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PETROLOGY OF THE MIDDLE CAMBRIAN BLACKSMITH FORMATION, SOUTHEASTERN IDAHO AND NORTHERNMOST UTAH

by

David Paul Zelazek

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Geology

Approved:

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Logan, Utah

1981

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David P. Zelazek

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ABSTRACT

Petrology of the Middle Cambrian Blacksmith Formation, Southeastern Idaho and Northernmost Utah

by

David Paul Zelazek, Master of Science

Utah State University, 1981

Major Professor: Dr. Peter T. Kolesar, Jr.
Department: Geology

The Blacksmith Formation of Middle Cambrian (Albertan) age was studied in southeastern Idaho and northernmost Utah. Lithology and sedimentary structures were compared with modern environments and ancient rocks to determin environments of deposition, paleogeography, diagenetic alterations and patterns of dolomitization.

The Blacksmith Formation can be divided into five basic rock types. Rock type A has cryptalgalaminae, mudcracks, and lacks bioturbation. Rock type A is inferred to have been deposited in the upper intertidal to supratidal environment. Rock type B is extremely dolomitized and brecciated. It is inferred that rock type B was deposited in the upper intertidal to supratidal environment. Rock type C may have cryptalgal mats, stromatolites consisting of laterally linked hemispheroids, birdseye structures, vertical burrows and pseudomorphs after evaporite minerals. Rock type C is inferred to have been deposited in the lower intertidal environment. Rock type D is fine grained, often dark gray in color, has trails and often contains fossil fragments. Rock type D is inferred to have been deposited in subtidal-lagoon or open-platform environments. Rock type E is ooid-rich, and is often cross-stratified. Rock type E is inferred to have been deposited in an agitated-shoal or quiet-water shoal environment. All rocks of the Blacksmith Formation were deposited in supratidal to shallow subtidal environments.

During Albertan time the study area was located in the tropics, and the adjacent area had little relief. Clay mineralogy of the insoluble residues suggests a relatively humid paleoclimate.

Tidal amplitude was probably low, as suggested by small algal domes, LLH stromatolites, and cryptalgal mats. Water depth varied throughout the area. Less restricted fauna to the north suggest that water depth increased to the north. It is inferred that a transgression from the west, regression to the west, a second transgression, and possibly a second regression controlled the distribution of facies.

Early diagenesis included minor compaction of intertidal or very shallow subtidal deposits, whereas deeper subtidal deposits may have undergone more compaction. Cementation occurred early in the intertidal or shallow subtidal environment. Dolomitization of the Blacksmith by a hypersaline brine is suggested by pseudomorphs after evaporites, authigenic quartz, desiccation features and cloudy dolomite rhombs. Chemical analyses for sodium also indicate a hypersaline fluid. The association of some of the dolomite with the oolite-shoal environment suggests that the dolomite distribution may be in part facies-controlled. The hypersaline brine likely developed on tidal flats south of the area, and percolated through the sediments via refluxion and through the permeable sediments via hydrostatic head. The amount of dolomite decreases to the north, farther from the source of the brine. As the dolomitizing brine moved downward, the Mg/Ca ratio was lowered so that a ferroan dolomite formed in the subsurface, under reducing conditions.

Late diagenetic events include aggrading neomorphism by low-Mg calcite which may obliterate grains and cement or preserve grains and episodes of cementation. Late dolomitization, producing coarse dolomite rhombs exhibiting undulose extinction and curved crystal faces may have been epigenetic in origin.

(141 pages)

INTRODUCTION

General Statement

This report summarizes a study of the environments of deposition and diagenesis of the Middle Cambrian Blacksmith Formation in southeastern Idaho and northernmost Utah. In the study area the Blacksmith is underlain conformably by the Ute Formation and overlain conformably by the Bloomington Formation.

The Blacksmith Formation was selected for study because it is generally a resistant, well-exposed formation with a wide distribution, and it is easily accessible (Fig. 1). Its deposition in shallow seas marginal to the Cordilleran miogeosyncline makes the Blacksmith ideal for the understanding of ancient environments of carbonate deposition and diagenesis.

Purpose of the Investigation

The purposes of this investigation were: (1) to reconstruct the original environments of deposition as indicated by lithology and sedimentary structures; (2) to reconstruct the paleogeographic setting; (3) to determine the sequence of diagenetic alteration, including dolomitization; (4) to determine if the dolomitization of the Blacksmith fits any published dolomitization model.

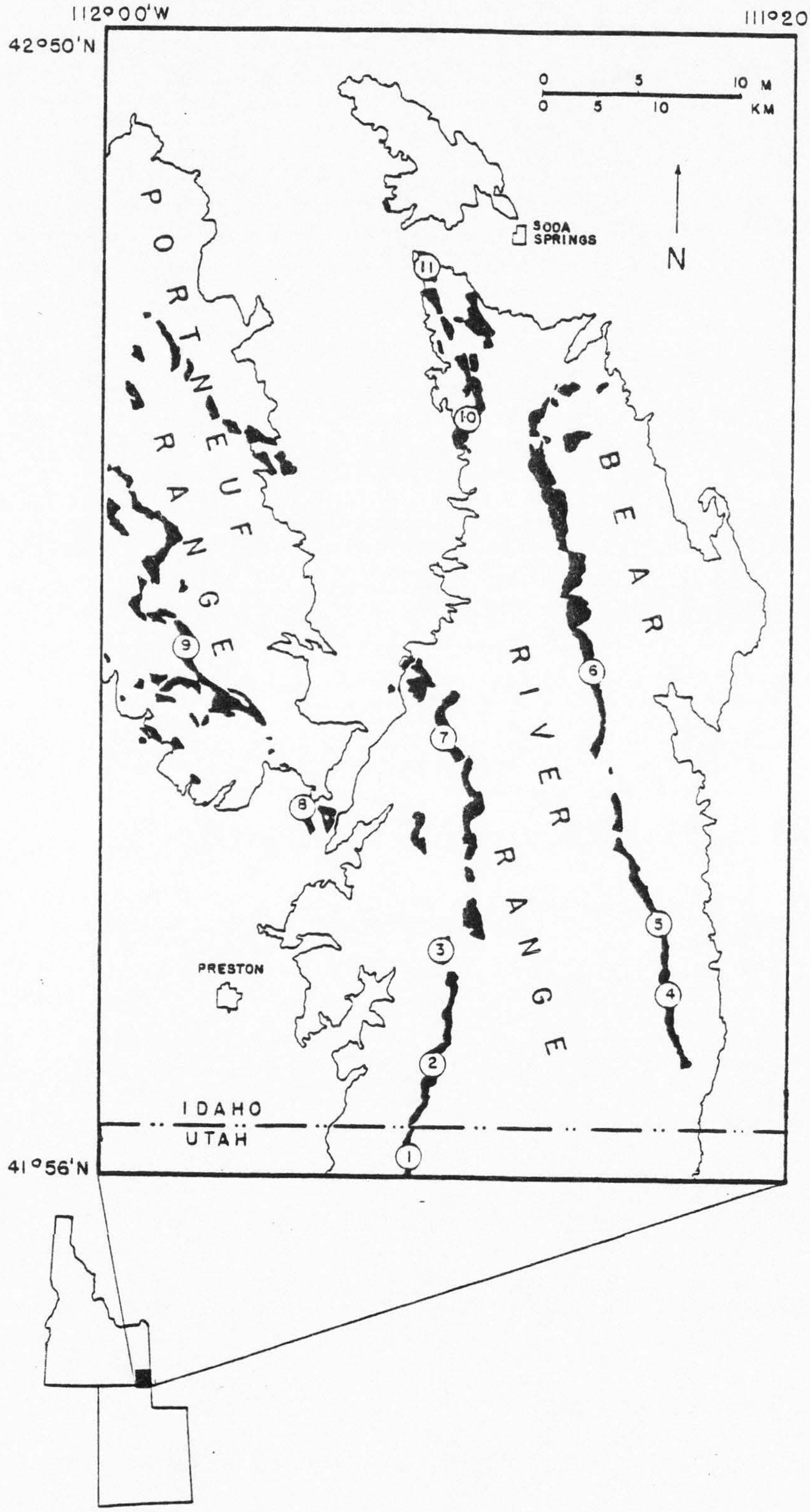
FIG. 1.- View southeast of the cliff-forming Blacksmith Formation, South Fork High Creek Canyon, Utah.

Location of the Study Area

The study area comprises the northernmost portion of the Logan quadrangle, the Preston quadrangle, the southwestern quarter of the Bancroft quadrangle, the southern portion of the Soda Springs quadrangle, and the western part of the Montpelier quadrangle. The southern boundary is a line at 41° 56' N. latitude, extending from 112° 00' W. longitude in the west to 111° 20' W. longitude in the east, a distance of 52 km. The northern boundary is a line at 42° 50' N. latitude, extending between the same longitude lines. A distance of 87 km separates the northern and southern boundaries, making the study area 4524 square km. To the north of the area, much of the Blacksmith is covered by Quaternary basalts of the Snake River Plain. South of the study area, Hay (1981, in prep.) is making a complementary study of the Blacksmith.

Ten stratigraphic sections were measured in the Bear River Range, the northern extension of the Wasatch Range. Outcrops in this block-faulted range generally dip east on the west side of the range and west on the east side, into the Logan Peak Syncline. Locally, dips may deviate from this generalization due to numerous faults. Three other sections in the Bear River Range were considered for study but were not measured because of extensive faulting and/or poor exposures. One section was measured in the Portneuf Range, west of Gem Valley. Locations of outcrops of the Blacksmith Formation, and measured sections, are shown in Figure 2.

Of the eleven sections measured, seven were on south facing


112°00'W
111°20'W
42°50'N
41°56'N
0 5 10 M
0 5 10 KM
N
SODA SPRINGS
PORTNEUF RANGE
BEAR RIVER RANGE
PRESTON
IDAHO
UTAH
1
2
3
4
5
6
7
8
9
10
11

slopes, two were on north facing slopes, and two were on east-west ridge crests. At eight sections, at least 80 percent of the section was exposed and not obviously faulted. At the Cub River, Strawberry Creek, and Beaver Basin sections (3, 7, and 9), faulting, talus and poor exposures inhibited complete measurements.

Forest Service, county, and private roads provided access to within 2 km of all sections. The final 2 km on foot normally required a substantial climb of 200 to 250 m.

Geologic Setting

The Cambrian section in Utah follows a definite sequence: a basal sandstone or quartzite, overlain by a thin shale, which in turn is overlain by thick carbonates, some with shale members (Hintze, 1973). In southeastern Idaho and northernmost Utah the basal Brigham Formation is overlain by 5800 feet of thin shale and thick carbonate (Hintze, 1973). Kepper (1972) concluded that the mottled muddy limestone and stromatolitic dolomite were deposited in very shallow, marine waters which deepened westward. Bathurst (1967), Lucia (1972), and Wilson (1975) described ooids, bioturbation, birdseye structures, and algal structures as common in shallow water. The Middle Cambrian Blacksmith Formation has structures typically indicating deposition in shallow water. Kepper (1972) concluded that, during Middle and early Late Cmabrian times in the eastern Great Basin region, a broad, linear, north-trending, shoal near sea level separated a deeper-water, open-shelf environment, to the west, from a wide, shallow, shelf-lagoon environment to the east.

An interlacing pattern of tidal algal mudbanks and shallow subtidal basins characterized the shoal (Kepper, 1972). The study area was in the shallow, shelf-lagoon environment east of this shoal, marginal to the Cordilleran miogeosyncline, with the craton farther to the east during the Middle Cambrian.

In Early and Middle Cambrian times the shoreline migrated slowly eastward from Nevada to central Utah over an area of little relief (Hintze, 1973). Lochman-Balk (1970) concluded that the regression at the top of the Bolaspidella zone marks the end of Middle Cambrian deposition in north-central Utah and southeastern Idaho.

The Paleozoic rocks of the Bear River Range are folded into north-south-trending folds which are dislocated by high angle faults (Coulter, 1956). Coulter (1956) agreed with Eardley (1949, cited in Coulter, 1956) that the broad north-south-trending folds occurred during the Laramide orogeny, and produced most of the relief, not the later high-angle faulting of the Basin and Range orogeny. Williams (1948) concluded that the Bear River Range was a result of the Bannock overthrust, with eastward thrusting causing the north-south-trending folds (Crittenden, 1961) which were later cut by high-angle faults.

Field and Laboratory Methods

The information necessary to locate complete sections of the Blacksmith Formation was obtained from geologic maps of the Soda Springs quadrangle (Armstrong, 1969), the Preston quadrangle (Oriel and Platt, 1968), the southwest quarter of the Bancroft quadrangle

(Oriel, 1965), the southwest portion of the Montpelier quadrangle (Davis, 1969), and the northernmost portion of the Logan quadrangle (Williams, 1948). The sections were located 7 to 22 km apart, which was adequate for north-south and east-west stratigraphic control.

Reconnaissance and field work were completed between June 1 and October 25, 1980. Thirty-four days were spent in the field, during which 11 stratigraphic sections were measured and described in detail. It took between 2 to 5 days to complete work at each section. All sections were measured using a Jacob-staff and Brunton compass, after the methods described by Compton (1962) and Kottlowski (1965). Samples were taken near the base of each unit and where changes in lithologic character were evident.

Field descriptions included rock types, grain sizes and types, colors (Goddard, 1963), types and nature of contacts, and bedding thickness. Inorganic sedimentary structures including ooids, pisoliths, cross- and parallel laminae, mudcracks, birdseye structures, color and texture mottling, and stylolites were recorded. Organic sedimentary structures described include trace fossils, oncoliths, and cryptalgal structures. General features, such as thickness of covered intervals and locations of ledge or cliff-forming units, were noted.

After the completion of field work, polished slabs of selected samples were prepared and described in detail. Thin sections of 70 samples from 10 stratigraphic sections were prepared, stained with Alizarin-red S (Friedman, 1959) and examined petrographically. In order to examine extensively recrystallized rocks, a permanent diffuser was prepared using slight modification of the method described by Delgado (1977). A magnesium oxide coating was applied to one side of a glass slide, sandwiched between a second glass slide, and the two slides were then taped together. In use the diffuser was placed beneath the thin section in question.

Insoluble residues were isolated from 140 rock samples by powdering with a Bico pulverizer, type UA, so that most grains would pass a 60 mesh sieve. Most samples initially contained 30-40 grams, and were dissolved using 10 and 20 percent hydrochloric acid. One hundred thirty-five residues were analyzed by x-ray diffraction, using an oriented sample, to determine composition. All samples were scanned from 2° 2θ to 35° 2θ at 2° 2θ per minute using Ni-filtered Cu K_α radiation at 35 Kv and 16 mA on a Siemens Krystalloflex IV x-ray diffractometer.

Chemical analyses of a limited number of samples for sodium was performed with a Perkin-Elmer model 303 atomic absorption spectrophotometer. Samples were prepared by dissolving in 10 percent HCl. Standards were prepared from stock solutions.

Physical correlation of sections was done by comparing the stratigraphic sections. Construction of an isopachous map, geologic sections, a fence diagram, and a lithofacies map of percent-dolomite provided valuable information necessary to make paleoenvironmental and paleogeographic interpretations.

PREVIOUS STUDIES

King (1878) first recognized the presence of Cambrian rocks in northern Utah, and mapped them as a single undifferentiated unit (Maxey, 1941, p. 5). Peale (1879), working with geologists of the 40th Parallel Survey, reported that the strata below the Carboniferous in the northern Bear River Range was "Silurian" or "Pre-Silurian," and admitted that his examination was not detailed enough to determine which.

Walcott (1908a) first named the Blacksmith Formation, and described it as gray arenaceous limestone in massive layers. He reported a thickness of 570 feet at the type section in Blacksmith Fork Canyon, Utah. Later Walcott (1908b) divided the Blacksmith at the type section into a lower unit, 195 feet thick, of dark lead-gray limestone, and an upper, cliff-forming unit 375 feet thick. Walcott assigned the Blacksmith to the Middle Cambrian due to its position between two formations containing fossils of Middle Cambrian age.

Richardson (1913) studied in the Randolph quadrangle, Utah, and measured 700 feet of Blacksmith near Garden City, Utah. He described the Blacksmith as massive fine-grained gray to bluish limestone.

Mansfield (1927) described the Blacksmith in the Portneuf quadrangle, Idaho, as a cliff-forming arenaceous limestone which becomes purer up-section. He emphasized the presence of thick bedding, and noted some oolitic beds. The contacts of the Blacksmith were defined by Mansfield (1929); the contact with the Ute Formation below is conformable and is placed where the interbedding with shales ceases; the upper contact is placed at the base of the Hodges Shale Member of the Bloomington Formation. The Bloomington-Blacksmith contact is conformable.

Deiss (1938) remeasured the Blacksmith Fork section originally measured by Walcott, found what he believed were errors, and proposed an emended definition of the Blacksmith. Deiss described the Blacksmith was white-gray, dull steel-gray dolomite, not limestone as Walcott described, and only 450 feet thick, 120 feet less than Walcott.

Maxey (1941) and Maxey and Williams (1941) described the Blacksmith as predominantly light- to dark-neutral gray, compact to medium-crystalline dolomite, which at High Creek, Utah, contains some limestone and is 710 feet thick. Williams (1948) mentioned the Blacksmith as dolomite, dolomitic limestone, and limestone, and indicated the Blacksmith is Albertan in age. Hanson (1949) reported 444 feet of Blacksmith occurring as thin- to thick-bedded oolitic limestone at Clarkston Mountain; he also noted some algal beds.

Keller (1952) described the Blacksmith within the study area. However, he had difficulty in locating the Ute-Blacksmith contact, and so mapped them together as the Ute-Blacksmith Formation. He described the Blacksmith as a cliff-forming unit which contains limestone and dolostone, and noted that the dolostone thins rapidly to the north. Coulter (1956, p. 12) briefly mentioned the Blacksmith in southeastern Idaho as 723 feet of "... cliff-forming, bluish-gray limestone with some oolitic and pisolitic beds near the middle" of the formation.

Maxey (1958) changed the location of his original (1941) Ute-Blacksmith contact at High Creek to exclude a thick basal limestone unit from the Blacksmith, and thus reduced the thickness there to 485 feet. Holmes (1958) in the northern Portneuf Range, reported 1018 feet of Blacksmith, and described the formation there as dolomite, dolomitic limestone, and limestone. Bright (1960, cited in Oriel and Armstrong, 1971) reported approximately 1200 feet of Blacksmith near Onieda Narrows, Idaho.

All the workers listed previously worked on the Blacksmith as part of local or regional mapping projects, most of which were outside the study area. Only Maxey (1941, 1958), Williams (1948), Keller (1952), Coulter (1956), Bright (1960), and Oriel and Armstrong (1971) have worked within the study area. This thesis is the first detailed report dealing only with the Blacksmith Formation in the area.

TERMINOLOGY

General Statement

According to Leighton and Pendexter (1962, p. 51) a carbonate rock is composed of at least 50 percent carbonate. A limestone has at least 90 percent of the carbonate as calcite, a dolomitic limestone has 50-90 percent of the carbonate as calcite, a calcareous dolostone has 50-10 percent of the carbonate as calcite, and a dolostone has 10-0 percent of the carbonate as calcite. A slight modification in terminology was made, in that dolostone is used for the rock name instead of dolomite. This compositional terminology, and Dunham's (1962, p. 117) classification of carbonate rocks according to depositional texture, were used throughout the study. Grain and crystal size range and average size are listed for most samples to avoid confusion.

Cryptalgal Structures

Cryptalgal structures were defined by Aitken (1967, p. 1163) as "... rock and rock structures believed to originate through the sediment-binding and/or carbonate-precipitating activities of non-skeletal algae." A cryptalgalaminated rock is "... a carbonate rock displaying more or less planar lamination believed to have resulted from the activities upon and within the sediment of successive mats or films of blue-green and green algae" (Aitken, 1967, p. 1164).

The term algal stromatolite is restricted to "... fixed bodies of cryptalgal origin characterized by non-planar lamination and possessing definable boundaries with other stromatolites" (Logan and others, 1964, in Aitken, 1967, p. 1163). Stromatolites have been classified according to their geometry by Logan and others (1964), and that classification was used when possible. Oncoliths are spherical or ellipsoidal, unattached algal stromatolites 2mm or greater in diameter (Friedman and Sanders, 1978, p. 567), which have internal structure of either continuous or discontinuous, or random laminae (Logan and others, 1964). Friedman and Sanders (1978, p. 568) stated "... a pisolith is a spherical or ellipsoidal, non-skeletal particle 2mm in diameter, with two or more concentric laminae" which may or may not be of algal origin (Bathurst, 1975).

