonate bioclasts within the cherts flanking the carbonate bioherms and the lack of burrowing infauna is suggestive of a more acidic environment which was toxic to organisms with calcareous tests at depth within the sediment. The solubility of silica decreases with decreasing pH which would be conducive to chert lithification with depth below the sediment-water interface.

The interpreted method of lithification of the Rex Cherts within the study area is summarized in Figure 29, after Sharma.

The most noticeable difference between the chert lithification model (Figure 29) and that of Sharma (1965) is the deletion of Sharma's Zone D of replacement of silica by carbonate. This is justifiable since there is no evidence within the system studied for replacement of chert by carbonate. Actually, replacement of carbonate by silica occurs much more commonly.
Chert Petrology - Synthesis

Most of the petrologic evidence supports deposition of the chert lithotypes described (with the exception of 1B) in a very low energy regime environment. Textural maturity of the chert lithotypes is summarized in Table 4 relative to the carbonate lithotypes.

The genesis of the Rex Chert Member has been interpreted variously by Warner (1956), Keller (1941), Bissell (1959), and McKelvey and others (1959). Most of the differences of opinion may be resolved as a matter of the area in
which the member was studied. The cherts of the Rex Chert Member are most certainly polygenetic.

TABLE IV Relative Textural Maturity - Chert Lithotypes, South Sage Creek Bank

<table>
<thead>
<tr>
<th>LITHOTYPES</th>
<th>ENERGY REGIME</th>
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<tbody>
<tr>
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<td>HIGH</td>
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<tr>
<td>1B</td>
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<td>1A</td>
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<tr>
<td>1D</td>
<td></td>
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<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>1E (Replacement)</td>
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</tbody>
</table>

Keller, for instance, studied the member near the Idaho-Wyoming border where the influence of clastic sediments of the Shedhorn facies (Figure 8, Page 16) lead to the supposition of clastic origin for most of the silica. Warner was partially misled by his own interpretation of silica solubility (opposite that presently accepted) to conclude that Rex Cherts were primarily inorganically precipitated. Bissell has studied the miogeosynclinal facies where there is a possible influence of volcanism. McKelvey and others studied the shelf facies where, as in the area of this study,
the origin of the cherts was primarily due to organic activity - mostly siliceous sponges.

On the basis of examination of samples collected by J. A. Peterson in 1970 from the Rex Chert Member in the Sublette Range (Figure 6, Section 5, Page 13) west of the study area, the basinal facies of the Rex Chert appears to have formed primarily from different mechanisms than those active within the study area. There is a notable paucity of siliceous spicules in those samples as previously noted by Warner (1956). The abundance of carbonate minerals and siliceous crystalline dolomitic limestone is most compatible with a replacement origin for this area. Similar rock types were noted in the study area (lithotypes 1D and 1C).

Lithotype 1F within the study area is similar to rock types described by Keller (1941) in that it contains moderately abundant quartz silt. The greater distance from the clastic influx of the Shedhorn Sandstone (Figure 8, Page 16) precludes an abundance of silt in the chert within the area of study.

In conclusion, most of the hypotheses of the origin of the Rex Cherts are not only acceptable, but when considered in context with the regional stratigraphic setting, allow additional understanding of the paleoenvironments of the Rex Chert Member.
CHAPTER 7

FACIES DISTRIBUTION - SOUTH SAGE CREEK BANK

The Sage Creek and South Sage Creek localities were studied in detail with respect to paleontology and petrology for reasons already discussed:

a. Quality of the exposures.
b. Lateral stratigraphic relationships observable in the field.
c. Apparent lateral facies changes.
d. The possibility that the two localities represent exposures of a single bank or bank complex.

The lithotypes described in the section on petrology, the faunal associations and bioclast distributions discussed in the section on paleontology and the field stratigraphic evidence from these two localities will all be considered in an attempt to reconstruct biofacies, lithofacies, and paleo-environmental distributions within the South Sage Creek bank.

The Sage Creek and South Sage Creek localities are on the west and east limbs respectively of the Webster syncline (Figure 30). There is no evidence that the two carbonate exposures are separate or unrelated. The Sage Creek carbonate occurrence is terminated on the west flank of the Snowdrift anticline by an outcrop of chert. The facies
change is eroded from the crest of the anticline (Figure 30). At the South Sage Creek locality the eastern limit of the carbonate occurrence is poorly defined. The east fork of the asymmetric Boulder Creek anticline is overturned and faulted to the east of the locality (Mansfield, 1927, Plate VII). In the one poor outcrop of the Rex Chert Member observed immediately to the east (below) the reverse fault, no carbonate was exposed. For this reason, the bank is interpreted to occur only to the eastern boundary of Section 18, T. 9 S. - R. 46 E. (Figure 30).

The carbonate isolith (Figure 30) shows the interpreted extent of the South Sage Creek bioherm, projecting outcrop thicknesses into the subsurface beneath the Webster syncline. The symbols for stratigraphic sections and observed sections are the same as those in Figure 19, Page 52. Thicknesses of total carbonate are shown for each section. As mentioned before, the maximum carbonate occurrence at Sage Creek is breached and partially covered with alluvium. That portion of the isolith, then, is restored, as are the portions west of the Sage Creek locality and east of the South Sage Creek locality where the Rex Chert Member has been removed by erosion.

The stratigraphic cross sections (Figures 31 and 32) illustrate the generalized lithofacies distributions for the two localities. Figure 31 was generalized from the detailed lithotypes described petrologically for South Sage
Stages of Bank Growth

LITHOFACIES DISTRIBUTION
Multiple Datum Cross Section
So. Sage Crk. Bioherm
FIGURE 31
LITHOFACIES DISTRIBUTION
Multiple Datum Cross Section
So. Sage Crk. Bioherm
FIGURE 31
FIGURE 32
LITHOFACIES DISTRIBUTION
Stratigraphic Cross Section
Sago Crk. Locality
So. Sago Crk. Bioherm
Creek (Plate IV). The lithotypes included in each lithofacies are listed for comparison with Plate IV. The same lithotypes were recognized in the petrologic study of the Sage Creek locality and are generalized in the lithofacies distribution shown in Figure 32 (see Appendix A for detailed distribution of lithotypes).

Interpretation of time-stratigraphic relationships are difficult at both of the localities, but the datums used in construction of Figure 31 are felt to be more closely isochronous than the datums previously used at South Sage Creek (Figure 20, Plates II and IV). The datum used in Figure 32, the base of the Rex Chert Member, is also considered to be the mostly closely isochronous of any arbitrary datum available. The use of the multiple datum system at South Sage Creek is necessitated by the lack of exposure of the base of the Rex Chert Member.

These are only arbitrary datums used for interpretations of time-stratigraphic relationships and probably approach isochroniety only very locally. The interpreted time-stratigraphic relationships at various stages of development of the bank are shown on the overlay to Figure 31 and are illustrated in the facies distribution maps (Figures 37-41). The maps include data synthesized from Figures 30 and 31, Plates II, III, and IV, field relationships, interpreted faunal associations, and experience gained from observations at other localities.
The vertical stacking of lithofacies, as defined in the stratigraphic cross sections (Figures 31 and 32) is considered to be indicative of paleotopographic control of carbonate productivity. In the case of the South Sage Creek bank the highest degree of productivity occurred in the area of Section B, South Sage Creek and immediately south of Section B, Sage Creek, and was initiated in that area and restricted to it by pre-existing topography.

The spiriferid brachiopods and crinoids, for instance, which inhabited the main bank area received the highest degree of current action and circulation of nutrients. In the face of sea level changes the productivity of the fauna rose and fell in compliance with the restrictions of the environment, but because of the paleotopographic control did not migrate from the area they initially occupied.