Ooids

Much has been written about ooids (Eardley, 1938; Newell and others, 1959; and many others), but there is no uniform size classification present in the literature. Ooids are "...spherical or ellipsoidal particles, smaller than 2mm in diameter, typically composed of calcium carbonate, and having a central nucleus sponsored by a rim consisting of more than one layer, that displays concentric or radial fabric" (Friedman and Sanders, 1978, p. 567).

Birdseye Structures

Birdseye structures, or fenestral fabric, have been described from carbonate sediments by Logan (1974) and from carbonate rocks by Shinn (1968). Fenestrae are "... primary or penecontemporaneous gaps in rock framework, larger than grain-supported interstices. They may be open, partially or completely filled by secondarily introduced sediment or cement. The distinguishing characteristic of fenestrae is that the spaces have no apparent support in the framework of primary grains forming the sediment" (Tebbutt and others, 1965, p. 4).

Pellets and Peloids

According to Friedman and Sanders (1978, p. 568), a pellet is "a sand-size structurally homogeneous, spherical or ellipsoidal non-skeletal particle, consisting of non-digested residue, commonly calcium carbonate mud, secreted anally by deposit-feeding organisms." A pellet-grapestone is two or more pellets bound together. According to McKee and Gutshick (1969), a peloid is an allochem formed of cryptocrystalline or microcrystalline material, irrespective of size or origin (Bathurst, 1975, p. 567). In this study peloids are particles of cryptocrystalline or microcrystalline carbonate unidentifiable as pellets, ooids, oncoliths, or pisoliths.

Intraclasts

Intraclasts are non-skeletal particles broken or ripped from consolidated sediments accumulating within the basin of deposition (Friedman and Sanders, 1978).

Trace Fossils

Trace fossils are sedimentary structures resulting from biological activity (Seilacher, 1964, p. 296), and the classification of trace fossils according to behavior (Seilacher, 1953, cited in Frey, 1975) was used in this report (Fig. 3).

Bioturbation

Bioturbation is any disruption of bedding or lamination by organic activity, including trace fossils. Bioturbation lacks a distinctive geometry, and is caused by intensive reworking of the sediment, sometimes producing a burrowed-mottled texture (Anstey and Chase, 1974, p. 71). As used in this study, bioturbation resulted in lack of lamination, and burrowed sediment resulted in preservation of the laminae.

<table>
<tr><th colspan="5">TRACE FOSSILS</th></tr>
<tr><th rowspan="2">RESTING TRACE</th><th colspan="2">DWELLING TRACE</th><th colspan="2">LOCOMOTION TRACE</th></tr>
<tr><th></th><th colspan="2">FEEDING TRACE</th><th></th></tr>
<tr><td>RESTING TRACE</td><td>DWELLING STRUCTURE</td><td>FEEDING TRACE</td><td>GRAZING TRACE</td><td>CRAWLING TRACE</td></tr>
<tr><td>Cubichnia</td><td>Domichnia</td><td>Fodinichnia</td><td>Pascichnia</td><td>Repichnia</td></tr>
<tr><td><u>Asteriateites</u></td><td>U-tubes</td><td>spreite structures</td><td>packed structures</td><td>worm traces</td></tr>
</table>

FIG. 3.- Classification of trace fossils according to behavior (Seilacher, 1953, cited in Frey, 1975, p. 49).

ROCK TYPES, SEDIMENTARY STRUCTURES, AND NATURE OF CONTACTS

General Statement

Due to the lack of widespread marker units and consistent lithologic changes, the Blacksmith Formation was correlated throughout the study area on the basis of rock type. The Blacksmith Formation can be divided into 5 rock types in the study area. The rock types are consistent throughout the study area and recognizable at most sections measured.

Petrographic, insoluble residue, and x-ray data are given in Appendix A, detailed descriptions of measured sections are in Appendix B.

Rock Type A

Rock type A is characterized by more or less planar cryptalgalaminations. It may be a mudstone or boundstone, and has grains ranging from 0.25mm to 0.003mm(?) in diameter, and averaging 0.06mm. Rock type A may be limestone, dolomitic limestone, or dolostone in composition. There are mudcracks and rare birdseye structures; there are never ooids or bioturbation associated with this rock type (Fig. 4a and 4b).

Rock type A is typically nonresistant in outcrop, and forms low slopes with moderate exposures. It occurs as thin units, 3.3 to 6.1 meters thick, and comprises from 1.5 to 3.2 percent of a

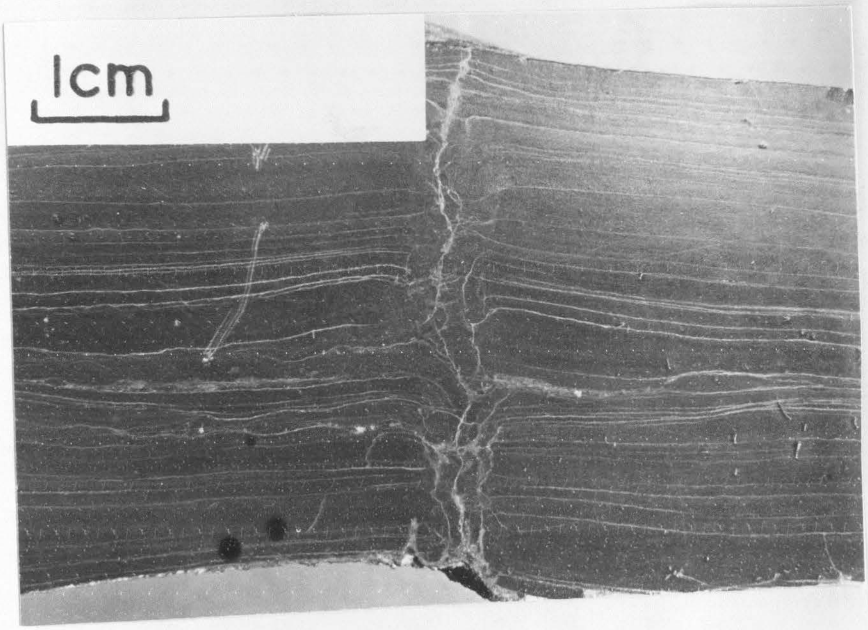


FIG. 4a.- Large-scale mudcracks in rock type A disrupt the cryptalgalminae.

FIG. 4b.- Small-scale mudcracks in rock type A do not disrupt the cryptalgalminae.

single stratigraphic section. Units are very-thinly bedded, averaging 3 cm.

Rock type A is typically dark gray, N3, on the fresh surface and medium dark gray, N4, on the weathered surface. This may be due to the high amount of organic matter present in many samples. Insoluble residues averaged 8.6 percent non-carbonate. The composition of the residue is quartz, microcline, and illite in all samples, kaolinite in 50 percent of the samples, and plagioclase in 17 percent of the samples.

Petrographic analysis showed most grains to be pellets and peloids, with some quartz. The quartz is equant to subequant, subrounded to rounded, averaging 0.12mm in diameter. Wavy laminae in thin section are alternately light and dark. The light laminae averaging 0.9mm thick, the dark 0.1mm. If dolomite is present, it is usually associated with the thinner, dark laminae.

Rock type A is found in the middle to upper portions of six sections (1, 2, 3, 4, 6, and 11), and is readily recognized in the field by its very-thin bedding, laminations, topographic expression, and dark color.

Rock Type B

Rock type B is found in the southeastern portion of the study area, at sections 4 and 5, and is by far the rarest rock type. It is calcareous dolostone or dolostone in composition and a packstone or crystalline dolostone texturally. The most conspicuous feature of this rock type is brecciation. Angular to subrounded intraclasts up to 10mm in diameter are common. Petrographic analysis showed most grains to be peloids which ranged in size from 1.3mm to 0.07mm, and averaged 0.7mm. Crystals ranged from 1.3mm to 0.03mm and averaged 0.5mm; they are anhedral to euhedral in shape.

The thin units, 4.0 to 4.6 meters thick, comprising 1.7 to 2.1 percent of the section, are non-resistant and form low slopes. There are never any ooids or bioturbation associated with this rock type. Bedding was obscured and difficult to measure due to dolomitization and subsequent brecciation, so that the bedding thickness of 22 cm may not be significant.

Rock type B is medium gray, N5, on the fresh surface, very light gray to medium light gray, N8 to N6, on weathered surfaces.

Insoluble residues averaged 3.4 percent, and consisted of quartz, microcline, and illite in all samples, and kaolinite, K-feldspar, and plagioclase in 50 percent of the samples.

Rock type B is recognized in the field by its brecciation and lack of resistance to weathering.

Rock Type C

Rock type C has birdseye structures (Fig. 5) and is locally associated with algal structures such as cryptalgal mats (Fig. 6), LLH-type stomatolites, small domes, and rare oncoliths. A distinguishing characteristic of this rock type is its low content of skeletal debris and the very high pellet and pellet-grapestone component. Ooids are present locally, although not common, and generally associated within algal structures.

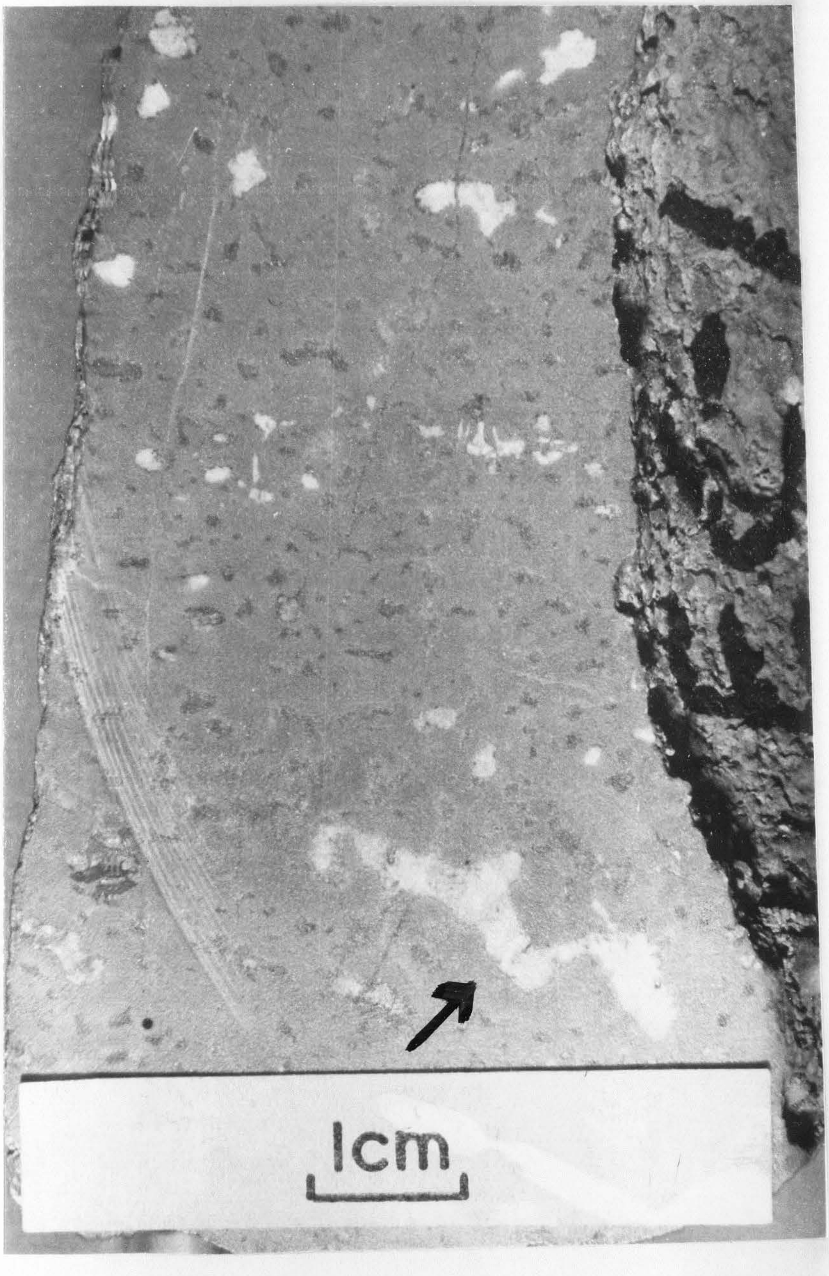


FIG. 5.— Birdseye structures filled with clear calcite and pseudomorphs of calcite after gypsum in rock type C.

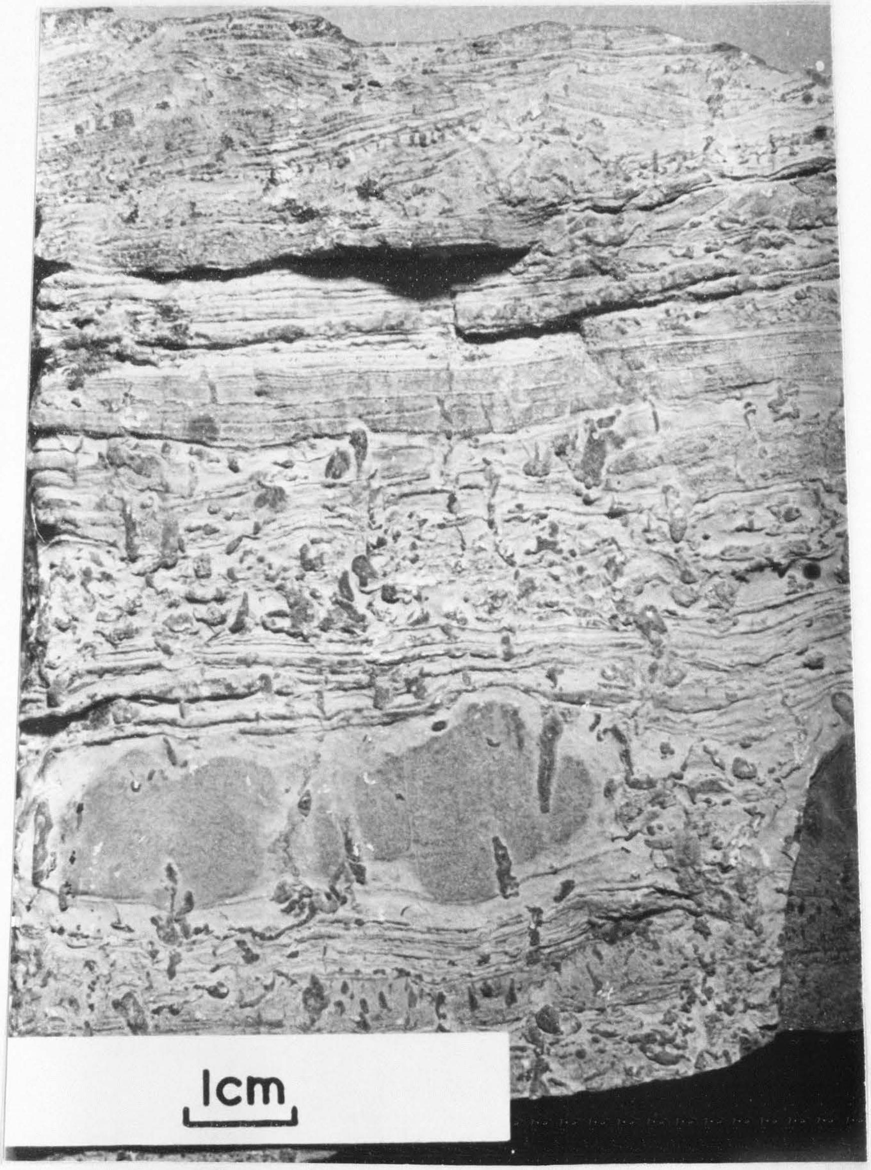


FIG. 6.- Cryptalgal mats and vertical burrows in rock type C.

Rock type C is ordinarily a packstone or wackestone and rarely a mudstone. It may be limestone, dolomitic limestone, or dolostone. The dolostones are concentrated in the southern and southeastern portion of the area. Rock type C is widespread stratigraphically, and is present in all sections except the Cub River section, section 2. The well-exposed outcrops may be cliffs, ledges, or steep slopes, which indicate resistance to weathering. The bedding is generally thick to very-thick, averaging 32 cm, but may be occasionally thin-bedded, about 8 cm. When algal structures are absent and birdseyes are sparse, the bedding appears massive. Rock type C is in units between 1.5 and 65 meters thick, and may comprise 16 to 52 percent of a stratigraphic section.

Variation of the fresh surfaces from light gray to grayish black, N7 to N2, is common. The weathered surfaces vary from very light gray to medium dark gray, N8 to N4. The darker samples at High Creek, section 1, give off an odor of H_2S when broken or crushed. Although there is typically little bioturbation associated with this rock type, vertical burrows are present locally (Fig. 6). Usually there is not much organic matter, but it may be present, especially in the darker samples.

Grains range from 17mm to 0.01mm, and average 0.3mm in size. The larger grains are intraclasts or a rare oncolith. The smaller grains are skeletal fragments (trilobite, brachiopod, or echinoderm fragments), ooids which have radial or concentric internal structure, or pellets and pellet-grapestones.

Insoluble residues averaged 4.7 percent non-carbonate. All samples contain quartz, 83 percent contain illite, 77 percent contain microcline, 46 percent contain kaolinite, 26 percent contain plagioclase, 11 percent contain albite or K-feldspar, 9 percent contain montmorillonite, and 3 percent contain ilmenite or chlorite. Pseudomorphs after evaporites are present in some samples. At High Creek a pseudomorph of calcite after halite(?) was present in sample HC-3, and at Emigration Canyon pseudomorphs of calcite after halite and gypsum were present in sample EC-1 (Fig. 5). The pseudomorphs are now pale-yellowish orange (10 YR 8/6) calcite, and are resistant protuberances on the weathered surface. Some of the halite pseudomorphs show "hopper crystal" form.

The birdseye structures are 8mm to 1mm long and are completely filled with clear calcite. In most cases the birdseyes show lamination described by Logan (1974, p. 215) as "fine laminoid type."

Rock type C is easily recognized in the field by its topographic expression, birdseye structures, and thick bedding.

Rock Type D

Rock type D is by far the most abundant rock type in the study area. It occurs in units from 3 to 66 meters thick, and may comprise 35 to 63 percent of a stratigraphic section at a single locality. Bedding is variable; it ranges from 6 cm to 30 cm, and averages 17 cm thick. Outcrops of this rock type generally form moderate to steep slopes; exposures are moderate to very good. Outcrops are present in all sections and at different locations within a stratigraphic section.

Typically dark gray to grayish black, N3 to N2, on the fresh surfaces and medium dark gray to medium gray, N4 to N5, on the weathered surfaces, in many cases the rocks are rich in organic matter, up to 0.5 percent by weight.

Rock type D may be a packstone, wackestone or mudstone in texture, and limestone, dolomitic limestone, or dolostone in composition. Grains range from 8mm to 0.01mm and average 0.3mm in size, and are bladed to equant and subrounded to rounded in shape. Grains include pellets, peloids, pisoliths, ooids, oncoliths, intraclasts, and skeletal fragments. Petrographic analysis indicated that 30 percent of the samples of rock type D have fossil fragments present. The fossil fragments occur in sections 2, 5, 6, 7, 8, 9, 10, and 11; sections 2 and 5 have fewer fossil fragments than the other sections.

The most characteristic feature of this rock type is the bioturbation usually associated with it, although the amount of bioturbation is not consistent. Extensively bioturbated rocks typically show color and texture mottling. The trace fossils collected are 3mm to 1mm in diameter, branched or unbranched, and are typically parallel to bedding (Fig. 7a and 7b).

Insoluble residues averaged 4.1 percent non-carbonate residue. The composition of the residue varies; 97 percent of the samples contain quartz and illite, 77 percent contain microcline, 40 percent contain kaolinite, 25 percent contain plagioclase, 20 percent contain K-feldspar, 17 percent contain pyrite, 14 percent contain albite, 5

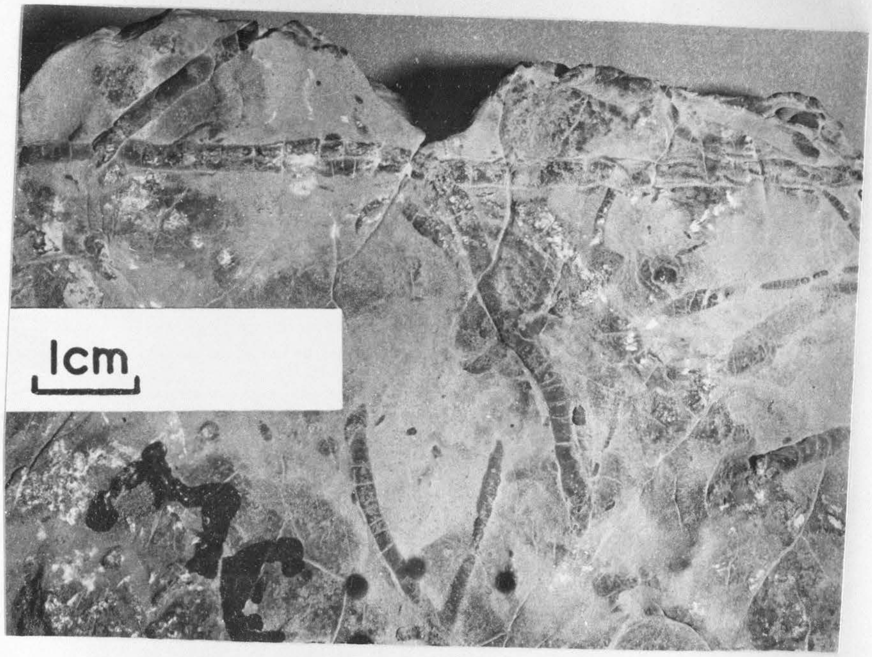


FIG. 7a.- Trace fossils on bedding plane in rock type D.

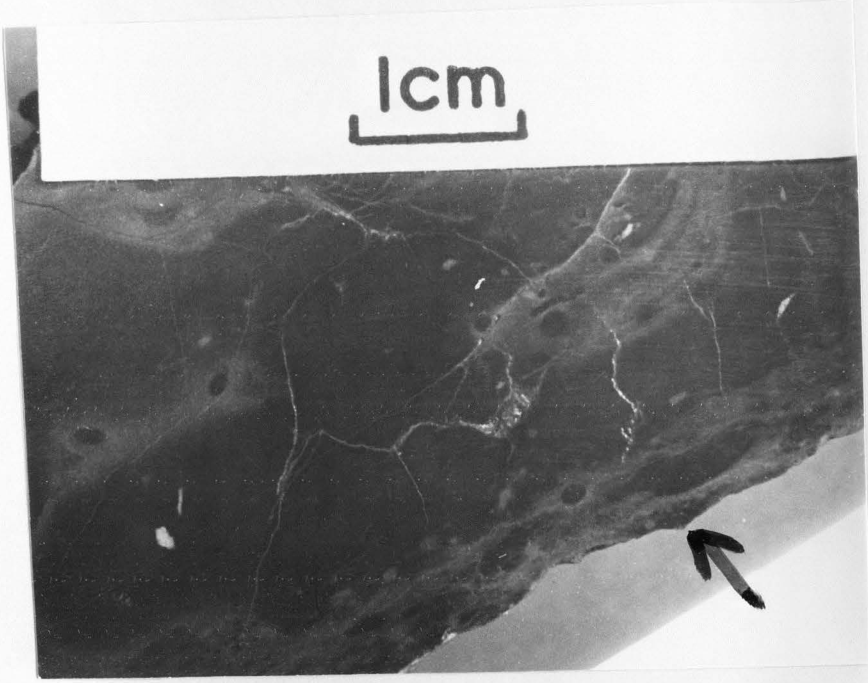


FIG. 7b.- Trace fossils , normal to bedding, in rock type D.

percent contain chlorite, 3 percent contain montmorillonite, and 1.5 percent contain limonite.

Rock type D is identified in the field by its dark color and the typical bioturbation associated with it.

Rock Type E

Rock type E is characteristically ooid-rich, and lacks bioturbation. Very often it has low-angle cross-stratification, which is generally the planar type (Krumbein and Sloss, 1963, p. 130). In cases where cross-bedding is not present, parallel laminations are present. Rock type E usually has little skeletal material, but there may be a skeletal component, and pisoliths are not uncommon.

Rock type E is either a grainstone or packstone, and may be limestone, dolomitic limestone, calcareous dolostone, or dolostone in composition. Outcrops are well exposed, and form steep slopes, ledges, or cliffs, depending upon the thickness of the unit. Units of this rock type range from 7 to 58 meters thick and comprise from 6.2 to 57 percent of each section. Bedding is thick to very thick, and ranges from 18 cm to 40 cm with the average being 25 cm. Interbedding with another rock type, often C, is not uncommon in the thick units. Rock type E is present at all sections in the study area.

Colors vary from medium dark gray to light gray, N4 to N7, on fresh surfaces and medium light gray to yellow gray, N6 to 5 Y 8/1, on weathered surfaces. Typically there is a low content of organic matter but 25 percent of the samples do contain some organic matter.

Grains range from 7mm to 0.05mm, and average 0.6mm in size. The grains are mostly ooids, together with minor amounts of oncoliths, pellets, pellet-grapestones, skeletal fragments, and intraclasts, and may be bladed to equant and subrounded to rounded in shape.

Insoluble residues averaged 2.3 percent non-carbonate residue. The composition of the residue varies; all of the samples contain quartz, 75 percent contain microcline and/or illite, 45 percent contain kaolinite, 25 percent contain pyrite, plagioclase, or albite, and there are traces of montmorillonite in a few samples.

Rock type E is recognized in the field by the great amount of ooids, the common cross-bedding, and its topographic expression.

Nature of Contacts

The Ute-Blacksmith Contact is placed where the bedding thickness changes from very-thin- or thin-bedded to thick- or very-thick bedding. The Ute-Blacksmith contact is conformable.

The Blacksmith-Bloomington contact is often a change from dolostone or limestone to shale or shaly limestone, and is easier to locate than the Ute-Blacksmith contact. There is no proven hiatus between the Blacksmith and the Hodges Shale Member of the Bloomington.

INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS

General Statement

In recent decades great advances have been made in the understanding of modern carbonate deposition by Newell and others (1959), Cloud (1962), Purdy (1963a, b), Shinn and others (1969), and many others. Classic interpretations of ancient carbonates by Matter (1967), Laporte (1967, 1969), and Lucia (1972) are the result of applying the knowledge gained from studying modern environments.

In warm, shallow, tropical waters, where carbonate production is greatest, life forms are abundant. Bathurst (1975, p. 139) noted that a great wealth of information is lost during lithification of carbonate sediments, mostly due to the dissolution of aragonite. Bathurst (1975, p. 138, 139) implied that much less information can be observed in ancient limestones which have been diagenetically altered. He also stated that the interpretation of diagenetically altered limestones produces "... immense difficulties, of which many are perhaps insurmountable," and adds "... the older the limestone, the more hazardous the comparisons must be."

Fortunately, not all information is lost, and environmental interpretations may be attempted, but one must be aware of the limitations of such interpretation. Studies of modern sediments and ancient rocks provide the basis for interpreting the environments in which the Blacksmith Formation was deposited.

Chemical Requirements of Carbonate Deposition

A discussion of carbonate deposition would be incomplete without considering the chemical conditions necessary for the production of calcium carbonates.

Krauskopf (1979, p. 64) stated that "... seawater is a concentrated and exceedingly complex solution, containing electrolytes in great variety plus an abundance of living and dead organic matter." Later he stated "... the chemistry of seawater can be described satisfactorily in general terms, but the details about the behavior of even so simple a substance as $CaCO_3$ remain obscure."

The deposition of $CaCO_3$ is controlled primarily by equilibrium in the reaction:

$$CaCO_{3\,(s)} + H_2CO_3 \rightleftarrows Ca^{+2} + 2\,HCO_3^- \qquad \text{(Krauskopf, 1979)}$$

However, this reaction is controlled by a number of other factors. Using available solubility data and equilibrium constants, the calculated solubility of calcite in water free of CO_2 at the temperature and pressure of surface waters is 1.3×10^{-4} M (13 mg/l), that of aragonite, 1.4×10^{-4} M (14 mg/l). Upon addition of CO_2 to the water, the solubility can reach hundreds of mg/l (Bathurst, 1975). Therefore one of the principal factors in the dissolution or precipitation of $CaCO_3$ in water is the presence or absence of CO_2 (Bathurst, 1975).

In cold water, CO_2 becomes more soluble and promotes dissolution of $CaCO_3$; this is evidenced by the very small amounts of $CaCO_3$ found below the carbonate compensation depth (Krauskopf, 1979). Krauskopf (1979, p. 65) indicated that precipitation and dissolution of $CaCO_3$ may occur in temperate regions when trapped seawater is warmed and cooled by daily fluctuations in temperature.

The $CaCO_3$ precipitated from seawater may occur either inorganically or by organisms, and is either aragonite or calcite, with the majority being aragonite. With time, either during or after diagenesis, the aragonite sediment inverts to calcite (Friedman, 1964; Krauskopf, 1979) or it may be replaced by dolomite (Gaines, 1980).

Inferred Environments of Deposition

Supratidal to Upper Intertidal.- Lucia (1972) described supratidal deposits as possessing irregular laminations, birdseye structures, mudcracks, LLH-stromatolites, and lithoclastic conglomerates.

Matter (1967) however, described mudcracks, LLH-stromatolites, birdseye structures, and lack of fossils as characteristics of the intertidal zone. Wilson (1975) indicated that intertidal deposits commonly contain birdseye structures, mudcracks, burrows, and trails. Logan (1974) has described birdseye structures in Holocene carbonate sediments in the intertidal zone, and he found the fine laminoid type restricted to the lower intertidal zone. Shinn (1968, p. 68) stated "... birdseye structures may occur in supratidal sediments, sometimes in intertidal, but never in subtidal sediments."

Rock type A has mudcracks, cryptalgalaminae, rare birdseye structures, lacks fossils and bioturbation, and is commonly dolomitized. The dolomite rhombs are found in the thin laminae (seen in thin section). Rock type A is inferred to have been deposited in the upper intertidal to lowest supratidal environmkent.

Wilson (1975) reported collapse breccias, which form by dissolution of evaporite minerals, from supratidal deposits. However, Tebbutt and others (1965) and Logan (1974) indicated evaporite minerals may be deposited within birdseye structures. This suggests that evaporite minerals may be deposited in the intertidal zone, assuming the birdseyes are intertidal. Rocks in the Blacksmith which may be collapse breccias have been classified as rock type B. Rock type B is inferred to have been deposited in the uppermost intertidal to lower supratidal environment.

Lower Intertidal.- Logan (1974) indicated that fine laminoid birdseye structures form in the intertidal environment, and suggested evaporites also may be precipitated in the intertidal zone.

Rock type C has fine laminoid birdseye structures, cryptalgal mats, LLH-stromatolites, pseudomorphs after evaporites, and rare vertical burrows. Rock type C is inferred to have been deposited in the intertidal environment, and, based on the fine laminoid birdseye structures, lower intertidal.

Subtidal.- Rocks possessing characteristics of the marine subtidal have been described by Laport (1967), and many others, as fossiliferous pellet mudstones with bioturbation. Lucia (1972) also noted bioturbated, churned and burrowed rocks as being subtidal. Heckel (1972) described traces, similar to those in the Blacksmith, in the shallow subtidal environments, both above and below wave base.

Agitated shoal.- Bathurst (1975) indicated that supersaturation with respect to calcium carbonate, constant agitation, and available nuclei are prerequisites for the production of ooids.

Wilson (1975) described facies belt six as well-oxygenated, but not hospitable to marine life due to a shifting substrate. These rocks may have grains which are mostly ooids, although coated and/or micritized grains which may be skeletal in origin may be present. Wilson (1975) indicated that oncoliths may be present in addition to ooids, and that cross-stratification may be present. Wilson (1975) interpreted this facies as an unrestricted shoal in agitated water. Tidal shoals represent optimum conditions for the formation of ooids, with very shallow water being constantly agitated as a result of tidal and wind currents (Multer, 1977).

Experimental work by Simons and others (1965, p. 36) indicated that planar cross-stratification occurs in the upper portion of the lower flow regime, and that parallel lamination occurs in the lower portion of the upper flow regime. Cross-stratified deposits, and parallel laminated deposits associated with cross-stratified deposits, are inferred to have been deposited in the flow regimes stated above.

Quiet-water shoal.- Environments in Wilson's (1975, p. 25) facies belt seven, open-platform and restricted-marine shoals, are described as "... environments located in straits, open lagoons and bays behind the platform edge with water depth a few meters at most and moderate circulation." Rocks of facies belt seven may be grainstones to mudstones, and Wilson (1975) suggested that fossil fragments may be abundant and bioturbation is common in open-platform environments. He indicated that restricted shoals, which contain peloids, small intraclasts, and fossil fragments together with ooids, and which may be packstones, can form at the edge of this belt. In addition to the unrestricted platform and restricted shoals, restricted shelf-lagoon environments with bioturbated peloid- and pellet-lime mudstones, wackestones and occasional packstone can occur within this facies belt (Wilson, 1975).

Wilson (1975) interpreted sediments within this belt as being deposited in shallow water of relatively low energy, at or below wave base and below mean low tide.

Rock type E of the Blacksmith Formation lacks bioturbation, and is very ooid-rich, often with low angle cross-stratification or planar laminations, and usually little skeletal material. Rock type E is inferred to have been deposited in the environments of facies belt six, the agitated shoal, and in the restricted shoal environment on the edge of facies belt seven. However, some rocks classified as type E may, in some cases, have been deposited in tidal channels. Klein (1965) described similar carbonate channel deposits as being cross-stratified, and containing skeletal fragments in addition to ooids. Jindrich (1969) noted that the source of sediment lies along the entire channel, and sediment mixing is prevalent. He also noted that the proportion of skeletal and rock fragments increases as the channel mouth is approached. Multer (1977, p. 139) in a discussion of tidal channels, stated that "... ancient analogs of similar situations would certainly make proper environmental interpretations challenging."

Lagoon, open-platform.- Wilson (1975) described facies belt eight as containing restricted platform lagoons, cut-off ponds, and the whole tidal flat environment. He stated that "... conditions are extremely variable and is considered a stress environment for organisms. Fresh, marine, and hypersaline water occur as well as subaerial exposure." Laminated to bioturbated pellet-lime mudstones and wackestones dominate, as well as micrite with oncoliths. The fauna represents very restricted conditions.

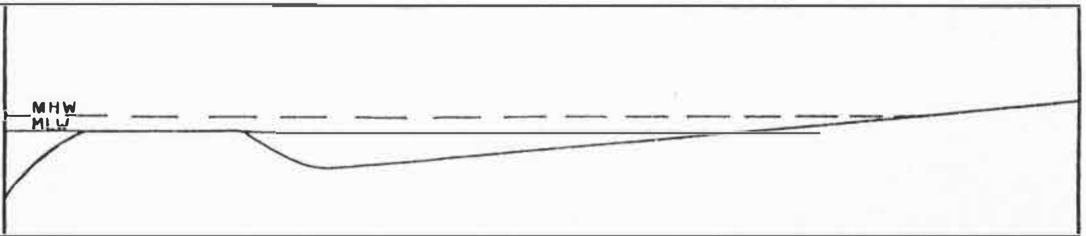
Rocks containing oncoliths, micrite, skeletal fragments, bioturbation, and typically dark color have been classified as rock type D, and are inferred to have been deposited subtidally in the environments of facies belt seven, i.e. open-marine platform, restricted marine shelf lagoons, and cut-off ponds, which grade into the environments of facies belt eight.

Deposits found on open-platform with unrestricted circulation characteristically have a wide diversity of fossil fragments and bioturbation, which may be extensive, that serve to identify the environment. Such rocks may contain trilobite, echinoderm, and/or brachiopod fragments, and sponge spicules.

Trace fossils in rock type D are grazing traces (pascinhnia) and/or traces produced by locomotion (repichnia); see Figure 3. The traces were probably produced by a worm, of unknown identity, and, as Seilacher (1967) indicated, either trace can result from the activity of organisms at or near the sediment-water interface. Traces of these types have been reported from shallow to intermediate subtidal environments in modern sediments (Seilacher, 1967, p. 418) and in ancient rocks (Howard, 1972, p. 216).

Deposits formed in the restricted shelf-lagoon environment are characterized by some bioturbation, and paucity of fauna. Occasionally reducing conditions prevail in such an environment, resulting in rocks which are rich in organic matter, are dark in color and which lack the skeletal fragments characteristic of unrestricted conditions. See Figure 8 for a summary of the characteristics of environments, and Figures 9, 10, 11, and 12 for the distribution of environments in the study area.

Diagrammatic Cross-Section



Facies	SHOAL		OPEN PLATFORM	RESTRICTED PLATFORM	INTERTIDAL		SUPRA-TIDAL
	Agitated	Restricted			Lower	Upper	
Rock Type	E	E	D	D	C	A	B
Color	N6-N7	N4-N7	N2-N5	N2-N5	N2-N8	N3-N4	N5-N6
Grain Type	Ooids	Ooids, peloids, skeletal fragments	Pellets, peloids, ooids, pisoliths, and a diversity of skeletal frags.	Pellets, peloids, ooids, pisoliths, Intraclasts, oncoliths, and few skeletal frags.	Pellets, intraclasts, pellet-grapestones, and skeletal fragments.	Pellets, peloids, quartz	Peloids
Depositional Texture	Grainstone	Grainstone or packstone	Packstone, wackestone, or mudstone	Packstone, wackestone, or mudstone	Packstone or mudstone	Mudstone or boundstone	Packstone
Sedimentary Structures	Cross- and parallel stratification	Cross-stratification	Bioturbation		Birdseyes, vertical burrows, and crypt algalaminae	Planar cryptalgalaminae, rare birdseyes	Brecciation
Average Insoluble Residue	2.3%		4.1%		4.7%	8.6%	3.4%

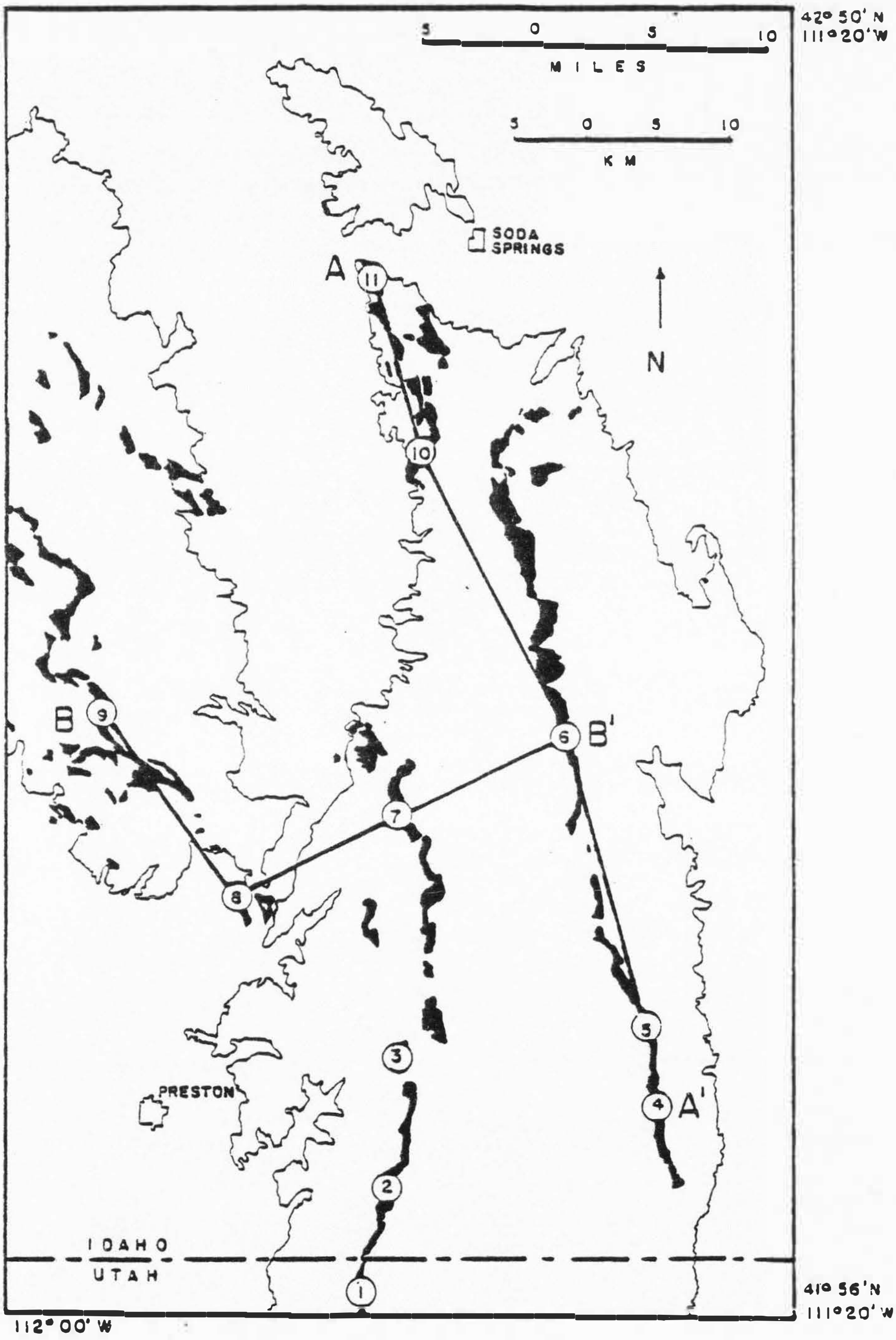


FIG. 9.- Locations of geologic sections.