Not all lithofacies are stacked as is the spiriferid lime bioclastic facies (Figure 32). The bryozoan lime biopackstone-grainstone facies (21), for instance, transgresses from southeast to northeast from the area of initial bank development to the northeast margin of the bank where the environment was stabilized to form the stacked bryozoan lime biopackstone-wackestone facies.

The general distribution of facies, defined by cross sections A-A' and B-B' is interpreted to represent a genetic sequence as illustrated in the diagrammatic cross sections (Figures 33 - 36):
A. Spicular chert deposition: Following deposition of the Meade Peak phosphatic shales, dark crystalline limestones and phosphorites in a semi-restricted basin under regressive conditions (Peterson, 1969, personal communication, and Cole, 1969) the lower Rex Chert Member in the area of study was deposited mainly as disarticulated demosponges in a less restricted transgressing sea.

B. Pioneer stage of carbonate deposition (Figure 33): With continued transgression and increased circulation of vital nutrients, carbonate producing organisms, mostly ramose and fenestrate bryozoans, inhabited areas of slight topographic relief where the necessary circulation and nutrients were in greatest abundance. In the off bank areas spicular cherts were continuing to be deposited.

C. Mature stage of carbonate deposition (Figure 34): At maximum transgression a diverse fauna occupied all available environments created within the carbonate bank and maximum productivity of carbonate particles was attained. In the protected interbank areas spicular cherts were continually deposited.

D. Climax stage (A) of carbonate deposition (Fig-
Figure 33

Mature Stage

Pioneer Stage
Figure 35

CLIMAX STAGE A

Figure 36

CLIMAX STAGE B
ure 35): With the initiation of regression of the seas and decreasing water depth and circulation, a carbonate sand bar developed on the unprotected flank of the bank. To the north disarticulated sponge spicules were winnowed by currents or waves to form spicular "sand" bars.

E. Climax stage (B) of spicular chert deposition (Figure 36): With continued regression of the seas and more restricted circulation spicular cherts were again deposited in the areas previously occupied by carbonate banks. Locally over the banks carbonate sedimentation continued, as evidenced by the dark fossiliferous limestone found in float in the cherty shale member at South Sage Creek, Section B.

The overlay to cross section A-A' (Figure 31) illustrates in greater detail the interpreted time-stratigraphic relationships from which the diagrammatic cross sections presented in Figures 33 -36 were made. Facies distribution maps (Figures 32 - 41) were constructed from the data presented in Figures 31 and 32 and will now be considered in context with the paleontologic and petrologic data previously presented.
Pioneer Stage

As an initial stage of carbonate sedimentation in the area, ramose bryozoa occupied small topographic highs (Figure 37). The bryozoa were originally restricted to small microcommunities surrounded by spicular siliceous muds but rapidly spread to form larger mounds. With increased circulation, in response to the transgressing sea, brachiopods inhabited the areas of greatest circulation.

Field evidence from all localities observed in the study area supports a similar mode of bank initiation. Also, the northward transgression of the South Sage Creek bank (Figure 31) may be directly attributed to pioneering communities of bryozoa which initiated carbonate deposition in protected areas on the lee side of the bank.

Mature Stage

With continued transgression of the sea, maximum carbonate productivity was achieved and diverse environments within the bank were occupied by a variety of faunal elements. The types of sediment deposited within an environment (Figure 39) were affected by the organisms living within or immediately adjacent to that environment (Figure 38) and were modified by the processes active within the environment (Figure 40).

Biofacies

The interpreted biofacies distribution for the South
Figure 3B

BIOFACIES
SO. SAGE CRK. BIOHERM
MATURE STAGE

See Figs. 31 & 32 for cross sections
LITHOFACIES
SO. SAGE CRK BIOHERM
MATURE STAGE

FIGURE 39

COARSE LITHOCLASTIC
CHERT PACKSTONE

MEDIUM LIME BIOGRAINSTONE
SPICULAR

SAGE CRK. LOC

SCALE

0 1/2 1 Mi

See Figs. 31 & 32 for cross sections
Sage Creek bank (Figure 38) was generalized from Plates II, III, and IV, Figure 26 (Page 98), Figures 31 and 32, and other paleontological evidence previously described (Pages 66–96). The faunal elements included within each biofacies are summarized as follows (listed in order of abundance):

A. Siliceous Sponge Biofacies:
1. Siliceous Sponges
2. Orbiculoid Brachiopods
3. Scaphopods

B. Crinoid-Spiriferid Biofacies
1. Spiriferid Brachiopods
   *Spiriferina, Composita*
2. Crinoids
3. Derbyia
4. Ramose Bryozoa
5. Pectinoid Pelecypods

C. Crinoid-Ramose Bryozoa Biofacies
1. Crinoids
2. Ramose Bryozoa
3. Productid Brachiopods
   *mostly? Sphenostegus*
4. Spiriferid Brachiopods
5. Fenestrate Bryozoa
6. Pectinoid Pelecypods
7. Foraminifera
8. Echinoids
9. Rugose Corals

D. Crinoid-Productid Biofacies
1. Crinoids
2. Productid Brachiopods
   "Liostella"
   *Echinaris, Bathymyonia*
3. Ramose Bryozoa
4. Pectinoid Pelecypods
5. Echinoids
6. Rugose Corals (other localities)

E. Bryozoa-Pelecypod Biofacies
1. Ramose Bryozoa
2. Fenestrate Bryozoa
3. Nuculoid Pelecypods
4. Encrusting Bryozoa
5. Foraminifera
6. Echinoids
7. Algae
The carbonate debris shed off the steeper southern flank of the bioherm encroached upon the toxic bottom muds of the siliceous sponge biofacies. Existence within such an environment would have been very difficult for organisms with carbonate shells; therefore, the environment is considered to have been relatively barren of living carbonate secreting organisms.

Lithofacies

The lithofacies distribution for the South Sage Creek bank was generalized from Plate IV, Figure 31 and Figure 32. When considered in context with the biofacies described the distribution of lithofacies is a good measure of depositional processes and environments.

A. Coarse Lime Biograinstone Lithofacies:

This lithofacies contains the texturally most mature lithotypes (2B, 2C; Plate IV, and Table 3, Page 131) of the bank complex. It also represents the maximum accumulation of carbonate sediment within the bank. It was certainly deposited under optimum conditions for carbonate sedimentation.

B. Medium to Coarse Lime Biograinstone-Packstone Lithofacies:

An intermediate degree of textural maturity is exhibited by the lithotypes representative of this lithofacies (2E, 2D, 2G; Table 3, Page 131). The presence of minor amounts of mud matrix is indicative of the lower degree of textural maturity. However, locally some lithotypes, especially the crinoid grainstones (2E), exhibit a high degree of textural maturity, which along with the cross bedding and mounding (Plate IV) suggests the presence of small local carbonate shoals leeward of the main bank.
C. Medium Lime Biopackstone-Wackestone:

Of the carbonate lithofacies, this facies includes the texturally least mature lithotypes (2H, 2I; Table 3, Page 131). Mud matrix occurs in moderate abundance in this lithofacies. The presence of articulated ramose bryozoa as well as the rest of the fauna within this facies is compatible with the low degree of textural maturity.

D. Litho-Biograinstone Lithofacies:

This facies was not actually observed at the Sage Creek or South Sage Creek localities because of the lack of exposures in the critical area of the southwest facies change to chert. The facies is interpreted to exist on the basis of experience at other localities (especially Timber Creek, Figures 16 and 17) where that facies change is better exposed. At other localities this lithofacies is most often highly silicified.

E. Very Coarse Brachiopod Biograinstone, Coarse Lithoclastic Chert Packstone and Coarse Bryozoan Biopackstone Lithofacies:

These lithofacies represent anomalous occurrences of more mature lithotypes in areas occupied by much less mature lithotypes. All lines of evidence: scoured bases, discontinuous nature, aligned bioclasts, coarse grain size, etc., suggest transportation to the areas of deposition in current channels.

F. Chert Wackestone-Packstone Lithofacies:

Two subfacies may be recognized dependent upon the lithotypes found within this facies. The presence of the most texturally mature spicular chert lithotype (1A) within the facies (Table 4, Page 139) as opposed to the presence of the silty chert lithotype (2F) is one of the criteria for recognition of the subfacies. The former occurs southwest of the bank and the latter immediately to the northeast.

Paleoenvironments - Processes

The depositional processes and paleoenvironments for the South Sage Creek bank (Figure 40) were interpreted from
FIGURE 40
PALEO ENVIRONMENTS
SO SAGE CRK. BIOHERM
MATURE STAGE
SCALE

See Figs 31 & 32 for cross sections.
the lithofacies and biofacies distribution. Depositional processes are described only in terms of energy regimes interpreted from the textural maturity, faunal content, sedimentary structures, and stratigraphic relationships of the rocks:

A. BANK — High Regime: This depositional environment represents the highest degree of carbonate productivity as evidenced by the volume of sediment produced within it. All aspects of the environment are indicative of a high energy regime. The fauna were especially well adapted and thrived in this area of high circulation and resultant abundant nutrients. The main bank environment was most probably the highest topographic expression of the South Sage Creek bank (Figure 31).

B. BACK BANK — Moderate to High Regime, Low to Moderate Regime, and Low Regime: The back bank environments are interpreted to represent decreasing energy regimes from southwest to northeast as a result of the protection afforded by the main bank from wave or current action. Locally, energy regimes were higher where small crinoidal shoals (lithotype 2E, Figure 31) developed or where current channels transversed the bank.

C. CURRENT CHANNELS: Varying energy regimes were active in the current channel environment as indicated by the diversity of rock types within them, ranging from low (lithoclastic chert packstone), or moderate (bryozoan biopackstone) to high (brachiopod biograinsone).

D. FOREBANK TALUS: The energy regime of this environment was also probably quite variable. Much of the deposition within this environment could have occurred as a simple downslope gravity process, but a certain amount of winnowing must also have been involved. Interpretation of the textural maturity of the sediments is difficult (even at other localities where exposures are better) because of the degree of silification.

E. OPEN INTERBANK: In the areas between carbonate banks where siliceous spicular muds were deposited only a very low energy regime existed. The sili-
ceous sponges thrived with only slight current action. The open interbank environment exhibits a slightly higher regime than the restricted interbank environment as evidenced by the presence of lithotype 1A (spicular chert packstone-wackestone) in that environment.

F. SLIGHTLY RESTRICTED INTERBANK: The lowest degree of textural maturity and consequently the interpreted lowest energy regime is typical of this environment. The difference in energy regime in relation to the more normal interbank environment was afforded by the protection from current activity by the carbonate bank.

Energy Modes

The primary energy mode for the mature stage of carbonate development is interpreted to have been current action, most probably upwelling currents, as evidenced by:

A. The regional position of the banks relative to the interpreted basin geometry and the shelf edge.
B. Evidence for deposition primarily, if not entirely, in subtidal conditions at moderate depths.
C. Evidence for moderate winnowing over long periods of time.
D. Presence of current channels.
E. Moderate development of cross-bedding.

The interpreted mean current direction is shown on all the map figures (Figures 30 and 37-41) and was interpreted primarily from the geometry of the bank. Cross-bedding directions were not determinable in the field; however, alignment
of articulated ramose bryozoan fronds on bedding planes in a roughly north-south orientation supports the interpreted current direction.

**Climax Stage**

In the last stage of carbonate deposition with regression of the Phosphoria Sea a shoal developed on the unprotected flank of the South Sage Creek bank (Figure 41). The regressive or progradational nature of the unit is illustrated in the stratigraphic cross section for that locality (Figure 31). The textural maturity of the carbonate lithotype (2A; Table 3, Page 131) representative of this stage of deposition, the massive bedding and evidence of cross-bedding (Section C, Plate IV) and the fauna which inhabited the environment of deposition all indicate deposition in shallow subtidal waters (possibly less than 60 feet).

The spiriferid-foram-algal-pelecypod biofacies of the climax stage of deposition includes the following faunal elements (Plate IV).

A. Spiriferid Brachiopods  
B. Ramose Bryozoa  
C. Foraminifera  
D. Algae  
   Dasyclad - Epimastapora  
   Blue green?  
E. Pelecypods  
F. Echinoids  
G. Gastropods  
H. Encrusting Bryozoa  
I. Ostracodes

Other bioclasts found within lithotype 2A are not con-
FIGURE 41

BIOFACIES

SO. SAGE CRK BIOHERM

CLIMAX STAGE A

SCALE

0 1/2 1 m

Sec 23

Sec 19

Sec 1

Outcrop Rex chert Mbr

SOUTH SAGE CRK. LOC.

SAGE CRK. LOC.

Outcrop Rex chert Mbr

Mean Current Direction

SILICEOUS SPONGE BIOFACIES

SPIRIFERID BIOFACIES

SPONGE SPICULE BAR

SPIRIFERID FORAM BIOFACIES

ALGAL-PELECYPOD

See Figs. 31 & 32 for cross sections
sidered to be indigenous to the depositional environment (Page 106).

On the leeward side of the carbonate shoal sponge spicule bars were formed from the winnowing of siliceous sponge spicules. Chert lithotype 1B (Table IV, Page 139) deposited in this environment exhibits a high degree of textural maturity. Other than siliceous sponge spicules, bioclasts are rarely found within lithotype 1B and it is doubtful that any faunal element occupied the environment in abundance.

Laterally in more protected waters siliceous sponges thrived and were disarticulated to form spicular cherts (lithotype 1A). The energy regime of the depositional environment of lithotype 1A was very low relative to carbonate lithotype 2A and chert lithotype 1B but slightly higher than the lithotypes deposited in the interbank environments during the mature stage of bank development.

Carbonate deposition was culminated as the basin became restricted and adequate circulation for carbonate productivity was not achieved. At this time spicular cherts of lithotype 1A and finally, with slight transgression of the Phosphoria Sea and influx of fine clastics, the basinal siliceous shales of the cherty shale member were deposited in the area.
CHAPTER 3

SUMMARY OF CONCLUSIONS

The carbonate lentils within the Rex Chert Member of the Permian Phosphoria Formation in southeast Idaho were studied to further determine:

A. The location of the lentils, their lateral extent and geometry;
B. The stratigraphic relationships of the carbonate and enclosing chert through studies of the field relationships, paleontology, and petrology;
C. The genesis of the carbonate lentils and cherts.

The Rex Chert Member and enclosed carbonate lentils are the shelf edge facies and time equivalents of the Franson Member shelf carbonates to the east in Wyoming. The carbonate lentils occur at eight localities with lateral extents in outcrop up to three miles and thicknesses up to one-hundred fifty feet. The lateral and vertical relationships of the carbonate and enclosing chert are gradational. Definite lithologic and paleontologic variations exist laterally and vertically within each lentil.

From the nature of the biota and lithologies of the lentils they are interpreted to have originated as carbonate banks separated by interbank sponge spicular siliceous muds. The main biotic constituents of the banks are crinoids, brachiopods, and bryozoa with lesser amounts of algae, foraminifera, pelecypods, gastropods, echinoids, and ostracodes. The rugose coral *Bradyphyllum idahoensis* (n. sp.) occurs in
moderate abundance at several localities. The predominant faunal element of the chert is siliceous monaxial sponge spicules. The main lithologic constituents of the banks are crinoid and spiriferid brachiopod biograins with varying degrees of textural maturity. The back bank lithologies are primarily bryozoan lime biopackstone-wackestones of relatively low textural maturity. The interbank cherts are primarily bituminous spicular chert biowackestones of very low textural maturity. From the facies relationship with the carbonates, chert deposition is interpreted to have occurred in water depths of less than 100 feet.