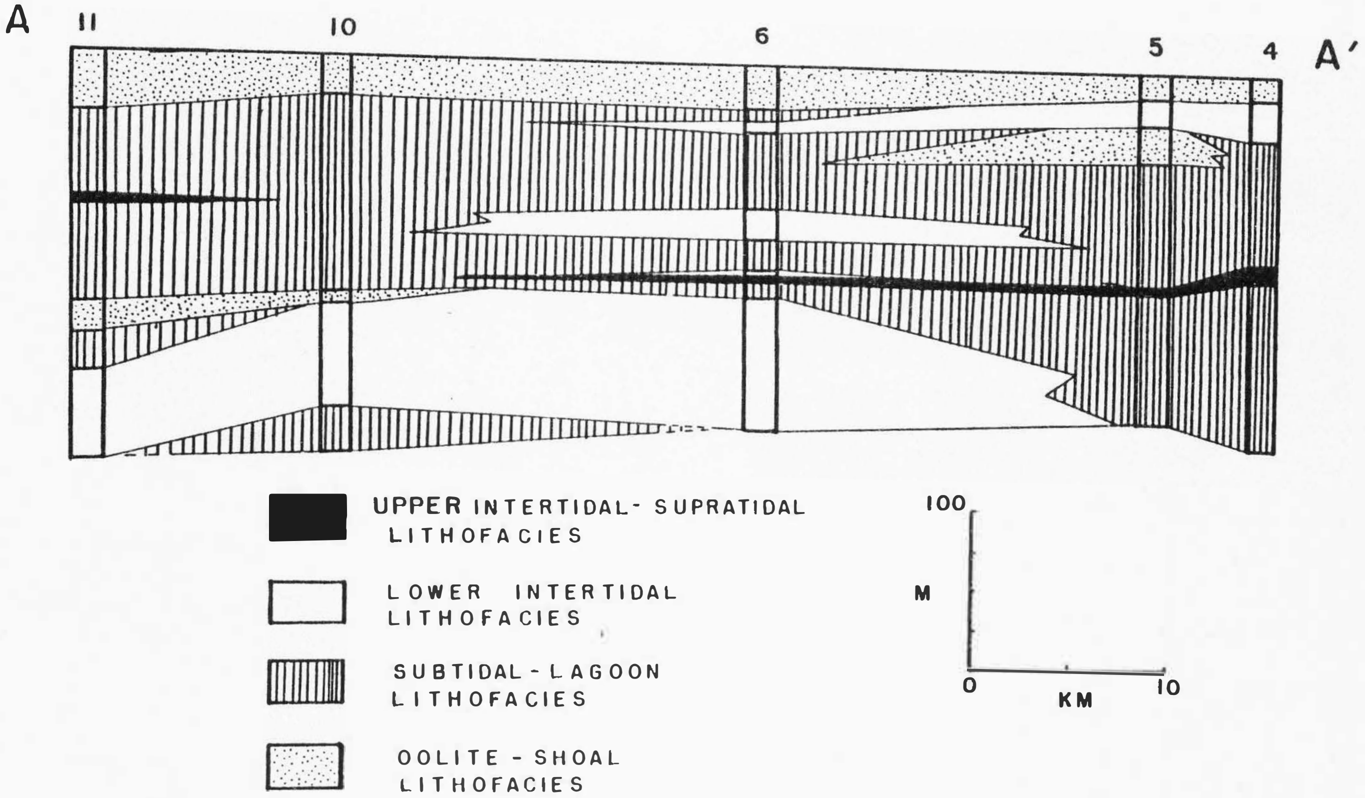


FIG. 10.- North-south geologic section of the inferred depositional environments of the Blacksmith Formation. Numbers indicate measured sections.

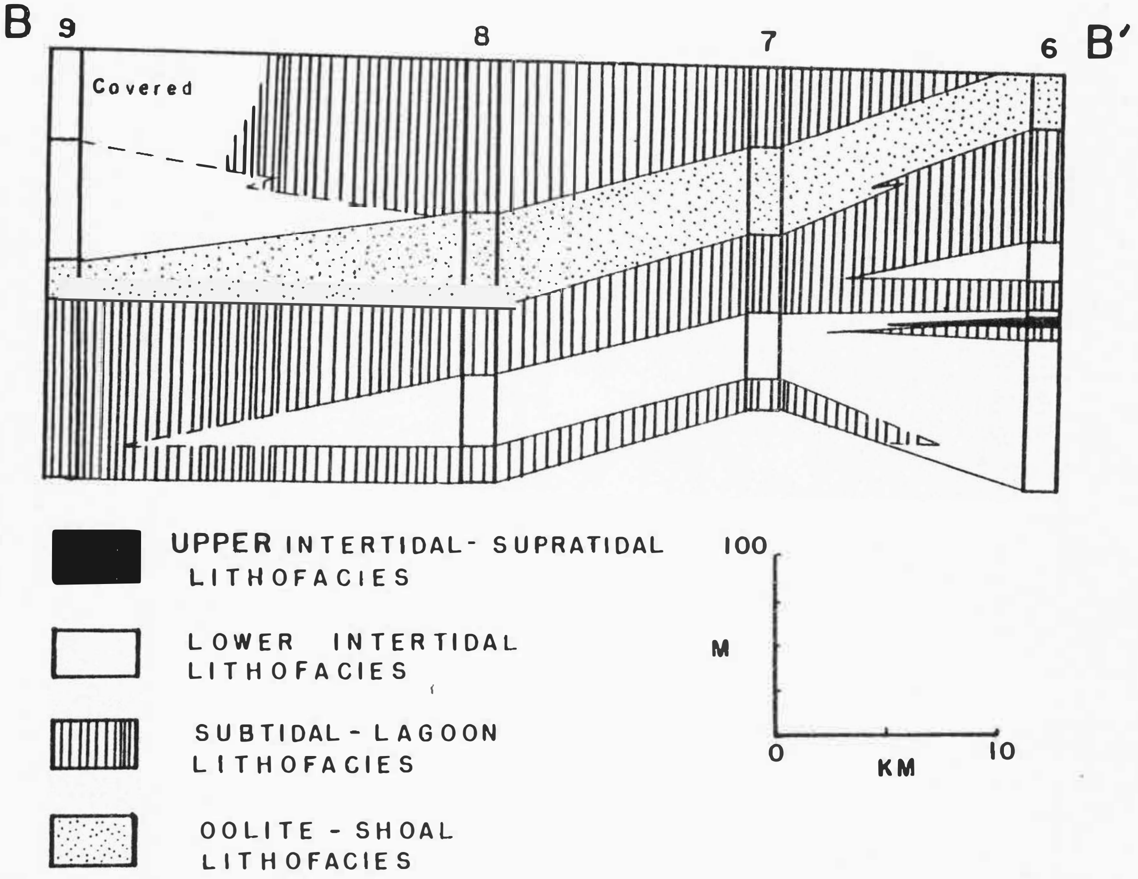


FIG. 11.- East-west geologic section of the inferred depositional environments of the Blacksmith Formation. Numbers indicate measured sections.

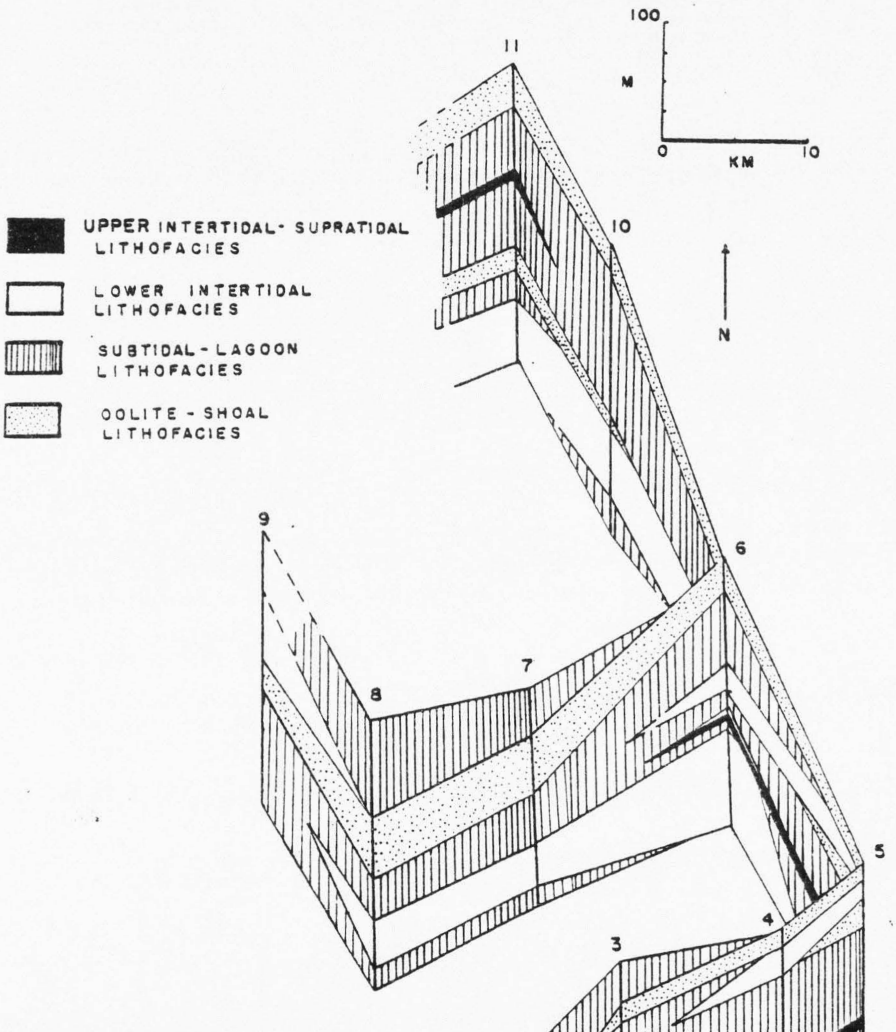


FIG. 12.- Fence diagram of the Blacksmith Formation southeastern Idaho and northernmost Utah. Numbers indicate measured sections.

PALEOGEOGRAPHIC RECONSTRUCTION

Seyfert and Sirkin (1979, p. 251, 252) indicated that during Albertan time the study area was located approximately 10° south of the equator. However, Ziegler and others (1979) and Scotese and others (1979) placed the study area approximately 10° north of the equator, and also suggested that the region adjacent to the study area had little relief. These results place the study area in the tropics during Middle Cambrian time, although there is some question as to whether it was north or south of the equator.

Carroll (1970), Griffin (1962), and Keller (1956) suggested that general paleoclimatic conditions may be inferred from the type of clay minerals present. Grim (1968) indicated that illite is invariably present in marine sediments, and is particularly abundant in calcareous sediments. Carroll (1970) indicated that kaolinite is a product of more intense chemical weathering, and is more abundant in humid tropical regions, whereas montmorillonite is produced in areas of less chemical weathering and is more abundant in arid and semi-arid regions.

The clays present in the insoluble residues of the Blacksmith Formatin vary; illite is present in 97 percent of the samples, kaolinite in 50 percent, montmorillonite in 5 percent, and chlorite in 3 percent. If paleoclimatic conditions may be generally inferred from the clay mineralogy, then the study area had a relatively humid, tropical climate throughout the deposition of the Blacksmith. Grim

(1968) indicated that montmorillonite alters to chlorite when deposited in the marine environment; it is possible that the chlorite present in the insoluble residues was originally montmorillonite. The small amount of montmorillonite present is not restricted to a particular facies or to a certain time interval, and may be windblown in origin.

The slope of the broad platform on which the Blacksmith was deposited was gentle, between 0.1 and 1.0 feet per mile, and probably was similar to the slope of the Bahamas Platform, 0.52 feet per mile (Irwin, 1965). Tidal amplitude was probably low, as suggested by the small algal domes, LLH-stromatolites, and cryptalgal mats.

Water depth varied throughout the study area at any given time due to seasonal fluctuations and the topography of the sea floor. Presence of deposits formed in unrestricted platforms and lagoons in the northern portion and deposits characteristic of more restricted conditions to the south suggest that water depth increased to the north.

Early in Blacksmith time, deposits of lagoons and the open-platform were widespread, and intertidal deposits were sparse and scattered. It is inferred that a rise in sea level brought oolite shoals into the area from the west. A later regression caused the shoals to shift back to the western portion of the area. A second transgression caused the choals to migrate to the eastern portion of the area. The migration of the shoals farther toward the craton suggests that the second transgression lapped farther onto the craton than the first. There is also some evidence for the beginning of another regression.

Subsidence was not the same at all locations in the area. The isopachous map (Fig. 13) indicates that subsidence was greater to the north, west, and east of a north-trending "peninsula" of lesser subsidence. It is doubtful that the "peninsula" shed sediment into the surrounding area, although it indirectly may have influenced sedimentation.

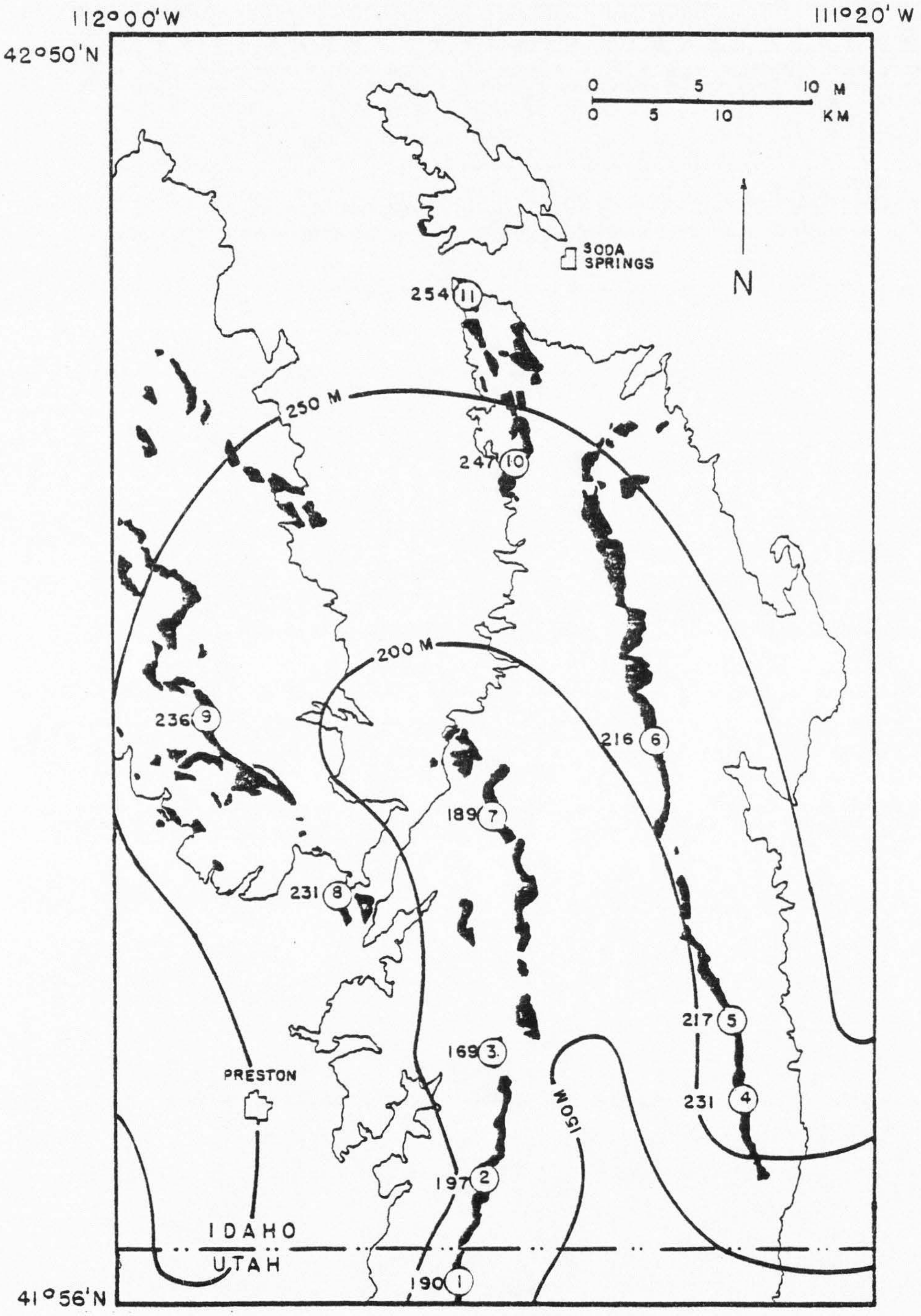


FIG. 13.- Isopachous map of the Blacksmith Formation, southeastern Idaho and northernmost Utah. Contour interval 50 meters.

DIAGENESIS

General Statement

Diagenesis of carbonate sediments encompasses primarily compaction, micritization, cementation, all phases of neomorphism including recrystallization, and dolomitization. The first four events will be discussed in this section and dolomitization in the following section.

Early Diagenesis

Compaction.- Evidence for the compaction of carbonate sediments is often scant (Shinn and others, 1977); the absence of crushed or broken fossils is not necessarily evidence against compaction of fine-grained carbonate sediments (Shinn and others, 1977). However, burrows and trails may be deformed and oolitic grainstones may show evidence of broken or spalled grains (Coogan, 1970).

It is inferred that there was little compaction before cementation in the shallow subtidal and intertidal deposits of the Blacksmith Formation. Evidence indicating lack of compaction is as follows: undeformed burrows and trails, undeformed cavities floored with micrite and roofed with calcite spar, most grains unbroken since deposition, and early cement forming fibrous rims. A few ooid-bearing rocks do contain some deformed ooids adjacent to undeformed ooids and, as Carozzi (1961) suggested, deformation may have occurred during formation. Some open-platform and lagoon deposits show orientation of fossil fragments parallel to bedding and deformation of some grains, suggestive of some compaction. Therefore compaction cannot be ruled out entirely, and there may have indeed been some compaction before cementation. The amound of compaction is probably insignificant in intertidal and shallow subtidal sediments, but may possibly be significant in the deeper subtidal deposits.

Micritization.- Micritization is evident in some rocks with development of micrite envelopes, and in a few cases total micritization. Since the earliest cement has formed on the micritized grains, the micritization occurred before cementation.

Cementation.- Marine cementation typically forms a rim of fibrous aragonite or high-Mg calcite with the c-axes oriented normal to the surface of the grain (Bathurst, 1975; Scholle, 1978). The fibrous or bladed habit of the cement is due to the poisoning of side growth sites by Mg^{+2} ions present in seawater (Folk, 1974).

Fresh water percolating through the sediments often forms a cement at grain-to-grain contacts. The cement developed is commonly of the meniscus type (Dunham, 1971), and is often blocky in habit due to the lack of Mg^{+2} ions in the fresh water (Folk, 1974).

The early cement formed in many of the Blacksmith rocks is a fibrous rim cement, which was probably aragonite or high-Mg calcite with the c-axes oriented normal to the grain surfaces. The mudstones and boundstones do not show rim cementation, but are inferred to have been cemented early due to the lack of compaction features. Because there is no evidence for prolonged subaerial exposure of fresh-water cementation, the early cement is inferred to have formed in the shallow subtidal or intertidal environment.

Open-platform and lagoon deposits, which may have undergone compaction, sometimes show syntaxial overgrowths on echinoderm fragments, but in most cases the stages of cementation have been obliterated by aggrading neomorphism, and now the grains float within a large single crystal. Therefore, timing of the cementation relative to compaction often cannot be determined.