Carbonate bank development was initiated as the transgression of the Phosphoria sea introduced open circulation resulting in the deposition of the Franson carbonates. Ramose bryozoa colonized areas of slight topographic relief along the shelf edge, representing the pioneer phase of carbonate deposition. Laterally siliceous sponges were disarticulated to form the spicular cherts enclosing the carbonate. As the Franson transgression continued, with increased circulation, more invertebrate larvae migrated basinward establishing a mature community consisting largely of brachiopods, crinoids, and bryozoas. As a climax stage of carbonate deposition, foraminifera, algae, molluscs, and brachiopods occupied a carbonate shoal flanked by a winnowed sponge spicular bar.
SELECTED REFERENCES


Chilingar, G. V., 1958, Sponge spicule deposits as indicators of physical-chemical environments of deposition: Compass of Sigma Gamma Epsilon, v. 35, p. 215-219.


Pevear, D. R., 1966, The estuarine formation of United States Atlantic Coastal Plain phosphorite: Econ. Geol., v. 61, p. 251-256.


APPENDIX A

The following are brief descriptions of some of the sections measured for this study and detailed locations of localities and measured sections. Petrologic descriptions of the South Sage Creek localities are summarized on Plate IV and included as noted in the lithologic descriptions of other sections studied petrographically. Otherwise, field terms are used in the lithologic description.

**Dry Valley Creek Locality**

The Dry Valley Creek exposures occur on the southeast side of a prominent ridge easily accessible from a gravel road just south of the outcrop. The units below the Rex Chert Member are exposed in bulldozer trenches on the north-east side of the ridge. The carbonate unit of the Rex Chert Member is exposed only on the south end of the ridge and was measured and sample laterally at one-hundred-foot intervals (Sections A-C).
Dry Valley Creek Section A, NW^1_2, SE^1_4, NV^2_3, Sec. 31, T. 4 S., R. 44 E., Caribou Co., Idaho. The section below the Rex Chert Member was described by the U. S. Geological Survey (Davidson, et al, 1963, lot #1259) from bulldozer trenches. The section of the Rex Chert Member was measured, described, and sampled by the writer in August, 1969.

<table>
<thead>
<tr>
<th>Unit &amp; Sample No.</th>
<th>Thickness</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>cherty shale member</td>
<td>not exposed</td>
<td>Covered by weathered blocks of chert</td>
</tr>
<tr>
<td>Rex Chert Member</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVC-R8A</td>
<td>10 ft. expo.</td>
<td>Chert, pink, massive bedded, spicular, highly fractured.</td>
</tr>
<tr>
<td>DVC-R7A1-7</td>
<td>24 ft.</td>
<td>Limestone, grey, coarse grained, bioclastic, crinoid particles, produs-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>tid brachiopods and bryozoa. Paleontological collection DVC-R7A.</td>
</tr>
<tr>
<td>DVC-R6A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DVC-R5</td>
<td>12 ft.</td>
<td>Chert, black, with scattered pods of limestone. Limestone pods, above,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>grey, biclastic, bryozoa. Detailed petrologic collections DVC-R5-P1 &amp;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DVC-R5-P2.</td>
</tr>
<tr>
<td>DVC-R4</td>
<td>40 ft.</td>
<td>Chert, dark grey, massive bedded</td>
</tr>
<tr>
<td>DVC-R3</td>
<td>10 ft.</td>
<td>Chert, black, nodular to irregular bedded with limestone partings, buff,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dense.</td>
</tr>
<tr>
<td>DVC-R2</td>
<td>9.5 ft.</td>
<td>Chert, grey-blue grey, thin bedded.</td>
</tr>
<tr>
<td>DVC-R1</td>
<td>1.0 ft.</td>
<td>Chert, black and mudstone brown, silty with thin laminations of phosphatic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mudstone.</td>
</tr>
<tr>
<td>Meade Peak Member</td>
<td></td>
<td>Mudstone, brown, phosphatic</td>
</tr>
</tbody>
</table>
Dry Valley Creek, Section B, approximately one-hundred feet northeast of Section A.

<table>
<thead>
<tr>
<th>Unit &amp; Sample No.</th>
<th>Thickness</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVC-RB,1-4</td>
<td>15.0 ft.</td>
<td>Limestone, grey, coarse grained, bioclastic.</td>
</tr>
</tbody>
</table>

Dry Valley Creek, Section C, approximately two-hundred feet northeast of Section A.

<table>
<thead>
<tr>
<th>Unit &amp; Sample No.</th>
<th>Thickness</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DVC-RC,1-4</td>
<td>16.0 ft.</td>
<td>Limestone, grey, coarse grained, bioclastic.</td>
</tr>
</tbody>
</table>

**Hot Springs Locality**

The exposures at the Hot Springs locality are on the east side of Hot Springs ridge east of Bear Lake and accessible by dirt road across a dry wash east of the outcrop. The carbonate lense in the Rex Chert Member is exposed in the central portion of the outcrop and pinches out laterally to the north and south along the outcrop. A complete section of the Rex Chert Member was measured, described, and sampled by the writer at Section I and several sections of the carbonate lense were measured laterally from that section. A section of the Meade Peak Member was measured by the U. S. Geological Survey (Sheldon, et al, 1953, lot #1317) south of Section I. The sections are all overturned.

Hot Springs Section I, Sec. 13, T. 15 S., R. 44 E., Bear Lake County, Idaho. A complete section of the Rex Chert Member was measured, sampled, and described by the writer in August, 1969.
<table>
<thead>
<tr>
<th>Unit &amp; Sample No.</th>
<th>Thickness</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>cherty shale member</td>
<td></td>
<td>Shale, dark brown, chert nodules.</td>
</tr>
<tr>
<td><strong>Rex Chert Member</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSI-1</td>
<td>47.0 ft.</td>
<td>Chert, grey and dark grey, 6 inch conglomerate bed near top.</td>
</tr>
<tr>
<td>HSI-2A-H</td>
<td>27.0 ft.</td>
<td>Chert, 60%, dark grey and limestone, 40%, coarse grained, bioclastic, crinoid debris, pelecypods, brachiopods. Very near southern pinchout of carbonate lense.</td>
</tr>
<tr>
<td>HSI-3</td>
<td>45.0 ft.</td>
<td>Chert, dark grey, irregular bedded and limestone pods, dark grey, dense, bryozoa. Covered to base.</td>
</tr>
<tr>
<td><strong>Meade Peak Member</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mudstone, brown and dark phosphatic mudstone.</td>
</tr>
</tbody>
</table>

Sections E, D, C, B, and A were measured at approximately fifty-foot increments respectively northward. Each section included the description and sampling of the carbonate lense and chert directly above and below.