In some rocks the cement exhibits a drusy mosaic texture, becoming coarser toward the center of the void and completely filling it. This is the case with the birdseye structures found in the present study, and similar fillings of birdseyes by early cement have been reported by Logan (1974) in recent sediments. In other cases cementation was interrupted by dolomitization and authigenic quartz formation. It is inferred that dolomitization took place before or during lithification. In some cases dolomitization was interrupted by precipitation of silica as euhedral quartz, or in some cases chert, possibly replacing evaporites (Friedman and Shukla, 1980; Folk and Pittman, 1971). The replacement of evaporite minerals by calcite has also occurred, and is inferred to have taken place after the sediment was removed from the marine environment, during burial, in silica-poor sediments.

Syntaxial overgrowths.- Syntaxial overgrowths may form early on echinoderm fragments (Evamy and Shearman, 1969). It was difficult to determine if the syntaxial overgrowths on the echinoderm fragments formed before or during the formation of the early cement.

Pyrite.- As burial continued, the Eh decreased from a positive value at the sediment-water interface to a negativ value below the interface. Pyrite can form in the absence of free oxygen (negative Eh), and is inferred to have formed below the sediment-water interface. Other evidence of reducing conditions is the preservation of organic matter in many samples.

Late Diagenesis

One of the main late-diagenetic events is aggrading neomorphism by low-Mg calcite. This process may result in grains floating within a large crystal of neomorphic spar that completely destroys any traces of previous cementation. This situation is evidence of more than a single stage of neomorphism (Friedman, 1964).

Almost all of the rocks of the Blacksmith contain stylolites which formed after lithification. The stylolites range from macroscopic, 4mm thick, to microscopic, and are oriented parallel to bedding. These stylolites are inferred to be the result of pressure-solution, with insoluble material being concentrated along the grooved surface (Bathurst, 1975).

In many cases stylolitization is the final event. However, dedolomitization, i.e., calcite replacing dolomite, was observed in some thin sections. It was impossible to determine when the dedolomitization began. It may have begun after uplift and exposure to fresh water (Evamy, 1967).

Upon uplift and exposure to the fresh-water environment, hematite and limonite formed. It may be that a ferroan dolomite formed in the subsurface under reducing conditions, and, upon uplift and oxidation, the iron oxidized, forming hematite zones in the dolomite rhombs (Katz, 1971).

In a few rare situations fracturing, and calcite infilling of the fractures, may be the final event.

DOLOMITIZATION

General Statement

Many models for dolomitization exist, because dolomite is believed to form under a variety of conditions (Friedman, 1980). For the great volumes of dolomite present in the rock record, replacement is more probably the method of formation, rather than primary precipitation.

Friedman (1980, p. 69) stated that "... dolomite is an evaporite mineral," so therefore it forms in a hypersaline environment. Invoking a hypersaline model requires intense evaporation to create a fluid with a salinity greater than seawater. This brine would have a high Mg/Ca ratio and larger amounts of other elements found in seawater, e.g., sodium. The high Mg/Ca ratio, approximately 10:1, allows Mg to replace 50 percent of the Ca in the $CaCO_3$ lattice to form dolomite. The hypersaline brine percolates downward due to the density difference and laterally due to the hydrostatic head produced. The dolomite formed under hypersaline conditions is often cloudy (Folk and Land, 1975).

Badiozamani (1973) and Folk and Land (1975) advocated a schizohaline environment, wherein seawater and fresh water mix, for the formation of dolomite. The "Dorag" model (Badiozamani, 1973) requires a low Mg/Ca ratio, approximately 1:1, for the replacement of Mg for Ca in the lattice. This model was applied to a Middle Ordovician formation which lacked evaporites, algal mats, mudcracks, and other evidence of restricted conditions. The "Dorag" model has been related to regressions and transgressions, structural highs, and the paleo-groundwater table (Badiozamani, 1973). The dolomite formed in schizohaline environments is often clear and limpid (Folk and Land, 1975).

The evidence found in the Blacksmith Formation suggests that a hypersaline fluid, together with partial facies control of the distribution of the fluid, is responsible for the dolomitization.

Synsedimentary Dolomitization

Friedman (1980) and Muir and others (1980) suggested that the lack of evaporite minerals in ancient rocks may be due to seasonal flushing, or lack of preservation, and not to the fact that the evaporites were not precipitated. Evidence for vanished evaporites may be pseudomorphs after the evaporites (Lucia, 1972), authigenic quartz (Friedman and Shukla, 1980) and microcline (Friedman and Radke, 1979), and length-slow chalcedony (Folk and Pittman, 1971).

The evidence which suggests dolomitization of the Blacksmith by a hypersaline brine consists of pseudomorphs after evaporite minerals (Fig. 5), authigenic quartz prisms, desiccation features (Figs. 4a and 4b), and many of the dolomite rhombs are cloudy. The minor amount of chert present is of the pinpoint type, and length-slow or length-fast determination could not be performed.

Land and Hoops (1973) and Veizer and others (1977) suggested that sodium content may be an indicator of a diagenetic fluid's salinity.

Preliminary chemical analyses of a few limestones and dolostones (from High Creek) for sodium content were done. Results indicate that the dolostones have a greater sodium content than the limestones, which suggests hypersalinity. Further chemical analyses must be done in order to validate the hypothesis.

The distribution of the dolomite in the Blacksmith Formation may in part be facies controlled. The association of some of the dolomite with the oolite-shoal environment (Figs. 14-17) suggests that the dolomitizing brine might have been able to percolate easily through the more permeable sediments, dolomitizing them along the way.

Dolomitization Model

The model for dolomitization of the Blacksmith Formation invokes dolomitization in the shallow subsurface by a hypersaline brine with a high Mg:Ca ratio. The brine could be developed by evaporation and gypsum precipitation, suggested by calcite and quartz pseudomorphs. The seepage reflux model originally proposed by Adams and Rhodes (1960), with slight modification by Deffeyes and others (1965), offers an acceptable mechanism for moving the brine through the sediments. Development of the brine may have occurred on the tidal flat and, because brine is denser than seawater, it would soak into the sediments beneath until it reached a permeable horizon, e.g., ooid-rich sediments. the brine should then travel laterally through the permeable sediment due to hydrostatic head. The brine may have also travelled along the floor of the lagoon to dolomitize some of the lagoonal sediments via refluxion (Fig. 18). This model requires extensive tidal flats

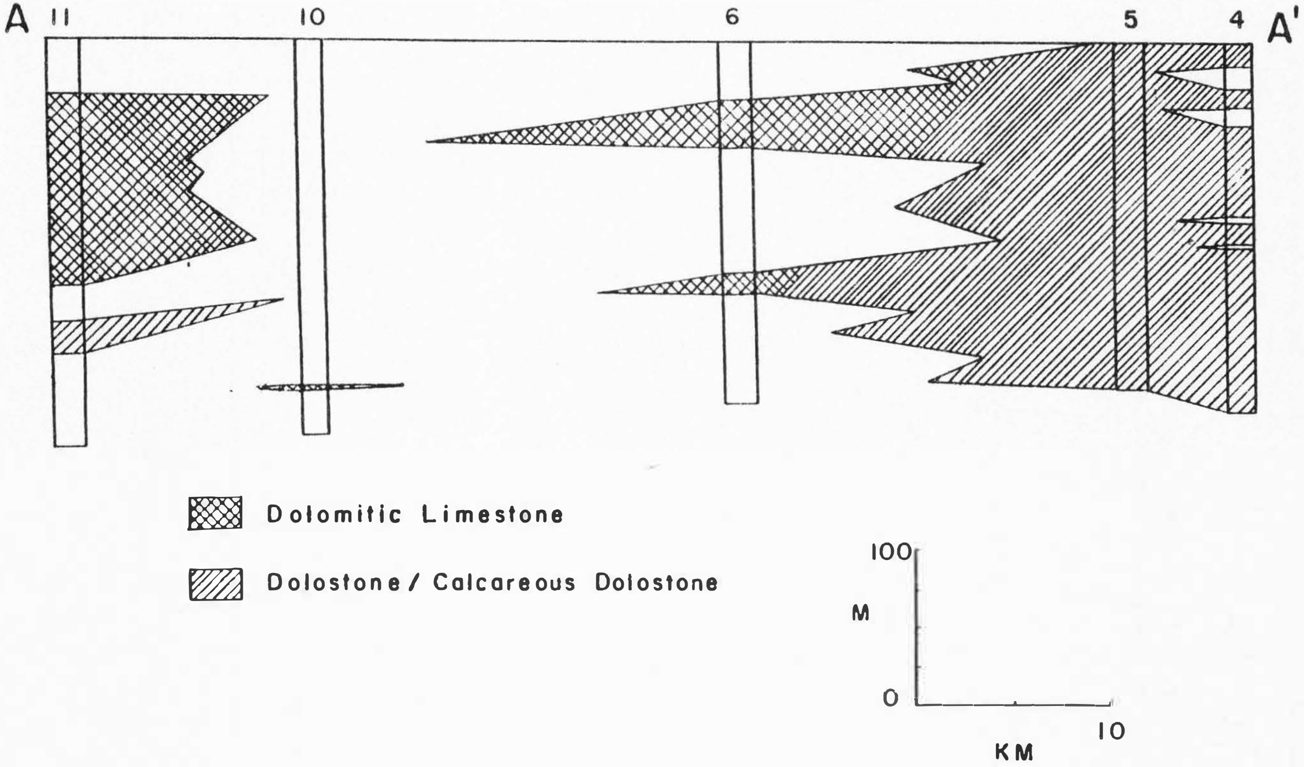


FIG. 14.- North-south geologic section showing the distribution of dolomitized deposits. Numbers indicate measured sections.

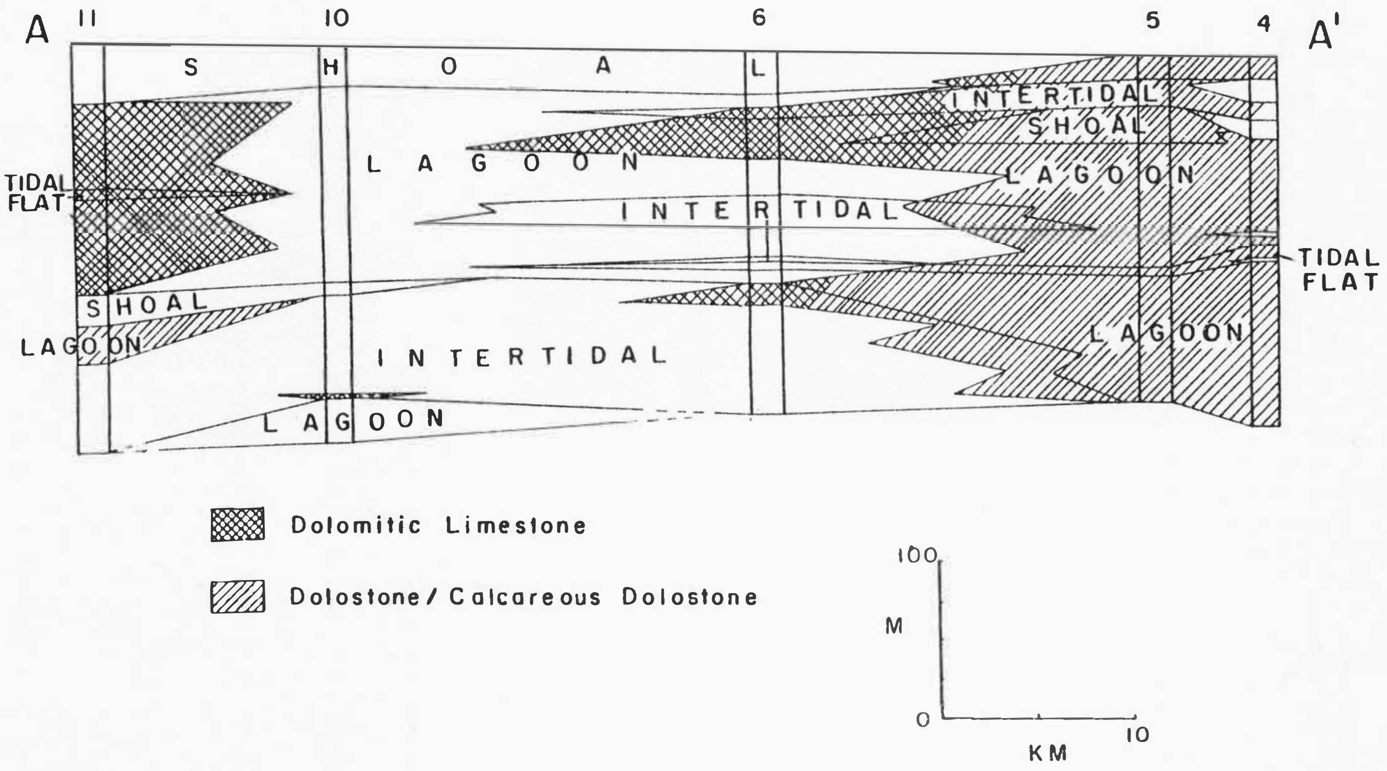


FIG. 15.- North-south geologic section showing the distribution of dolomitized deposits and of lithofacies. Numbers indicate measured sections.

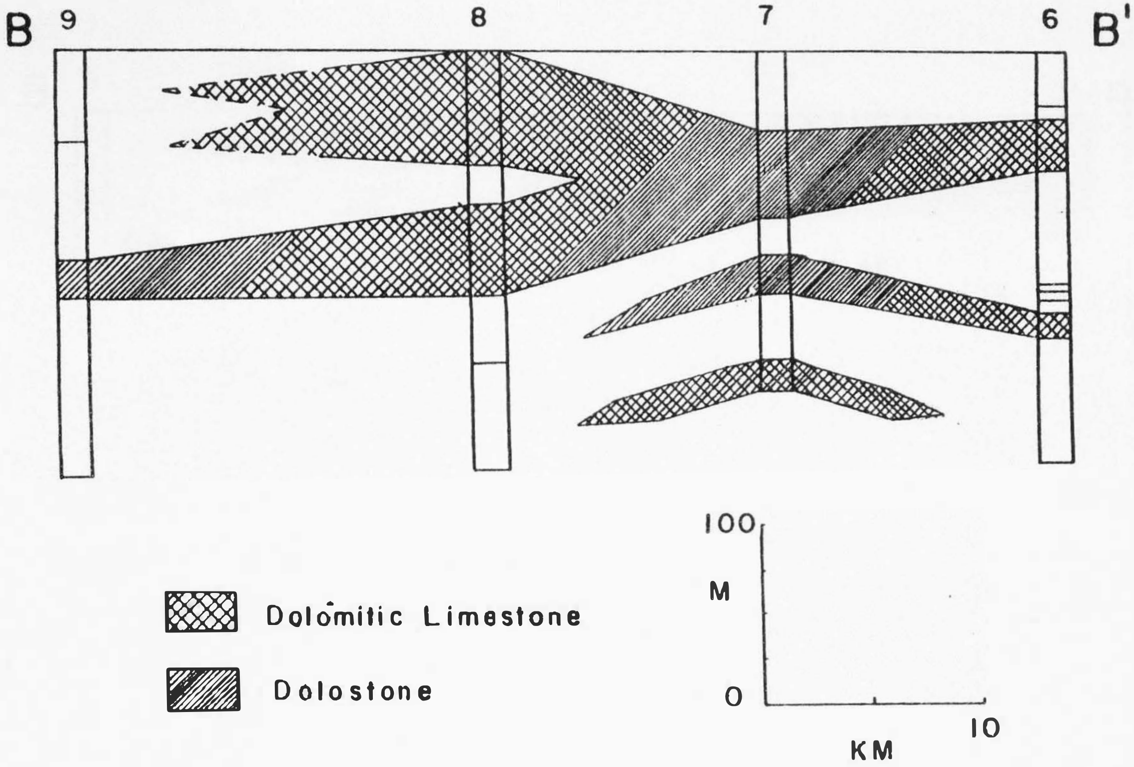


FIG. 16.- East-west geologic section showing the distribution of dolomitized deposits. Numbers indicate measured sections.

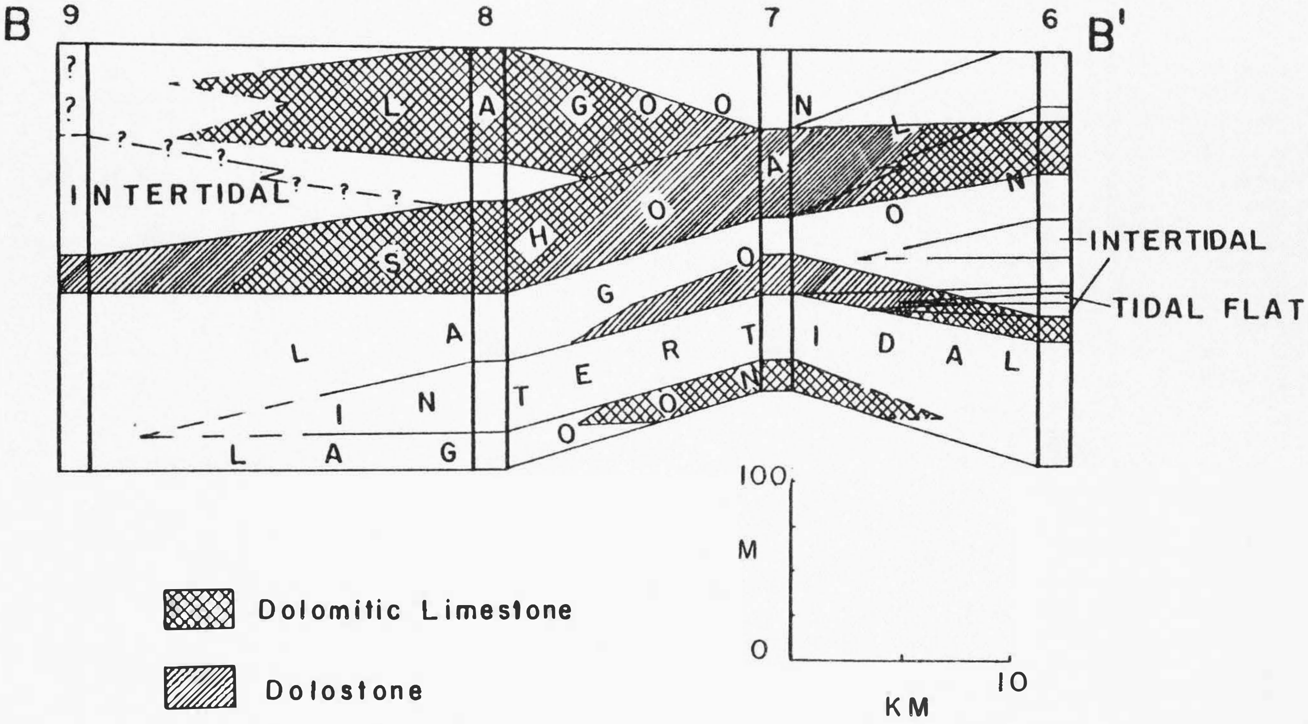


FIG. 17.- East-west geologic section showing the distribution of dolomitized deposits and of lithofacies. Numbers indicate measured sections.