**Hot Springs Section E**

<table>
<thead>
<tr>
<th>Unit &amp; Sample No.</th>
<th>Thickness</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>U. Rex Chert Member</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSE3</td>
<td></td>
<td>Chert, dark grey.</td>
</tr>
<tr>
<td><strong>Franson Lentil</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSE2</td>
<td>38.0 in.</td>
<td>Limestone, grey, bioclastic, irregular (scour?) contact with underlying unit, includes discontinuous beds of brachiopod hash.</td>
</tr>
</tbody>
</table>
L. Rex Chert Member

<table>
<thead>
<tr>
<th>Unit &amp; Sample No.</th>
<th>Thickness</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSE1</td>
<td></td>
<td>Chert, dark grey, with limestone pods, grey, dense.</td>
</tr>
<tr>
<td>HSD3</td>
<td>6.5 ft.</td>
<td>Chert, grey.</td>
</tr>
<tr>
<td>Franson Lentil</td>
<td></td>
<td>Limestone, grey, coarse, bioclastic, crinoid debris, brachiopods, ramose bryozoa with discontinuous brachiopod hash beds.</td>
</tr>
<tr>
<td>HSD2</td>
<td>6.5 ft.</td>
<td>Chert, grey.</td>
</tr>
<tr>
<td>Franson Lentil</td>
<td></td>
<td>Chert, grey with limestone pods and lenses, grey bioclastic.</td>
</tr>
<tr>
<td>HSC-2-4</td>
<td>5.0 ft.</td>
<td>Limestone, grey bioclastic, with brachiopod hash beds and lenses of chert, grey, fossiliferous.</td>
</tr>
<tr>
<td>HSC-8&amp;9</td>
<td></td>
<td>Chert, grey with discontinuous lenses of limestone, grey, bioclastic.</td>
</tr>
<tr>
<td>Hot Springs Section B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>----------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Unit &amp; Sample No.</strong></td>
<td><strong>Thickness</strong></td>
<td><strong>Description</strong></td>
</tr>
<tr>
<td><strong>U. Rex Chert Member</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSB-1-4</td>
<td></td>
<td>Chert, grey with lenses of limestone, grey bioclastic.</td>
</tr>
<tr>
<td><strong>Franson Lentil</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HSB-5-7</td>
<td>6.5 ft.</td>
<td>Limestone, grey, bioclastic, crinoidal with lenses of chert, blue grey.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hot Springs Section A</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unit &amp; Sample No.</strong></td>
<td><strong>Thickness</strong></td>
</tr>
<tr>
<td><strong>U. Rex Chert Member</strong></td>
<td></td>
</tr>
<tr>
<td>HSA1</td>
<td></td>
</tr>
<tr>
<td><strong>Franson Lentil</strong></td>
<td></td>
</tr>
<tr>
<td>HSA-2</td>
<td>30 in.</td>
</tr>
<tr>
<td><strong>L. Rex Chert Member</strong></td>
<td></td>
</tr>
<tr>
<td>HSA-3</td>
<td></td>
</tr>
</tbody>
</table>

**Sage Creek Locality**

The exposures at the Sage Creek locality are on the east side of the Freeman Ridge and are accessible by gravel and dirt roads. The carbonate lentil in the Rex Chert Member is exposed on the north side of the road and extends for 3/4 mile to the north. Outcrops on the south side of the road contain no carbonate. Petrographic descriptions and
measured sections are illustrated in Figure 17, Figure 32, and Plate III. Locations of the sections are described below.

Sage Creek Section A, NW¼, SE¼, Sec. 10, T. 9 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured and sampled by the writer in August and September, 1969. The upper part of the member is not exposed.

Sage Creek Section B, S½, NW½, NE¼, Sec. 10, T. 9 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in August and September, 1969. The lower and upper parts of the section are poorly exposed.

Sage Creek Section C, NW¼, NW¼, NW¼, Sec. 10, T. 9 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969. The lower portion of the section is poorly exposed.

Sage Creek Section D, NW½, SW½, SE¼, Sec. 3, T. 9 S., R. 45 E., Caribou Co., Idaho. A complete section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969.

Sage Creek Section E, NW¼, NW¼, SE¼, Sec. 3, T. 9 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969. The upper portion of the section was unexposed.

South Sage Creek Locality

The South Sage Creek exposures are located on the east side of the Webster Range and are accessible by gravel and dirt roads. The carbonate lentil is exposed for three and one-fourth miles which is the complete extent of its occurrence. Petrographic descriptions and measured sections are illustrated in Figure 20, Figure 31, Plate II, and Plate IV.
Locations of the sections are described below.

South Sage Creek Section A, SE\(\frac{1}{4}\), SE\(\frac{1}{4}\), SE\(\frac{1}{4}\), Sec. 1, T. 9 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969. The lower portion of the member is unexposed.

South Sage Creek Section B, SE\(\frac{1}{4}\), SE\(\frac{1}{4}\), Sec. 13, T. 9 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969. The lower portion of the member is poorly exposed.

South Sage Creek Section C, NE\(\frac{1}{4}\), NW\(\frac{1}{4}\), Sec. 24, T. 9 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969. The lower portion of the member is unexposed.

South Sage Creek Section D, SW\(\frac{1}{4}\), SW\(\frac{1}{4}\), NE\(\frac{1}{4}\), Sec. 13, T. 9 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969. The lower portion of the member is poorly exposed.

South Sage Creek Section F, NE\(\frac{1}{4}\), SE\(\frac{1}{4}\), NE\(\frac{1}{4}\), Sec. 13, T. 9 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969. The lower portion of the member is unexposed.

South Sage Creek Section G, C, SW\(\frac{1}{4}\), Sec. 7, T. 9 S., R 46 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969. The upper and lower portions of the member are unexposed.

East Sage Creek Section, SE\(\frac{1}{4}\), SE\(\frac{1}{4}\), SE\(\frac{1}{4}\), Sec. 1, T. 9 S., R. 45 E., Caribou Co., Idaho. The partial section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969. The lower portion of the member is unexposed.

East Sage Creek North Section, NW\(\frac{1}{4}\), SW\(\frac{1}{4}\), Sec. 6, T 9 S., R. 45 E., Caribou Co., Idaho. The section was observed, described, and sampled by the writer in September, 1969.
Stewart Canyon Locality

The Rex Chert Member is exposed on the east flank of Dry Ridge at the Stewart Canyon and is accessible by gravel and dirt roads. The exposures are not laterally continuous due to heavy plant cover and complex structure. The best exposures are south of Stewart Canyon. Measured sections are illustrated in Figure 13. Locations of the sections are described below.

Stewart Canyon Section A, NW\textsuperscript{1/4}, SW\textsuperscript{1/4}, SE\textsuperscript{1/4}, Sec. 30, T. 8 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in August, 1969. The lower portion of the member is unexposed.

Stewart Canyon Section B, NE\textsuperscript{1/4}, Sec. 31, T. 8 S., R. 45 E., Caribou Co., Idaho. A complete section of the Rex Chert Member was measured, described, and sampled by the writer in August, 1969. The section was previously measured and fossils collected by the U. S. Geological Survey (Cheney and Montgomery, 1967). The complete section is well exposed.

Stewart Canyon Section C, NW\textsuperscript{1/4}, NE\textsuperscript{1/4}, SE\textsuperscript{1/4}, Sec. 31, T. 8 S., R. 45 E., Caribou Co., Idaho. A complete section was measured, described, and sampled by the writer from bulldozer trenches and natural outcrops of the Rex Chert Member in August, 1969.

Stewart Canyon Section D, SE\textsuperscript{1}, NE\textsuperscript{2}, Sec. 31, T. 8 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer from bulldozer trenches and natural outcrops in August, 1969. Lower portion of the section is unexposed.

Stewart Canyon Section E, SW\textsuperscript{1}, NE\textsuperscript{2}, Sec. 31, T. 8 S., R. 45 E., Caribou Co., Idaho. A complete section of the Rex Chert Member was measured, described, and sampled by the writer from bulldozer trenches and natural outcrops in August, 1969.
Stewart Canyon Sections F & G, NE$, SW$, NE$. Sec. 31, T. 8 S., R. 45 E., Caribou Co., Idaho. Sections of the carbonate unit only of the Rex Chert Member were sampled by the writer in August, 1969.

Dry Ridge Section, SE$, NE$, Sec. 25, T. 8 S., R. 44 E., Caribou Co., Idaho. A complete section of the Rex Chert Member was measured from a bulldozer trench and natural exposures by the writer in August, 1969.

**Timber Creek Locality**

The exposures at Timber Creek occur on the plunging nose of an anticline and are easily accessible from gravel roads. The carbonate lentil is well exposed in the southern portion of the locality and poorly exposed to the north. Measured sections are illustrated in Figure 16 and the location of sections is described below.

Timber Creek Section A, SW$, SW$, Sec. 22, T. 8 S., R. 45 E., Caribou Co., Idaho. The lower portion of the Rex Chert Member was measured, described, and sampled by the writer in August, 1969. The upper part of the section is eroded and covered by alluvium.

Timber Creek Sections B & C, NE$, SE$, Sec. 21, T. 8 S., R. 45 E., Caribou Co., Idaho. Partial sections of the Rex Chert Member were observed and sampled by the writer in August, 1969.

Timber Creek Sections D & E, NW$, SE$, Sec. 21, T. 8 S., R. 45 E., Caribou Co., Idaho. Partial sections of the Rex Chert Member were observed and sampled by the writer in August, 1969.

Timber Creek Section F, SW$, NW$, SW$, Sec. 22, T. 8 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in August, 1969. The upper portion of the member is unexposed.
Timber Creek Section G, SW$_{1}$/2, SW$_{1}$/2, Sec. 22, T. 8 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in August, 1969. The upper portion of the section is unexposed.

Timber Creek Section H, NE$_{1}$/2, NE$_{1}$/2, NE$_{1}$/2, Sec. 21, T. 8 S., R. 45 E., Caribou Co., Idaho. Partial sections of the Rex Chert Member were measured, described, and sampled by the writer in August, 1969. The middle portion of the section is unexposed.

Timber Creek Section J, N$_{1}$/2, SW$_{1}$/2, SE$_{1}$/2, Sec. 21, T. 8 S., R. 45 E., Caribou Co., Idaho. A complete section of the Rex Chert Member was measured by the writer in August, 1969.

Timber Creek Section K, NW$_{1}$/4, SW$_{1}$/4, Sec. 22, T. 8 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, sampled, and described by the writer in August, 1969. The lower portion of the section is faulted out.

Timber Creek Section L, SE$_{1}$/4 SE$_{1}$/4, NE$_{1}$/2, Sec. 21, T. 8 S., R. 45 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was observed, described, and sampled by the writer in August, 1969.

**Wood Canyon Locality**

The Rex Chert Member is well exposed in outcrops north and south of Wood Canyon and is easily accessible by gravel roads in Trail and Wood Canyons. Measured sections are illustrated in Figure 11 and the location of sections is described below.

Wood Canyon Section A, NE$_{1}$/4, NW$_{1}$/4, Sec. 6, T. 9 S., R. 43 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969. The lower portion of the section is unexposed.

Wood Canyon Section B, NE$_{1}$/4, SW$_{1}$/4, Sec. 31, T. 8 S., R. 43 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the
The writer in September, 1969. The lower portion of the section is unexposed.

Wood Canyon Section C, SW\text{\textfrac{1}{4}}, SE\text{\textfrac{1}{4}}, NW\text{\textfrac{1}{4}}, Sec. 31, T. 8 S., R. 43 E., Caribou Co., Idaho. A complete section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969.

Wood Canyon Section D, NW\text{\textfrac{1}{4}}, SE\text{\textfrac{1}{4}}, NW\text{\textfrac{1}{4}}, Sec. 31, T. 8 S., R. 43 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969. The lower portion of the section is unexposed.

Wood Canyon Section E, NW\text{\textfrac{1}{4}}, NW\text{\textfrac{1}{4}}, Sec. 31, T. 8 S., R. 43 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969.

Wood Canyon Section G, W\text{\textfrac{1}{2}}, SW\text{\textfrac{1}{4}}, Sec. 30, T. 8 S., R. 43 E., Caribou Co., Idaho. A partial section of the Rex Chert Member was observed and sampled from a bulldozer trench by the writer in September, 1969. The lower portion of the section is poorly exposed.

Trail Canyon Section (T. C.), NW\text{\textfrac{1}{4}}, NW\text{\textfrac{1}{4}}, Sec. 30, T. 8 S., R. 43 E., Caribou Co., Idaho. A complete section of the Rex Chert Member was measured, described, and sampled by the writer in September, 1969. A complete section of the Phosphoria Formation was previously measured by the U. S. Geological Survey (Culbrandson, et al., 1956).
APPENDIX B

Photographic Plates
EXPLANATION

Photo Plate 1 - Algae

FIGURE 1
Magnification 4X
Sample Number SCB5A
Locality Stewart Canyon, Sec. B
Epimastipora (A) in crinoid, bryozoan, lime biograins-cone

FIGURE 2
Magnification 14X
Sample Number SSF1L
Locality South Sage Creek, Sec. F
Algal coated grain (A) in brachiopod lime biopackstone. Ovoid and circular objects are productid spines.

FIGURE 3
Magnification 10X
Sample Number SSCBL
Locality South Sage Creek, Sec. B
Filamentous algae? (A) supported by non-productid brachiopod fragment (B) in brachiopod lime biograins-tone.

FIGURE 4
Magnification 6X
Sample Number SCB5B
Locality Stewart Canyon, Sec. B
Crenulated algal(?) coating (A) on crinoid bioclast (B) in crinoid, bryozoan, lime biopackstone.
EXPLANATION

Photo Plate II -- Algae

FIGURE 1

Magnification 100X
Sample Number TCA2
Locality Timber Creek, Sec. A

Algal spore cases (A) in spicular chert biopackstone with minor carbonate bioclasts.

FIGURE 2

Magnification 8X
Sample Number SSCJM
Locality South Sage Creek, Sec. C

Algae? (A) in crinoid, bryozoan, brachiopod lime biopackstone. Crinoid plates (C) and fenestrate bryozoan bioclast (D).
PHOTO PLATE II - ALGAE

Figure 1

Figure 2
EXPLANATION

Photo Plate III - Foraminifera

FIGURE 1

Magnification 8X
Sample Number SSA2AU
Locality South Sage Creek, Sec. A

Globivalvulina (center) with other scattered indeterminate microfossils in brachiopod crinoid lime biograine.

FIGURE 2

Magnification 14X
Sample Number SSCNL
Locality South Sage Creek, Sec. C

Foram (center) in brachiopod lime biograine.

FIGURE 3

Magnification 14X
Sample Number SSA2AU
Locality South Sage Creek, Sec. A

Textularid foram (center) in brachiopod biograine.

FIGURE 4

Magnification 14X
Sample Number SSF2AL
Locality South Sage Creek, Sec. F

Encrusting foram (center) in bryozoan bioweckestone.
PHOTO PLATE III - FORAMINIFERA

Figure 1

Figure 2

Figure 3

Figure 4
EXPLANATION

Photo Plate IV - Foraminifera

FIGURE 1

Magnification 8X
Sample Number SSCBU
Locality South Sage Creek, Sec. B
Globivalvulina (center) in bryozoan, brachiopod, pelecypod lime biograinstone.

FIGURE 2

Magnification 20X
Sample Number TGA1U
Locality Timber Creek, Sec. A
Globivalvulina (center) in spicular chert biograinstone with minor carbonate bioclasts including ramose bryozoan.

FIGURE 3

Magnification 14X
Sample Number SSA2CU
Locality South Sage Creek, Sec. A
Globivalvulina (center) in crinoid lime biograinstone.

FIGURE 4

Magnification 14X
Sample Number SSA2AU
Locality South Sage Creek, Sec. A
Globivalvulina (center) in brachiopod biograinstone.
Figure 1

Figure 2
EXPLANATION

Photo Plate V - Microfossils

FIGURE 1

Magnification  100X
Sample Number  TCA2
Locality       Timber Creek, Sec. A
Indeterminate microfossils in spicular chert biopackstone.