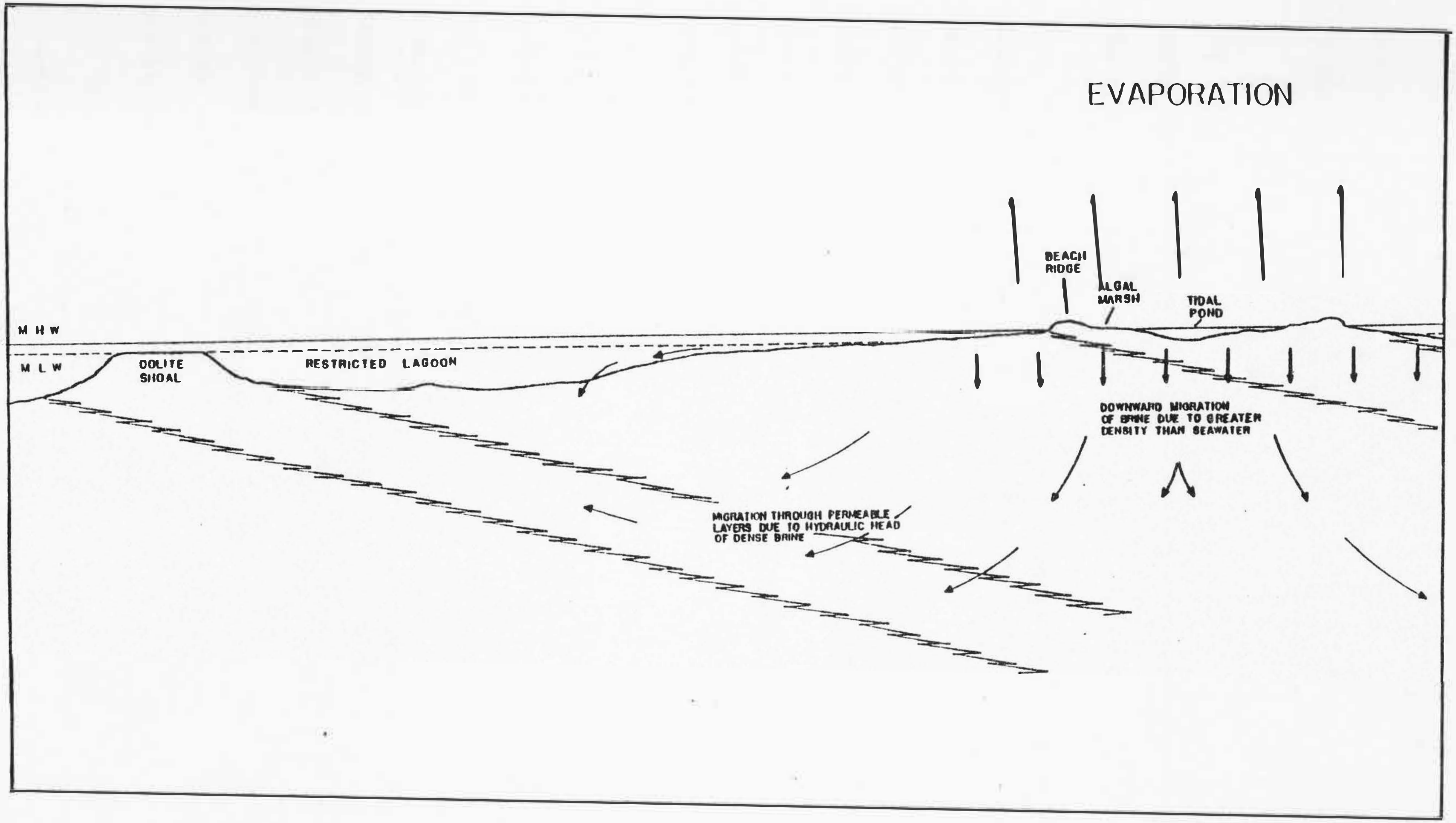


FIG. 18.- Simplified model of dolomitization by seepage reflux with both density gradient and minor refluxion. (After Deffeyes and others, 1965, and Adams and Rhodes, 1960)

for production of the brine. Hay (1981, in prep.) has found evidence of extensive tidal flats to the south of the study area.

The amount of dolomite decreases to the north and northwest in the study area. This is what would be expected if the dolomitizing fluid developed in the south, i.e., less dolomitization farther from the source of the brine (Fig. 19).

Some of the dolomite rhombs exhibit zoning and have hematite inclusions separating the zones. Katz (1971) described this type of zoning as an early diagenetic event occurring in the shallow subsurface. He indicated that ferroan dolomite zones are produced under reducing conditions coincident with a reduction in the Mg/Ca ratio. The iron may have been concentrated by organisms under reducing conditions and incorporated into the dolomite. Later, under oxidizing conditions, hematite was formed.

More than a single stage of dolomitization is evident in some of the rocks in the southeastern portion of the study area. Coarse dolomite rhombs with curved crystal faces and undulose extinction have been described by Choquette (1971) as a late diagenetic feature. Some rocks have a matrix of very fine grained dolomite rhombs (stage 1) and coarse rhombs with curved crystal faces and sweeping undulose extinction (stage 2). The first stage occurred early when the other sediments were being dolomitized, and the second much later. The mechanism which produced the very late dolomite could not be determined.

In a few cases cryptalgalaminated rocks are incompletely dolomitized. Dolomite rhombs are concentrated in the thin, dark

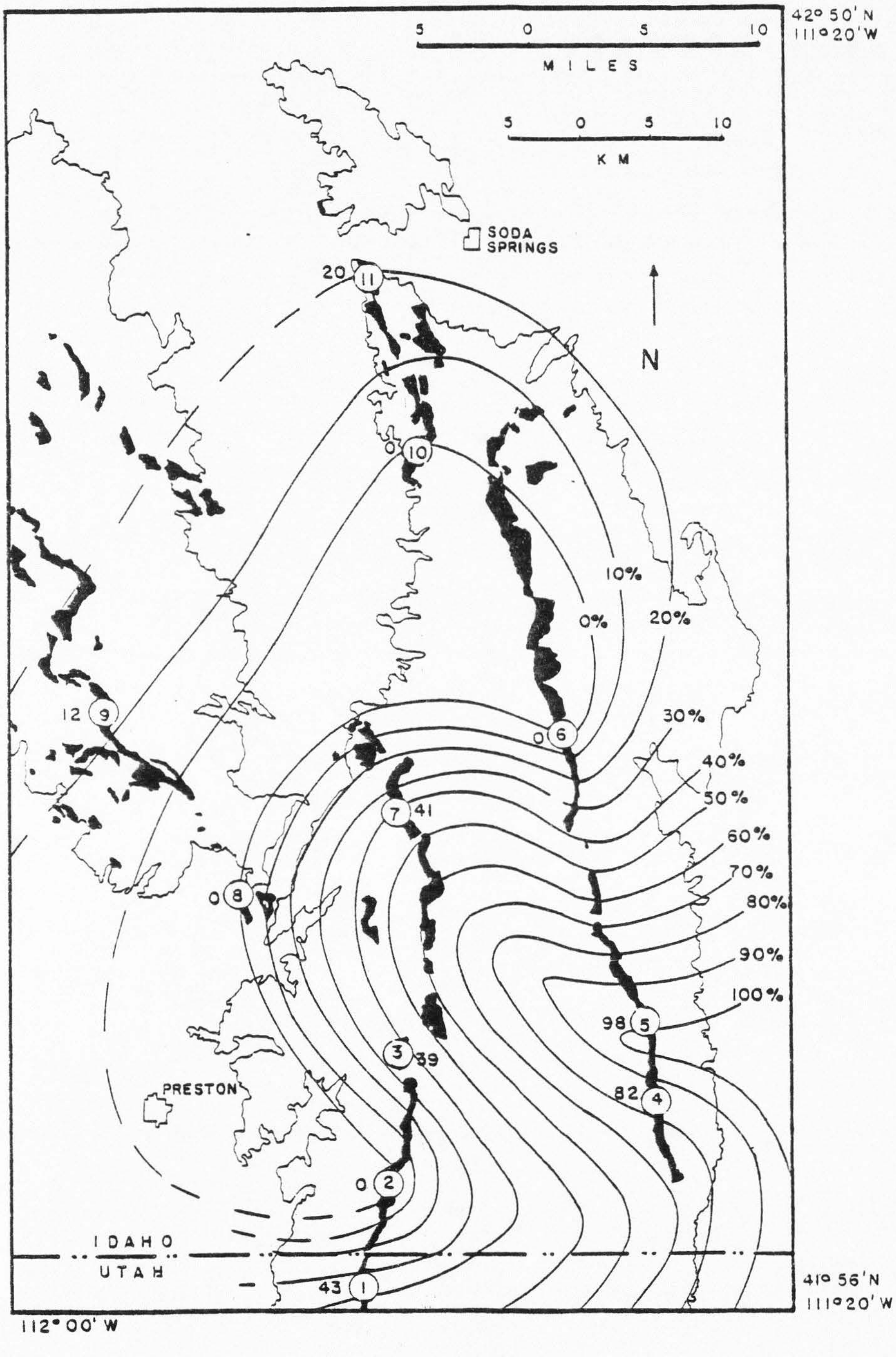


FIG. 19.- Percent dolomite in each measured section of the Blacksmith Formation, southeastern Idaho and northernmost Utah. Contour interval 10 percent.

laminae which are believed to be richer in organic matter from the algal mats than the lighter colored laminae. Gebelein and Hoffman (1973) described a similar situation, and proposed an *in situ* mechanism of dolomitization. They suggested that the Mg ions released from the decaying algae were incorporated, via replacement, into the $CaCO_3$ lattice to form dolomite. This same mechanism of organic decay and release of Mg ions may operate in situations when only ooids (which often contain algae) have been dolomitized, especially if the nuclei contain material derived from algae, although such a mechanism has not been documented in the literature to this writer's knowledge.

SUMMARY OF ENVIRONMENTAL AND DIAGENETIC CONDITIONS

All of the rock types of the Blacksmith Formation probably were deposited in shallow-marine environments, ranging from subtidal to upper intertidal and even low supratidal.

Paleomagnetic studies indicate that the study area was in the tropics during the Middle Cambrian. The clay minerals present, illite and kaolinite, suggest a relativelyy humid paleoclimate, reinforcing the interpretation of the paleoclimate as tropical.

Water depth varied at any given time throughout the study area, and possibly was deeper to the north where there was a less restricted fauna. It is inferred that a rise in sea level, followed by a regression, another transgression, and the beginnings of a second regression controlled the distribution of facies through time. Because the second transgression caused the oolite shoals to migrate farther eastward than the first transgression, it is inferred to have lapped farther onto the craton than the first transgression.

Diagenesis of the Blacksmith is inferred to have begun with micritization of some of the grains. There was little compaction of the sediments before cementation in the intertidal and shallow subtidal environments. Some slightly deper subtidal deposits may have been compacted slightly before cementation. The cement formed as fibrous rims probably of aragonite or high-Mg calcite. Even though the mudstones or boundstones do not show rim cementation, they are believed to have been cemented early also based on the lack of evidence of compaction.

Cementation may have been interrupted by dolomitization. It is inferred, from pseudomorphs of calcite after evaporites, quartz euhedra, and desiccation features, that a hypersaline brine may have been generated. This brine probably percolated through the sediments in the subsurface, perhaps by seepage refluxion. As burial proceeded, pyrite was formed which lacked free oxygen (negative Eh) below the sediment-water interface. Cementation or dolomitization may have been interrupted by precipitation of quartz, or chert, possibly replacing evaporites (Friedman and Shukla, 1980; Folk and Pittman, 1971).

Because some of the dolomite rhombs are zoned and many have hematite inclusions, it is inferred that the brine lost magnesium by dolomitizing aragonitic or calcitic sediments. This would lower the Mg/Ca ratio, and enhance formation of a ferroan dolomite in the reducing environment below the sediment-water interface (Katz, 1971). Later oxidation, perhaps after uplift and exposure to fresh water, or a storm, produced hematite (Katz, 1971).

Late diagenetic events that post-date lithification include aggrading neomorphism, which is the dominant event. It often obliterates evidence of episodes of cementation. Possibly epigenetic dolomitization is another late diagenetic event. Neomorphism that preserved the record of cementation episodes did occur in some rocks. Stylolites are present in almost all samples of the Blacksmith, and are due to pressure-solution (Bathurst, 1975). The pressure-solution may have provided the cement to fill the fractures found in some samples (Park and Schot, 1968). Dedolomitization was observed in some thin sections, and is believed to be a local event, occurring after uplift and exposure to fresh water.

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APPENDICES

Appendix A

Petrographic, Insoluble Residue and X-ray Data

Explanation

Descriptions given without any symbol in front of the sample number are those of thin sections. The symbol # in front of the sample number indicates a slab.

Grains are described as follows:

> Sphericity, Roundness, Size (largest to smallest, average grain size) modifiers and textural rock name; compositional name.

Sphericity:			Roundness	
	P	Platy	A	Angular
6:1				
	BL	Bladed	SA	Subangular
2:1				
	SE	Subequant	SR	Subrounded
1½:1				
	E	Equant	R	Rounded

Terminology of Folk (1968):

For compositions of insoluble-residue samples, the symbol * indicates that minerals are listed in order of decreasing relative peak heights.

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Insoluble Residue Composition*
HC-1	1	1	E, SR-R (.5mm-.01mm, .02mm) birdseye-and pellet-grapestone-bearing pelletal packstone; dolomitic limestone	3.98	Quartz, microcline, illite, kaolinite, montmorillonite
HC-1A	1	1	SE-E, R (.8mm-.14mm, .3mm) cryptalgalaminated ooid-bearing pelletal packstone; dolomitic limestone	3.22	Quartz, microcline, illite
HC-2	1	2	SE-E, SR-R (.25mm-.05mm, .09mm) organic-rich, birdseye-and pellet-grapestone-bearing pelletal packstone; limestone	0.91	Microcline, quartz, illite
HC-3	1	3	E-SE, R-SR (.5mm-.04mm, .2mm) birdseye-and pellet-grapestone-bearing pelletal packstone; limestone	0.38	Microcline, quartz, illite
# HC-4	1	4	Birdseye-bearing peloidal packstone; limestone	1.46	Quartz, microcline, illite
HC-4A	1	4	E-SE, SR-R (1.6mm-.25mm, .5mm) organic-rich, cryptalgalaminated, intraclast- and pellet-bearing oolitic packstone; limestone	0.70	Microcline, quartz, illite
# HC-5	1	5	Birdseye (?)-bearing peloidal packstone; limestone	0.43	Microcline, quartz, illite
# HC-5A	1	5	Oolitic packstone; limestone	--	--

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Insoluble Residue Composition*
HC-6	1	6	SE-E, SR-R (1.1mm-.1mm, .3mm) birdseye (?) or mottling (?) intraclast-bearing peloidal packstone; dolostone	0.34	Illite, microcline
# HC-6A	1	6	SE-E, R (.5mm-.2mm, .3mm) birdseye-(?) or mottled-(?) bearing peloidal packstone; dolostone	0.75	Microcline, illite, quartz, kaolinite
HC-6B	1	6	SE-E, SR-R (2.3mm-.1mm, .3mm) organic-rich, intraclast-and ooid-bearing peloidal packstone; dolostone	0.58	Microcline, illite, kaolinite
# HC-7	1	7	E, SR-R (.25mm-.05mm, .1 mm) birdseye- and peloid-bearing cryptalgal boundstone; dolostone	1.84	Quartz, microcline, illite, kaolinite (?)
# HC-8	1	8	SE-E, R (.25mm-?, .1mm) birdseye-bearing peloidal packstone; dolostone	0.78	Microcline, kaolinite, illite, quartz(?)
# HC-9	1	9	E, R (.5mm-.1mm, .25mm) bioturbated peloidal packstone; dolostone	0.73	Quartz, illite, feldspar(?)
# HC-9A	1	9	SE-E, R-SR (2.0mm-.1mm, .5mm) bioturbated peloidal packstone; dolostone	0.72	Quartz, microcline, illite, kaolinite
# MC-2	2	1	Birdseye-bearing peloidal wackestone; limestone	1.37	Microcline, quarts, albite, illite

Sample No.	Section	Unit	Rock Name	Insoluble Residue	
				Percent	Composition*
MC-3	2	2	E-SE, R (1.2mm-.7mm, .3mm) organic-rich, pellet-grapestone-bearing pelletal wackestone; limestone	1.08	Microcline, quartz, plagioclase(?), illite
MC-4	2	3	BL-E, SR-R (.12mm-.07mm, .09mm) cryptalgalaminated mudstone; dolomitic limestone	11.17	Quartz, microcline, illite
MC-5	2	4	BL-E, R (6mm-.05mm, .5mm) organic-rich, pellet-grapestone- and intraclast-bearing pelletal grainstone; limestone	5.62	Quartz, microcline, illite
MC-5A	2	4	E-SE, R (2.5mm-.25mm, .7mm) organic-rich, pellet-grapestone-and peloid-bearing oolitic grainstone; dolomitic limestone	5.31	Quartz, microcline, illite
# MC-6	2	5	Organic-rich, bioturbated mudstone; limestone	5.00	Quartz, microcline, illite, plagioclase(?)
# MC-6A	2	5	Organic-rich bioturbated mudstone; limestone	3.09	--
# MC-7	2	6	Organic-rich, peloid-bearing bioturbated mudstone; limestone	2.89	Quartz, microcline, illite, plagioclase(?)

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Insoluble Residue Composition*
MC-8	2	7	BL-E, A-R (30mm-.35mm, 2mm) organic-rich, brecciated, peloidal packstone; limestone	4.55	Quartz,microcline, limonite(?)
# MC-9	2	8	Organic-rich, peloid-bearing bioturbated mudstone; limestone	1.58	Quartz, microcline, illite, albite(?)
MC-9A	2	8	BL-E, SR-R (3.5mm-.2mm, .5mm) organic-rich, trilobite fragment- and peloid-bearing oncolitic packstone; limestone	1.66	Quartz, microcline, illite, kaolinite, plagioclase, pyrite(?)
# MC-10	2	9	Slightly organic-rich, peloid-bearing bioturbated mudstone; limestone	0.85	Microcline, illite, quartz
# MC-10A	2	9	Organic-rich, bioturbated mudstone; limestone	4.45	--
CR-1	3	1	E, R (.8mm-.12mm, .35mm) organic-rich, ooid-bearing pelletal packstone; limestone	2.35	Quartz, illite, kaolinite, microcline, pyrite(?)
# CR-2	3	2	E-SE, R (.3mm-.1mm, .2mm) bioturbated peloidal packstone; dolostone	0.80	Kaolinite, quartz, microcline, illite

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Composition*
CR-3	3	3	BL-E, SR-R (1mm-.3mm, .6mm) organic-rich, ooid-bearing pelletal packstone; dolomitic limestone	0.59	Quartz, illite, plagioclase, kaolinite, microcline, pyrite
# CR-4	3	4	BL-E, SR-R (3mm-.1mm, .5mm) slightly organic-rich, fossiliferous, peloidal grainstone; dolostone	0.29	Kaolinite, illite, quartz
# CR-4A	3	4	BL-E SR-R (3.2mm-.1mm, .7mm) fossiliferous, peloidal packstone; dolostone	2.45	Illite, quartz, microcline, kaolinite
CR-5	3	5	BL-E, SR-R (.1mm-.003mm(?), .05mm) cryptalgalaminated mudstone; dolomitic limestone	12.90	Quartz, illite, microcline, kaolinite
CR-5A	3	5	BL-E, SR-R (30mm-.05mm, .1mm) cryptalgal-rip-up-clast-bearing pelletal packstone; dolomitic limestone	7.32	Quartz, albite, chlorite, illite
# CR-6	3	6	Bioturbated mudstone; limestone	4.45	Quartz, microcline, illite, kaolinite
CR-7	3	7	BL-E, SR-R (1.8mm-.07mm, .9mm) slightly organic-rich, pellet-grapestone-and peloid-bearing oolitic packstone; limestone	1.19	Quartz, illite microcline(?)

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Insoluble Residue Composition*
CR-8	3	8	Bioturbated mudstone; limestone	13.10	Quartz, microcline, chlorite, illite
St.C-1	4	1	E-SE, A-SR (.89mm-.08mm, .3mm) anhedral-subhedral crystalline dolostone	5.53	Quartz, microcline, illite, plagioclase
# St.C-2	4	2	Peloidal packstone, dolostone	0.84	Quartz, illite, kaolinite
St.C-3	4	3	SE-E, SR-R (.35mm-.09mm, .2mm) slightly organic-rich, bioturbated peloidal wackestone; dolostone	1.60	Quartz, illite, kaolinite, microcline, pyrite(?)
St.C-4	4	4	SE-E, SR-R (.12mm-.02mm, .07mm) organic-rich, cryptalgalaminated mudstone; limestone	5.05	Quartz, microcline, illite, kaolinite
St.C-5	4	5	SE-E, A-R (1.3mm-.03mm, .5mm) brecciated, anhedral-euhedral crystalline calcareous dolostone	4.56	Quartz, microcline, illite, plagioclase(?)
# St.C-6	4	6	Bioturbated peloid-bearing mudstone; limestone	2.92	Quartz, microcline, illite.
St.C-7	4	7	E, SR-R (.7mm-.12mm, .3mm) slightly organic-rich, peloidal wackestone; dolostone	5.56	Quartz, K-feldspar, illite

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Insoluble Residue Composition*
St.C-7A	4	7	BL-E, SR-R (14mm-.1mm, 1mm) slightly organic-rich, cryptalgal-rip-up-clast-bearing pelletal packstone; dolostone	1.98	Quartz, illite, microcline, pyrite, kaolinite
St.C-7B	4	7	BL-E, SR-R (1.5mm-.15mm, .5mm) oncolith- and ooid-bearing peloidal packstone; dolostone	2.98	Quartz, illite, microcline kaolinite
# St.C-8	4	8	Burrowed mudstone; limestone	10.98	Quartz, kaolinite, microcline, illite, plageioclase(?)
St.C-8B	4	8	BL-E, SR-R (17mm-.03mm, 1.3mm) echinoderm and trilobite fragment- and peloid-bearing oncolitic packstone; limestone	7.77	Quartz, K-feldspar, albite, montmorillonite, illite
# St.C-9	4	9	Organic-rich, peloidal packstone; dolostone	1.16	Quartz, illite, microcline, plagioclase, kaolinite(?), pyrite(?)
# St.C-9A	4	9	Organic-rich, peloid-bearing oolitic packstone; dolostone	1.22	Quartz, illite microcline, albite, pyrite(?)