FIGURE 2

Magnification  700X
Sample Number  TCG2MM
Locality       Timber Creek, Sec. G
Organic walled microfossils in spicular chert biopackstone.

FIGURE 3

Magnification  4X
Sample Number  TCG2MM
Locality       Timber Creek, Sec. G
Siliceous monaxial sponge spicules in spicular chert biopackstone.

FIGURE 4

Magnification  100X
Sample Number  TCA2
Locality       Timber Creek, Sec. A
Indeterminate microfossil in spicular chert biopackstone.
EXPLANATION

Photo Plate VI - Coral

FIGURES 1 - 4

Holotype *Bradyphyllum idahoensis* n. sp.

Successive transverse section peels (negative prints) from base of corallite up (numbers in lower left corners indicate sequence). Major features are labeled on Figures 4 and 8. Note especially the distally dilated septa, prominent cardinal fossula, retracted cardinal septum and few dissepiments.
PHOTO PLATE VI - CORAL

Figure 1

Figure 2

Figure 3

Figure 4
FIGURES 1 and 2

Paratype *Bradyphyllum idahoensis*

Polished longitudinal sections slightly mis-oriented, positive prints. The septa and dissepiments are well illustrated in both sections. Note the prominent tabula in the lower portions of the axial region.
PHOTO PLATE VII - CORAL

Figure 1

Figure 2
EXPLANATION

Photo Plate VIII - Bryozoa

FIGURE 1

Magnification 8X
Sample Number SSCAM
Locality South Sage Creek, Sec. C
Encrusting bryozoan (center) supported by brachiopod bioclast in bryozoan biograinsstone.

FIGURE 2

Magnification 4X
Sample Number SCB5
Locality Stewart Canyon, Sec. B
Ramose bryozoan (left) in crinoid bryozoan biograinsstone.

FIGURE 3

Magnification 4X
Sample Number SSCKL
Locality South Sage Creek, Sec. C
Encrusting bryozoan (center) supported by non-productid brachiopod in brachiopod biograinsstone.
EXPLANATION

Photo Plate IX - Bryozoa

FIGURE 1

Magnification 8X
Sample Number ES2CM
Locality South Sage Creek, Sec. ES

Ramose and fenestrate bioclasts in bryozoan lime biograins to nite.

FIGURE 2

Magnification 14X
Sample Number SSA2GL
Locality South Sage Creek, Sec. A

Ramose bryozoa (C) and fenestrate bryozoan bioclasts (A) in crinoid, bryozoan lime biograins to nite.

FIGURE 3

Magnification 14X
Sample Number SSCBM
Locality South Sage Creek, Sec. B

Fenestrate bioclasts (A) and bored bioclasts (C) in bryozoan, brachiopod lime biograins to nite.

FIGURE 4

Magnification 40X
Sample Number TCGAU
Locality Timber Creek, Sec. G

Fenestrate bryozoa (A) in spicular bryozoan chert biograins to nite.
EXPLANATION

Photo Plate X - Brachiopods

FIGURE 1

Magnification 8X
Sample Number SSCDM
Locality South Sage Creek, Sec. D

Non-productid brachiopod (C) and bored brachiopod fragment (A) in brachiopod lime bioclastic rock.

FIGURE 2

Magnification 8X
Sample Number SSCBU
Locality South Sage Creek, Sec. B

Non-productid brachiopod (A) with typical lamellar microstructure, brachiopod spine cross section and longitudinal section (D), ostracode (C) in brachiopod lime bioclastic rock.

FIGURE 3

Magnification 4X
Sample Number SSG6L
Locality South Sage Creek, Sec. G

Productid brachiopod (A) with typical pseudopunctate microstructure and cross sections of productid spines (C) in brachiopod lime biopackstone.
PHOTO PLATE X - BRACHIOPODS

Figure 1

Figure 2

Figure 3
FIGURE 1
Magnification  8X
Sample Number  SSA2CU
Locality        South Sage Creek, Sec. A

Pectenoid pelecypod (A) illustrating typical prismatic microstructure and crinoid bioclasts (D) in crinoid lime biograinsstone.

FIGURE 2
Magnification  8X
Sample Number  SSCBU
Locality        South Sage Creek, Sec. C

Gastropod (A), Globivalvulina (C), non-productid brachiopod (D) with lamellar microstructure and crinoid bioclasts (E) in crinoid, pelecypod, bryozoan lime biograinsstone.

FIGURE 3
Magnification  4X
Sample Number  SSCKU
Locality        South Sage Creek, Sec. C

Gastropod (A), ostracode (C) in brachiopod lime biograinsstone.

FIGURE 4
Magnification  11X
Sample Number  SSBCU
Locality        South Sage Creek, Sec. E

Ostracode (A), productid spine (C) and ramose bryozoan (D) in brachiopod lime biograinsstone.
EXPLANATION

Photo Plate XII- Echinoderms

FIGURE 1

Magnification 4X
Sample Number SSGEL
Locality South Sage Creek, Sec. G

Crinoid bioclasts typified by complete extinction of each grain under crossed nicols in coarse crinoid lime biograinstone.

FIGURE 2

Magnification 4X
Sample Number SSA4JM
Locality South Sage Creek, Sec. A

Crinoid bioclasts with grain overgrowths (A) in brachiopod, crinoid lime biograinstone.

FIGURE 3

Magnification 4X
Sample Number SSA2EU
Locality South Sage Creek, Sec. A

Crinoid bioclasts (A) and pelecypod (C) in coarse crinoid lime biograinstone.

FIGURE 4

Magnification 4X
Sample Number SSCFL
Locality South Sage Creek, Sec. C

Echinoid bioclast (A) with typical reticulate pattern, pelecypod (C) and non-productid brachiopod (D) in brachiopod lime biograinstone.
PHOTO PLATE XII - ECHINODERMS

Figure 1

Figure 2

Figure 3

Figure 4
EXPLANATION

Photo Plate XIII - Carbonate Lithotypes

FIGURE 1  Lithotype 2A

Magnification  4X
Sample Number  SSCEU
Locality  South Sage Creek, Sec. C

Medium grained, moderately sorted, rounded, bryozoan, brachiopod lime biograinstone. Brachiopod (A), gastropod (C), Globivalvulina (D), crinoid (E), bryozoan bioclasts (F).

FIGURE 2  Lithotype 2A-2B

Magnification  4X
Sample Number  SSCEL
Locality  South Sage Creek, Sec. C

Coarse, unsorted, pelecypod, brachiopod lime biograinstone. Brachiopod (A), pelecypod (C), crinoid (D).

FIGURE 3  Lithotype 2B

Magnification  4X
Sample Number  SSBCM
Locality  South Sage Creek, Sec. C

Coarse, unsorted brachiopod lime biograinstone. Matrix porosity (A).

FIGURE 4  Lithotype 2C

Magnification  4X
Sample Number  SSBKL
Locality  South Sage Creek, Sec. B

Coarse, moderately sorted, brachiopod crinoid lime biograinstone. Brachiopod (A), crinoid (C) with overgrowth.
PHOTO PLATE XIII - CARBONATE LITHOTYPES

Figure 1

Figure 2

Figure 3

Figure 4
FIGURE 1  Lithotype 2D

Magnification 4X
Sample Number SSA4EU
Locality South Sage Creek, Sec. A

Medium grained, unsorted, unrounded, bituminous, brachiopod lime biograinstone.

FIGURE 2  Lithotype 2E

Magnification 4X
Sample Number SSGFL
Locality South Sage Creek, Sec. G

Coarse, unsorted, moderately rounded, bituminous, crinoid, lime biograinstone-packstone.