Sample No.	Section	Unit	Rock Name	Insoluble Residue	
				Percent	Composition*
PC-1	5	1	E, R (.5mm-?mm, .25mm) bioturbated peloidal packstone; dolostone	5.37	Quartz, microcline, illite, plagioclase(?)
PC-1A	5	1	--	12.22	Quartz, microcline, plagioclase, illite
# PC-2	5	2	Bioturbated mudstone; dolostone	11.19	Quartz, microcline, illite, plagioclase(?)
PC-3	5	3	E, R (.1mm-.05mm, .08mm) bioturbated peloidal packstone; dolostone	8.79	Quartz, microcline, illite
PC-4	5	4	BL-E, SR-R (.5mm-.06mm, .2mm) slightly organic-rich, burrowed, trilobite and brachiopod(?) fragment-bearing peloidal packstone; dolostone	2.93	Quartz, microcline, albite(?), illite
PC-5	5	5	SE-E, A-R (10mm-.07mm, .7mm) brecciated peloidal packstone; calcareous dolostone	2.29	Quartz, microcline, kaolinite, K-feldspar, illite
# PC-6	5	6	Bioturbated peloidal packstone; dolostone	4.81	Quartz, microcline, plagioclase(?), illite

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Insoluble Residue Composition*
PC-6A	5	6	--	8.46	Quartz, microcline, K-feldspar, plagioclase, illite
PC-7	5	7	E, R (.5mm-.05mm, .24mm) slightly organic-rich, burrowed, peloidal packstone; dolostone	3.05	Quartz, microcline, chlorite
PC-7A	5	7	BL-E, SR-R (.7mm-.2mm, .3mm) slightly organic-rich, ooid-bearing peloidal packstone; dolostone	1.03	Microcline, quartz, pyrite
# PC-8	5	8	Organic-rich, intraclast-bearing peloidal packstone; dolostone	0.25	Illite, quartz, microcline, pyrite
# PC-9	5	9	Peloid-bearing oolitic grainstone; dolostone	0.53	Quartz, microcline, illite, kaolinite
# PC-9A	5	9	Peloid-bearing oolitic grainstone; dolostone	0.74	--
PC-10	5	10	E, R (.12mm-?, .08mm) peloid(?)-bearing mudstone; dolostone	7.83	Quartz, microcline, K-feldspar, illite, kaolinite

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Insoluble Residue Composition*
# PC-11	5	11	E, SR-R mottled crystalline dolostone	1.83	Microcline, K-feldspar, quartz, illite, plagioclase(?)
# PC-12	5	12	Slightly organic-rich, intraclast-bearing peloidal packstone; dolostone	1.29	Microcline, quartz, kaolinite, illite, pyrite(?)
# PC-12A	5	12	Slightly organic-rich, peloidal grainstone; dolostone	0.43	--
# EC-1	6	1	Birdseye-and peloid-grapestone-bearing peloidal wackestone; limestone	0.86	Microcline, kaolinite, quartz, plagioclase, illite, ilmenite(?)
# EC-1A	6	1	Birdseye-and peloid-grapestone-bearing pelloidal wackestone; limestone	1.10	Kaolinite, illite, quartz, microcline
EC-2	6	2	SE-E, R (2mm-.01mm, .6mm) pellet-grapestone-bearing pelletal wackestone; dolomitic limestone	0.92	Kaolinite, quartz, microcline, illite
EC-3	6	3	SE-E, SR-R (.1mm-.01mm, .03mm) bioturbated mudstone; limestone	3.86	Quartz, kaolinite, illite, microcline

				Insoluble Residue	
Sample No.	Section	Unit	Rock Name	Percent	Composition*
EC-4	6	4	E, SR-R (.12mm-.01mm, .06mm) cryptalgalaminated mudstone; limestone	10.36	Quartz, microcline, illite
EC-4A	6	4	--	19.01	Quartz, microcline, illite, kaolinite, plagioclase(?)
# EC-5	6	5	BL-E, SR-R (11mm-.2mm, .5mm) organic-rich, intraclast-bearing, burrowed peloidal packstone; limestone	3.92	Quartz, microcline, illite, kaolinite
# EC-6	6	6	Organic-rich, bioturbated mudstone; limestone	4.46	Quartz, microcline, kaolinite, plagioclase, illite
EC-7	6	7	SE-E R(.25mm-.01mm, .07mm) organic-riach burrowed, cryptalgalaminated pelletal wackestone; limestone	10.57	Quartz, microcline, montmorillonite, illite, kaolinite, plagioclase(?)
# EC-8	6	8	E-SE, R (5mm-.12mm, .35mm) organic-rich, intraclast-bearing peloidal packstone; limestone	2.57	Quartz, microcline, illite

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Insoluble Residue Composition*
EC-9	6	9	BL-E, SR-R (2mm-.12mm, .4mm) slightly organic-rich, intraclast-, trilobite and brachiopod fragment-bearing pelletal packstone; dolomitic limestone	3.21	Quartz, microcline, plagioclase, kaolinite, illite
EC-9A	6	9	--	2.25	Microcline, quartz, illite
EC-10	6	10	BL-E, SR-R (14mm-.14mm, 1mm) intraclast-, trilobite, brachiopod and echinoderm fragment-bearing peloidal packstone; limestone	5.46	Quartz, kaolinite, microcline, illite
EC-10A	6	10	BL-E, SR-R (11mm-.2mm, 1.3mm) intraclast-, trilobite and echinoderm fragment-bearing peloidal packstone; limestone	--	--
# EC-11	6	11	Bioturbated mudstone; limestone	3.49	Quartz, microcline, kaolinite, illite
EC-12	6	12	BL-E, R (3.5mm-.2mm, .7mm) intraclast-, trilobite fragment- and ooid-bearing peloidal packstone; limestone	2.16	Quartz, illite, microcline, kaolinite Plagioclase(?)

Sample No.	Section	Unit	Rock Name	Insoluble Residue	
				Percent	Composition*
SC-1	7	1	SE-E, R (3.5mm-.2mm, .7mm) intraclast-bearing peloidal packstone; dolomitic limestone	0.58	Microcline, quartz, kaolinite, illite plagioclase
SC-1A	7	1	--	0.26	Quartz, microcline, albite, kaolinite, illite
# SC-2	7	2	Birdseye-bearing peloidal wackestone; limestone	2.39	Quartz, microcline, K-feldspar, illite, kaolinite, plagioclase
SC-3	7	3	SE-E, R (.85mm-.2mm, .4mm) slightly organic-rich peloidal packstone; dolostone	0.45	Kaolinite, illite, quartz
SC-4	7	4	BL-E, SR-R (.7mm-.12mm, .7mm) intraclast- and peloid-bearing, echinoderm, brachiopod, and trilobite fragment wackestone; limestone	5.66	Quartz, illite, chlorite, K-feldspar
SC-5	7	5	E, R (.3mm-.08mm, .2mm) organic-rich bioturbated peloidal wackestone; dolostone	0.79	Quartz, albite, illite, pyrite(?)

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Insoluble Residue Composition*
SC-5A	7	5	--	1.85	Quartz, microcline, illite, K-feldspar
SC-5B	7	6	SE-E R(.45mm-.2mm, .3mm) slightly organic-rich, peloidal packstone; dolostone	0.39	Illite, quartz, microcline, kaolinite, pyrite(?)
# SC-6	7	7	Organic-rich, bioturbated peloidal wackestone; limestone	3.55	Quartz, illite, K-feldspar, kaolinite, plagioclase
ON-1	8	1	BL-E, SR-R (6.5mm-.01mm, 1mm) organic-rich, trilobite fragment- and intraclast-bearing peloidal packstone; limestone	8.52	Quartz, illite, albite, kaolinite, pyrite(?), K-feldspar
ON-2	8	2	E, R (.5mm-.04mm, .25mm) bioturbated peloidal wackestone; limestone	12.14	Quartz, illite, kaolinite, plagioclase(?), K-feldspar
ON-3	8	3	BL-E, A-R (10mm-.03mm, .3mm) brecciated, brachiopod and trilobite fragment- and intraclast-bearing pelletal packstone; limestone	2.77	Quartz, microcline, kaolinite, illite

Sample No.	Section	Unit	Rock Name	Insoluble Residue	
				Percent	Composition*
# ON-4	8	4	(4mm-?mm, .5mm) organic-rich, fossiliferous- and intraclast-bearing peloidal packstone; limestone	2.82	Quartz, kaolinite, microline, illite pyrite(?)
ON-5	8	5	E-SE, A-R (7mm-.2mm, .5mm) brecciated, organic-rich, intraclast- and ooid-bearing pelletal grainstone; dolomitic limestone	1.04	Quartz, illite, pyrite(?), K-feldspar
ON-5B	8	5	E-SE, R (.8mm-.1mm, .3mm) organic-rich, ooid-bearing pelletal grainstone; dolomitic limestone	0.41	Quartz, kaolinite, illite, pyrite, microcline, plagioclase(?)
# ON-6	8	6	Slightly organic-rich, bioturbated mudstone; limestone	2.23	Microcline, quartz, illite, plagioclase, K-feldspar(?)
# ON-7	8	7	Organic-rich, fossiliferous, peloidal packstone; dolomitic(?) limestone	2.14	Kaolinite, quartz, illite, K-feldspar
# ON-7A	8	7	Organic-rich, peloidal packstone; dolomitic(?) limestone	1.56	--

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Insoluble Residue Composition*
ON-7B	8	7	BL-E, SR-R (3.5mm-.1mm, .3mm) organic-rich, intraclast- brachiopod and trilobite fragment-bearing peloidal packstone; dolomitic limestone	1.65	Quartz, kaolinite, microcline, illite, pyrite(?)
# BB-1	9	1	Peloid-bearing, bioturbated mudstone; limestone	2.58	Quartz, microcline, illite, kaolinite, albite(?)
# BB-2	9	2	BL-E, SR-R (1.0mm-?mm, .5mm) organic-rich, fossiliferous, bioturbated peloidal packstone; limestone	4.69	Quartz, microcline, illite
# BB-3	9	3	E, R (1.2mm-.5mm, .7mm) oolitic grainstone; dolostone	2.41	Quartz, illite, microcline
# BB-4A	9	4	Birdseye- and peloid-grapestone(?)-bearing peloidal wackestone; limestone	1.20	Microcline, quartz, illite, kaolinite
WC-1	10	1	BL-E, SR-R (1.2mm-.2mm, .35mm) sponge spicule(?)- and ooid-bearing pelletal packstone; limestone	6.87	Quartz, illite, albite, kaolinite
WC-1A	10	1	--	4.03	Quartz, albite, illite, chlorite, pyrite(?)

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	 Composition*
WC-1B	10	1	--	11.59	--
WC-2	10	2	SE-E, SR-R (.45mm-.25mm, .3mm) parallel laminated, ooid-bearing peloidal packstone, dolomitic limestone	--	--
WC-2A	10	2	E, SR-R (.25mm-.01mm, .1mm) birdseye- and cryptalgalaminated-bearing peloidal wackestone; dolomitic limestone	38.03	Quartz, albite, illite, kaolinite
WC-3	10	3	--	4.83	Quartz, illite, microcline, montmorillonite, pyrite(?)
WC-3A	10	3	SE-E, SR-R (10mm-.05mm, .7mm) intraclast-, trilobite, brachiopod, and echinoderm fragment- and ooid-bearing pelletal packstone; limestone	12.76	Quartz, illite, albite, kaolinite
WC-3B	10	3	--	4.79	Quartz, illite, albite.
WC-4	10	4	BL-E, SR-R (4mm-.25mm, .4mm) slightly organic-rich, pellet-grapestone, trilobite and echinoderm fragment- and pellet-bearing oolitic packstone; limestone	3.59	Quartz, illite, albite, montmorillonite, kaolinite, K-feldspar

Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Insoluble Residue Composition*
WC-5	10	5	SE-E, SR-R (4mm-.15mm, .45mm) intraclast- and ooid-bearing pelletal packstone; limestone	2.38	Illite, quartz, montmorillonite, microcline, plagioclase
WC-6	10	6	BL-E, SR-R (8mm-.07mm, .5mm) intraclast-, trilobite and echinoderm fragment- and sponge spicule-bearing pelletal packstone; limestone	7.51	Quartz, microcline, illite, montmorillonite, plagioclase(?)
WC-7	10	7	BL-E, A-R (4mm-.05mm, .45) pisolith-, echinoderm, brachiopod and trilobite fragment-bearing pelletal packstone; limestone	9.87	Quartz, microcline, plagioclase, illite, kaolinite
# WC-8	10	8	Peloid-bearing bioturbated mudstone; limestone	12.85	Quartz, microcline, albite, kaolinite, illite
WC-9	10	9	BL-E, SR-R (1.1mm-.05mm, .3mm) organic-rich, ooid-and peloid-bearing pelletal packstone; limestone	3.58	Kaolinite, quartz, illite, pyrite, K-feldspar
# WC-10	10	10	Organic-rich, peloid-bearing oolitic packstone; limestone	0.27	Quartz, microcline, K-feldspar, illite, pyrite, kaolinite

				Insoluble Residue	
Sample No.	Section	Unit	Rock Name	Percent	Composition*
WC-10A	10	10	--	1.41	Quartz, microcline, albite, illite
WC-11	11	11	BL-E, SR-R (3mm-.05mm, .5mm) intraclast-, trilobite and brachiopod(?) fragment-and peloid-bearing oolitic packstone; limestone	1.98	Quartz, microcline, illite, kaolinite, plagioclase(?)
# NC-1	11	1	Organic-rich, oncolith-bearing peloidal packstone; limestone	3.21	Quartz, microcline, illite, kaolinite
NC-1A	11	1	BL-E, SR-R (3.5mm-.13mm, .3mm) intraclast-, peloid, and ooid-bearing trilobite, brachiopod, and echinoderm fragment wackestone; limestone	2.92	Quartz, microcline, illite
# NC-1B	11	1	Bioturbated peloidal wackestone; limestone	--	--
# NC-2	11	2	Bioturbated peloid-bearing mudstone; limestone	5.20	Quartz, microcline, illite
NC-3	11	3	SE-E, A-R (20mm-.12mm, .35mm) brecciated, intraclast- and ooid-bearing pelletal packstone; calcareous dolostone	2.39	Quartz, microcline, illite

				Insoluble Residue	
Sample No.	Section	Unit	Rock Name	Percent	Composition*
# NC-3A	11	3	Peloidal packstone; calcareous(?) dolostone	3.18	Quartz, microcline, albite, illite, kaolinite
NC-3B	11	3	--	1.17	Quartz, microcline, illite
# NC-4	11	4	E, R ooid-bearing peloidal packstone; limestone	3.45	Quartz, illite microcline
NC-5	11	5	E, SR-R (.05mm-?mm, .03mm) organic-rich, bioturbated mudstone; dolomitic limestone	9.30	Microcline, quartz, K-feldspar, illite
# NC-5A	11	5	Slightly organic-rich, bioturbated mudstone; dolomitic limestone	4.24	Quartz, microcline, illite, kaolinite
# NC-6	11	6	Organic-rich, cryptalgalaminated mudstone; dolomitic limestone	10.38	Quartz, microcline, plagioclase, illite
NC-7	11	7	E, R (.05mm-?mm, .01mm) organic-rich, bioturbated mudstone; dolomitic limestone	4.72	Quartz, microcline, illite, kaolinite, plagioclase, pyrite(?)

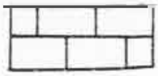
Sample No.	Section	Unit	Rock Name	Insoluble Residue Percent	Insoluble Residue Composition*
# NC-8	11	8	Organic-rich, peloidal packstone; dolomitic limestone	2.70	Quartz, microcline, illite, pyrite(?)
NC-8A	11	8	BL-E, SR-R (1.7mm-.08mm, .6mm) organic-rich, trilobite and echinoderm fragment- and oncolith-bearing peloidal packstone; dolomitic limestone	3.55	Quartz, microcline, illite, K-feldspar, pyrite(?)
# NC-9	11	9	Organic-rich peloidal packstone; limestone	5.80	Quartz, microcline, plagioclase, montmorillonite, illite
NC-9A	11	9	BL-E, R (4mm-.3mm, .6mm) slightly organic-rich, trilobite and echinoderm fragment- oncolith- and ooid-bearing peloidal packstone; limestone	11.20	Quartz, albite, K-feldspar, illite

Appendix B

Measured Stratigraphic Sections

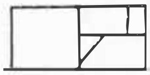
Explanation of Stratigraphic Sections

Rock Symbols



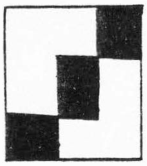
Limestone

Dolostone



Poorly exposed

covered



N2-N3

N4-N5 color

N6-N8

Section 1

Location: High Creek Canyon, measured west to east along ridge crest south of the South Fork of High Creek, approximately 6-1/2 miles northeast of Richmond, Utah, S.W. 1/4 sec. 11, T. 14 N., R. 2 E., Cache County, Utah, field assistant Bill Hay.

Bloomington Formation

Sharp, planar(?) contact

Blacksmith Formation

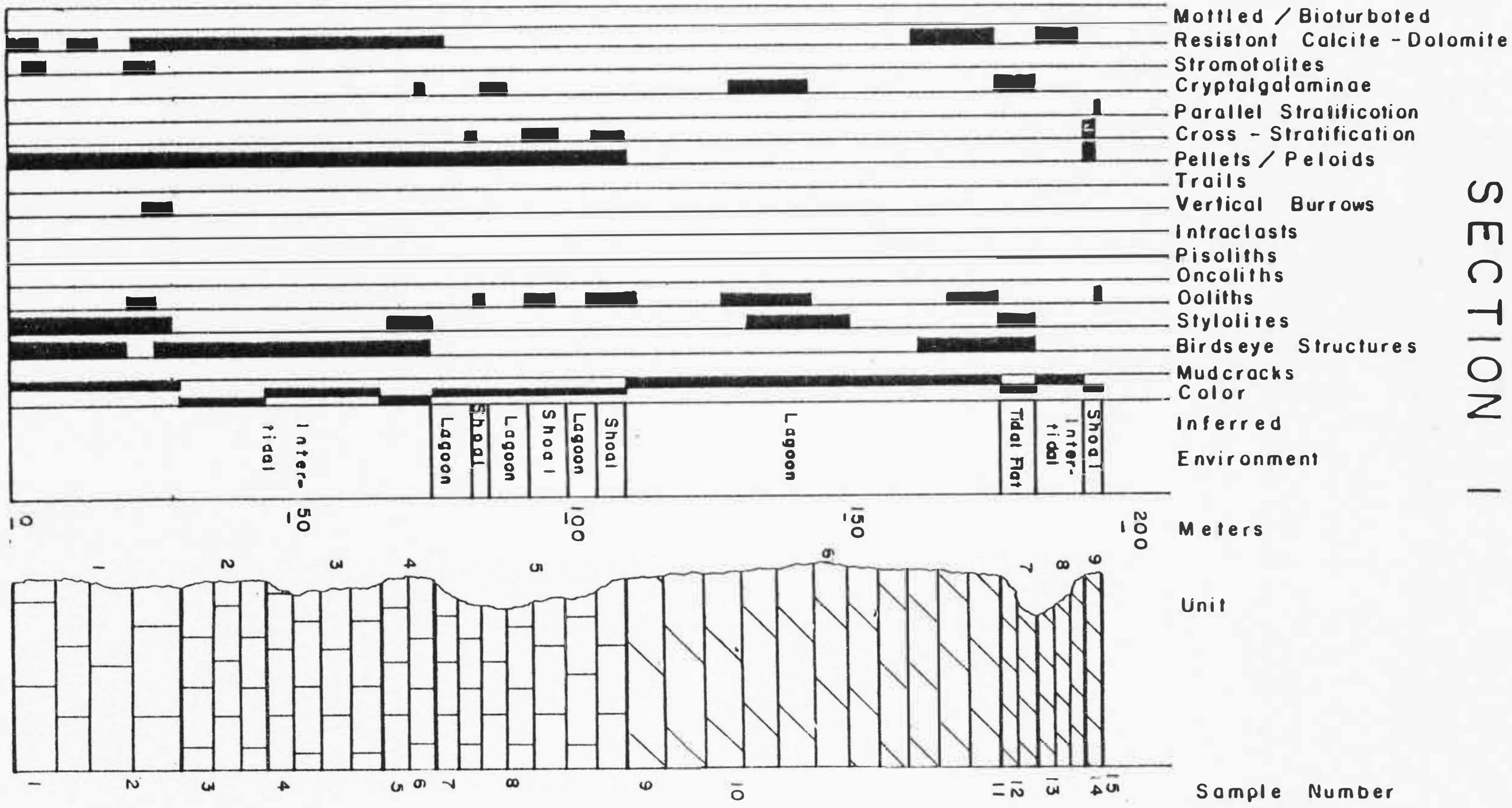
		Thickness in meters
Unit 9:	Dolostone, medium dark gray (N4), weathers medium light gray (N6), medium to fine grained, contains stylolites. Parallel laminae, may be mottled, an oolitic bed in upper portion, beds average 12 cm, exposed as thin ledge	3.1
Unit 8:	Dolostone, medium light gray (N6), weathers very light gray (N8), fine grained with blebs of coarse crystalline dolomite. No structures except faint parallel laminae, beds average 25 cm and appear massive	8.2
Unit 7:	Dolostone, medium dark gray (N4), weathers light gray (N7), medium to fine grained with stylolites parallel to bedding. Wavy cryptalgalaminae with a few birdseye structures, bedding is obscure and averages 6 cm, exposures form low slopes	6.1
Unit 6:	Dolostone, medium light gray (N6), weathers pinkish gray (5 YR 8/1), varies in color, medium to coarse grained with wavy cryptalgal(?) laminae associated with thin oolitic or pisolitic(?) beds near middle. Finer grained toward top, bioturbated(?), beds average 15 cm, exposed in steep slopes	65.5

Contact between unit 6 and unit 5, dolostone/limestone, is not parallel to bedding, steeply curved.