FIGURE 3  Lithotype 2E

Magnification 4X
Sample Number SSD3AM
Locality South Sage Creek, Sec. D

Coarse, unsorted, rounded, crinoid lime biograinstone. Grain overgrowths (A).

FIGURE 4  Lithotype 2E-2G

Magnification 4X
Sample Number SSA2EL
Locality South Sage Creek, Sec. A

Coarse, unsorted, unrounded, bryozoan, crinoid lime biograinstone.
PHOTO PLATE XIV - CARBONATE LITHOTYPES

Figure 1

Figure 2

Figure 3

Figure 4
FIGURE 1  Lithotype 2F

Magnification  4X
Sample Number  SSA4JM
Locality  South Sage Creek, Sec. A

Coarse, unsorted, unrounded, brachiopod lime biograinsstone with abundant productid brachiopods.

FIGURE 2  Lithotype 2G

Magnification  4X
Sample Number  SSA4AU
Locality  South Sage Creek, Sec. A

Medium to coarse, moderately sorted, crinoid bryozoan lime biograinsstone with abundant ramose bryozone bioclasts.

FIGURE 3  Lithotype 2H

Magnification  4X
Sample Number  ES1U
Locality  South Sage Creek, Sec. ES

Medium grained, unsorted, moderately rounded, bryozoan lime biograinsstone-packstone.

FIGURE 4  Lithotype 2H

Magnification  4X
Sample Number  ES1UA
Locality  South Sage Creek, Sec. ES

Medium grained, unsorted, unrounded, bituminous, bryozoan lime biopackstone.
PHOTO PLATE XV - CARBONATE LITHOTYPES

Figure 1

Figure 2

Figure 3

Figure 4
EXPLANATION

Photo Plate XVI - Carbonate Lithotypes

FIGURE 1  Lithotype 21

Magnification  
Sample Number  ES2FU
Locality  
South Sage Creek, Sec. ES
Fine to medium grained, moderately sorted, moderately rounded, bryozoan lime biograinstone.

FIGURE 2  Lithotype 21

Magnification  
Sample Number  SSA4BM
Locality  
South Sage Creek, Sec. A
Fine grained, moderately sorted, rounded, bryozoan lime biograinstone.
EXPLANATION

Photo Plate XVII - Chert Lithotypes

FIGURE 1  Lithotype 1A

Magnification  4X
Sample Number  SSD5L
Locality       South Sage Creek, Sec. D

Fine grained, sorted, spicular chert biograinsstone.  
Longitudinal section of spicule with axial canal (A).

FIGURE 2  Lithotype 1B

Magnification  4X
Sample Number  SSD5U
Locality       South Sage Creek, Sec. D

Fine grained, moderately sorted, bituminous, spicular 
chert biograinsstone.

FIGURE 3  Lithotype 1C

Magnification  4X
Sample Number  SSA6
Locality       South Sage Creek, Sec. A

Laminated, fine grained, unsorted, bituminous 
spicular and silty chert biograinsstone.
PHOTO PLATE XVII - CHERT LITHOTYPES

Figure 1

Figure 2

Figure 3
EXPLANATION

Photo Plate XVIII - Chert Lithotypes

FIGURE 1    Lithotype 1E-2F

Magnification    LX
Sample Number    SSA3AU
Locality         South Sage Creek, Sec. A

Coarse, unsorted, brachiopod, silicified chert biograins of silicified productid brachiopod (A).

FIGURE 2    Lithotype 1E-2H

Magnification    4X
Sample Number    ES3L
Locality         South Sage Creek, Sec. ES

Medium grained, moderately sorted, moderately rounded, bryozoan, silicified chert biograins of silicified matrix (A) is cryptocrystalline chert.

FIGURE 3    Lithotype 1D

Magnification    4X
Sample Number    SSA1
Locality         South Sage Creek, Sec. A

Laminated, dolomitic crystalline chert.
PHOTO PLATE XVIII - CHERT LITHOTYPES

Figure 1

Figure 2

Figure 3
EXPLANATION

Photo Plate XIX - Sedimentary Structures

FIGURE 1

Crossed Nicols
Magnification 2.5X
Sample Number SGE1
Locality Sage Creek, Sec. E

Crossbedded, coarse, lithoclastic chert packstone.

FIGURE 2

Magnification 4.5X
Same as above.

FIGURE 3

Magnification 2.5X
Sample Number SCBAL
Locality Stewart Canyon, Sec. B

Above: Laminated lime mudstone.
Below: Scoured (A) fine grained, moderately sorted, algal-fenestrate bryozoan, phosphatic lime biograins.
EXPLANATION

Photo Plate XX - Sedimentary Structures

FIGURE 1

Crossed Nicols
Magnification 2.5X
Sample Number SCB2
Locality Stewart Canyon, Sec. B
Burrowed lime mudstone with well developed sub-vertical burrow.

FIGURES 2 & 3

Crossed Nicols
Magnification 2.5X
Sample Number SCA2C&D
Locality Stewart Canyon, Sec. A
Bioturbated lime mudstone. Quartz filled fractures with undulose extinction define almost perfect conjugate shear.

FIGURE 4

Crossed Nicols
Magnification 2.5X
Sample Number SCB2AL
Locality Stewart Canyon, Sec. B
Burrowed lime mudstone (A) and fine grained, well sorted, rounded, bryozoan lime biopackstone.
EXPLANATION

Photo Plate XXI - Diagenetic Textures

ALL FIGURES
Thin sections stained with alizarin red-s.
Crossed Nicols
Magnification 12X
Locality South Sage Creek

FIGURE 1
Drusy quartz mosaic matrix texture. Bioclasts (red) are primarily crinoidal.

FIGURE 2
Microcrystalline quartz matrix texture. Partially replaced bioclasts (red) are bryozoa.

FIGURE 3
Drusy quartz mosaic matrix texture. Coarsely crystalline.

FIGURE 4
Microcrystalline quartz matrix texture.

Refer to text pages 127 and 128.
EXPLANATION

Photo Plate XXII - Diagenetic Textures

ALL FIGURES

Thin sections stained with alizarin red-s.
Crossed Nicols
Magnification 12X
Locality South Sage Creek

FIGURES 1 - 4

Microcrystalline quartz matrix texture and partial bioclast replacement. Figure 3 illustrates also chalcedonic overlay (A). Note pockets of dolomite rhombs in matrix associated with microcrystalline quartz.

Refer to text pages 127 and 128.
Figure 1

Figure 2

Figure 3

Figure 4
ALL FIGURES

Thin sections stained with alizarin red-s.
Crossed Nicols
Magnification 12X
Locality South Sage Creek

FIGURES 1 - 3

Various stages of leutecitic replacement of bioclasts best exhibited in Figure 3 (A).

FIGURE 4

Microcrystalline quartz matrix lower half, calcite matrix upper half.

Refer to text: pages 127 and 128.
EXPLANATION
Photo Plate XXIV - Diagenetic Textures

ALL FIGURES
Thin sections stained with alizarin red-s.
Crossed nicols
Magnification 12X
Locality South Sage Creek

FIGURE 1
Drusy quartz mosaic matrix texture (A) microcrystalline quartz bioclast replacement (B).

FIGURE 2
Original interparticle porosity destroyed by drusy quartz infill.
EXPLANATION

Photo Plate XXV - Diagenetic Textures

ALL FIGURES

Thin sections stained with alizarin red-s.
Crossed Nicols
Magnification 12X
Locality South Sage Creek

FIGURES 1 and 2

Extreme microcrystalline quartz replacement, complete in Figure 2.

FIGURES 3 and 4

Preferential replacement of originally porous ramose bryozoa versus dense crinoid bioclasts. Bryozoan zoecia in Figure 3 (A) show infill drusy quartz mosaic in original porosity.
Figure 1

Figure 2

Figure 3

Figure 4