		Thickness in meters
Unit 5:	Limestone, medium dark gray (N4), weathers medium light gray (N6), very fine to coarse grained, coarse crystalline protuberances on the weathered surface (fossil ?). Interbedded with cross-bedded oolitic beds, beds average 11 cm, exposures form moderate slopes to thin ledges	33.5
Unit 4:	Limestone, dark gary (N3), weathers medium gray (N5), fine to very fine grained, faint parallel (cryptalgal ?) laminations in upper half, bridseye structures and stylolites, beds average 13 cm, exposed as low slopes	9.1
Unit 3:	Limestone, medium gray (N5), weathers medium light gray (N6), very fine grained with birdseye structures filled with calcite. Faint parallelism of birdseyes and pseudomorph of calcite after gypsum, beds average 25 cm, appear massive, exposures form moderate slopes	19.8
Unit 2:	Limestone, grayish black (N2), weathers medium dark gray (N4), fine grained, birdseye structures throughout, bituminous odor on fresh surface, beds average 33 cm, exposures form moderate to steep slopes	16.2
Unit 1:	Dolomitic limestone, light gray (N7), weathers very light gray (N8), very fine grained, birdseye structures filled with coarse calcite. Faint parallelism of birdseyes and cryptalgal(?) and possible small domal stromatolites with ooids associated. Few vertical burrows near top, beds average 30 cm and appear massive, exposures form steep slopes	29.2
	Total	191.1

Sharp planar contact

Ute Formation


Mottled / Bioturbated
Resistant Calcite - Dolomite
Stromatolites
Cryptalgalaminae
Parallel Stratification
Cross - Stratification
Pellets / Peloids
Trails
Vertical Burrows
Intraclasts
Pisoliths
Oncoliths
Ooliths
Stylolites
Birdseye Structures
Mudcracks
Color
Inferred Environment
Inter-tidal
Lagoon
Shoal
Lagoon
Shoal
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Tidal Flat
Inter-tidal
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Sample Number
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SECTION I

Section 2

Location: Maple Creek Canyon, measured west to east along ridge crest north of Maple Creek, approximately 7 miles northeast of Franklin, Idaho, unsurveyed 1967, S.E. 1/4, S.E. 1/4, sec. 33, T. 15 S., R. 41 E., Franklin County, Idaho.

Bloomington Formation

Covered, probably sharp contact

Blacksmith Formation

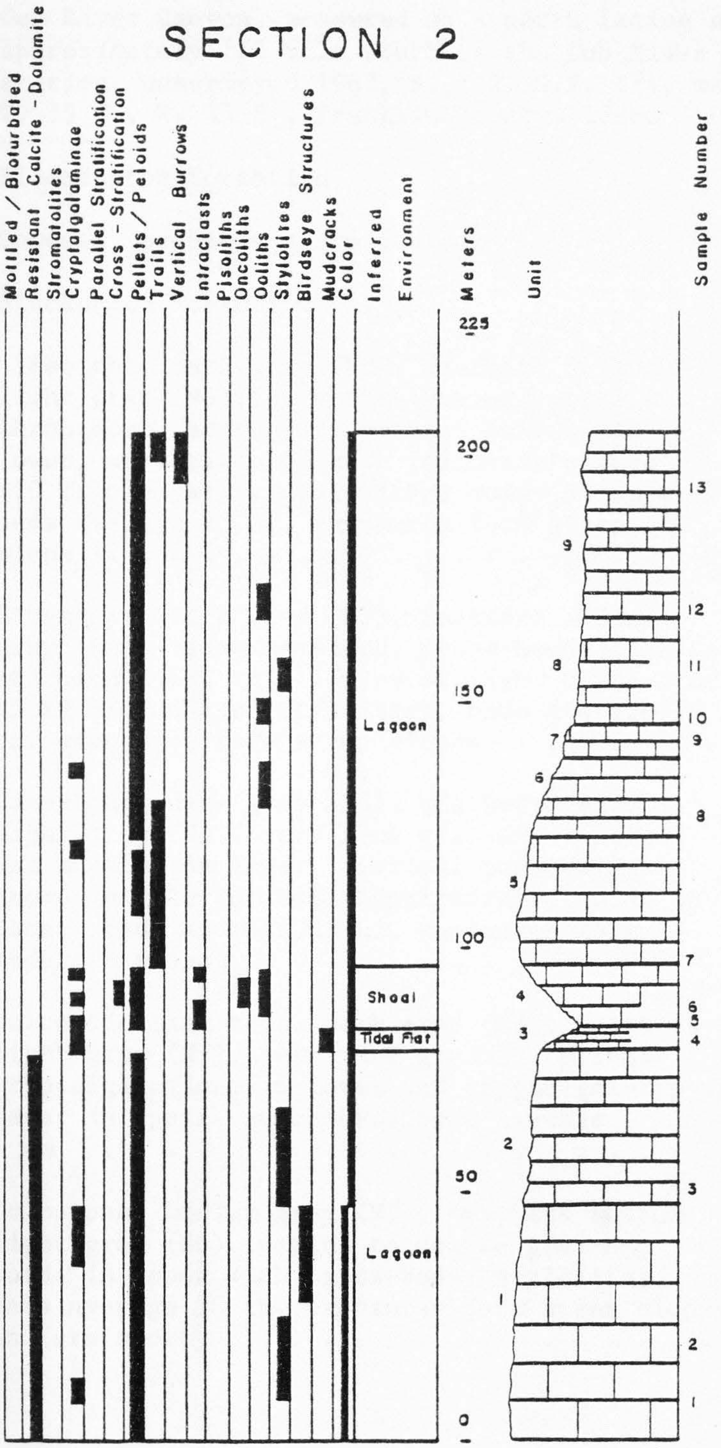
		Thickness in meters
Unit 9:	Limestone, dark gray (N3), weathers medium gray (N5), fine to very fine grained, trails and burrows in upper, few thin oolitic beds near base, beds average 9 cm, exposures form low slopes	36.6
Unit 8:	Limestone, dark gray (N3), weathers medium dark gray (N4), very fine grained with lenses of ooids or oncoliths near base, stylolites parallel to bedding, beds average 13 cm, 20 percent covered	21.3
Unit 7:	Limestone, dark gray (N3), weathers medium dark gray (N4), brecciated, grayish orange (10 YR 7/4) matrix, intraclasts angular, bedding massive, beds average 30 cm, 80 percent covered	6.1
Unit 6:	Limestone, dark gray (N3), weathers medium light gray (N6), very fine to fine grained with wavy parts, trails in lower half, few ooids in upper, beds average 15 cm, exposures form low slopes	15.2
Unit 5:	Limestone, dark gray (N3), weathers medium gray (N5), fine grained, wavy cryptalgal(?) laminations, trails and stylolites parallel to beds. Intraformational conglomerate with cryptalgalaminae at top, beds average 20 cm, exposures form low slopes	25.9
Unit 4:	Dolomitic limestone, dark gray (N3), weathers medium gray (N5), medium grained interbedded with very fine grained cryptalgalaminae and intraformational conglomerate, cross-bedded oolitic beds, beds average 15 cm, exposed as low slopes, 30 percent covered	12.2

		Thickness in meters
Unit 3:	Dolomitic limestone, dark gray (N3), weathers light gray (N7), very fine grained, parallel cryptalgalaminae, mudcracks, beds average 3 cm, exposures form low slopes, 35 percent covered	4.6
Unit 2:	Limestone, dark gray (N3), weathers medium dark gray (N4), very fine to fine grained, mottled. Coarse calcite on weathered surface (fossil ?), a thin oolitic bed near middle, stylolites, beds average 30 cm, exposures form moderate slopes	30.5
Unit 1:	Limestone, medium dark gray to medium gray (N4-N5), weathers light gray to very light gray (N7-N8), birdseye structures and faint cryptalgal(?) lamination on the weathered surface. Stylolites parallel to bedding, beds average 35 cm, exposures form steep slopes	45.7
	Total	198.1

Covered, probably sharp contact

Ute Formation

SECTION 2


Mottled / Bioturbated
Resistant Calcite - Dolomite
Stromatolites
Cryptalgalaminae
Parallel Stratification
Cross - Stratification
Pellets / Peloids
Trails
Vertical Burrows
Intraclasts
Pisoliths
Oncoliths
Ooliths
Stylolites
Birdseye Structures
Mudcracks
Color
Inferred Environment
Meters
Unit
Sample Number
225
200
150
100
50
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Lagoon
Shoal
Tidal Flat
Lagoon
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Section 3

Location: Cub River Canyon, measured up a north facing slope approximately 1/2 mile south of the Cub River Ranger station, unsurveyed 1967, S. 1/2, N.E. 1/4, sec. 9, T. 15 S., R. 41 E., Franklin County, Idaho

Bloomington Formation

Covered, probably sharp contact

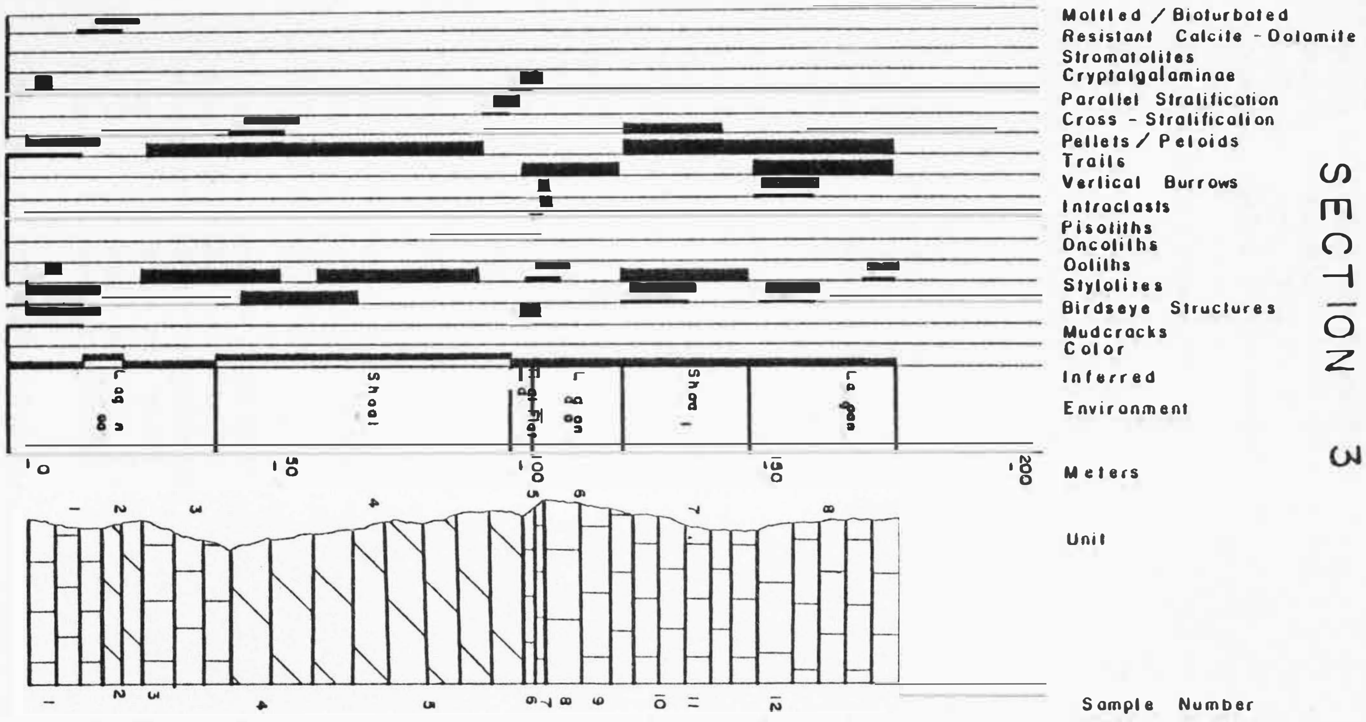
	Blacksmith Formation	Thickness in meters
Unit 8:	Limestone, dark gray (N3), weathers medium light gray (N6), very fine grained, trails throughout, scattered vertical burrows in lower, wavy parts of dark yellowish orange (10 YR 6/6) slit, stylolites, ooids in upper, beds average 25 cm, exposures form steep slopes	28.7
Unit 7:	Limestone, dark gray (N3), weathers medium gray (N5), medium grained, cross-bedded, ooids and oncoliths, thin lenses of light olive gray (5 YR 6/1) shale, stylolites, beds average 55 cm, exposures form steep slopes	21.9
Unit 6:	Limestone, dark gray (N3), weathers medium light gray (N6), very fine grained, trails and mottled in lower, vertical burrows just above intraformational conglomerate, ooids in lower, beds average 25 cm, exposures form moderate slopes	18.0
Unit 5:	Dolomitic limestone, dark gray (N3), weathers light gray (N7), very fine grained, planar cryptalgalaminae in lower and cryptalgal-rip-up layer in upper, mudcracks, beds average 3 cm	3.7
Unit 4:	Dolostone, medium gray (N5), weathers medium light gray (N6), medium to coarse grained, ooids in upper with cross-beds, stylolites, beds average 30 cm, exposures form steep slopes and are spotty	57.9

		Thickness in meters
Unit 3:	Dolomitic limestone, dark gray (N3), weathers medium gray (N5), fine to medium grained, oolitic throughout with thin layers of mud, beds average 20 cm, exposures form steep slopes	17.4
Unit 2:	Dolostone, medium gray (N5), weathers medium light gray (N6), fine grained, color and texture mottling, beds average 31 cm and appear massive, exposed as steep slopes	7.9
Unit 1:	Limestone, dark gray (N3), weathers medium gray (N5), very fine grained with silty parts, ooids, calcite blebs on weathered surface, beds average 40 cm, exposures form steep slopes and are spotty	14.3
	Total	169.8

Covered, probably sharp contact

Ute Formation

SECTION 3


Mottled / Bioturbated
Resistant Calcite - Dolomite
Stromatolites
Cryptalgalaminae
Parallel Stratification
Cross - Stratification
Pellets / Peloids
Trails
Vertical Burrows
Intraclasts
Pisoliths
Oncoliths
Oolitns
Stylolites
Birdseye Structures
Mudcracks
Color
Inferred
Environment
Lagoon
Shoal
Tidal Flat
Lagoon
Shoal
Lagoon
Meters
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Unit
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Sample Number
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Section 4

Location: Saint Charles Canyon, measured up a south facing slope north of Forest Service Saint Charles Road, approximately 3-1/2 miles west of Saint Charles, Idaho, S.W. 1/4, sec. 17, T. 15 S., R. 41 E., Bear Lake County, Idaho, field assistant Scott Wilde.

Bloomington Formation

Sharp, planar contact

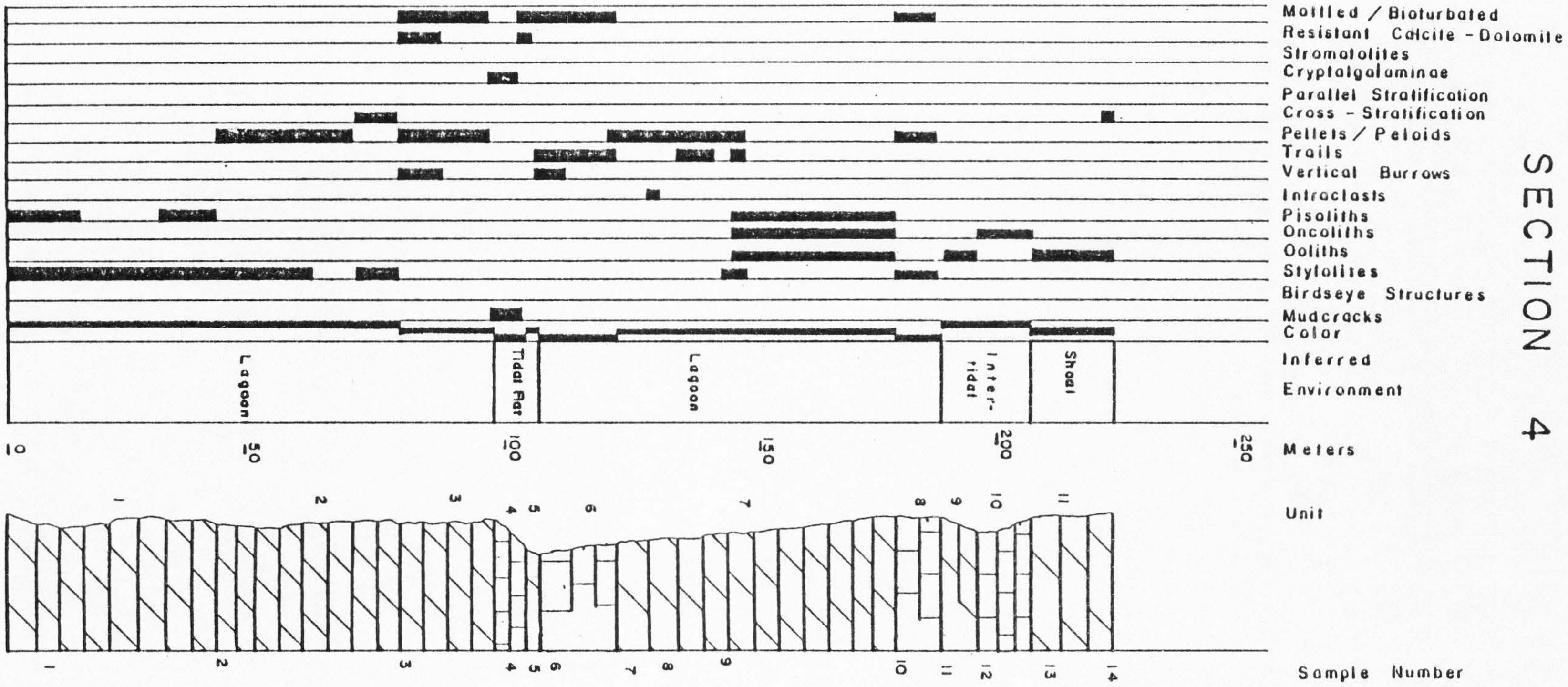
Blacksmith Formation

		Thickness in meters
Unit 11:	Dolostone, medium dark gray (N4), weathers medium light gray (N6), fine to medium grained, oolitic throughout, few oncoliths, cross-beds, beds average 25 cm, exposures form steep slopes	19.8
Unit 10:	Limestone, medium light gray (N6), weathers light gray (N7), fine to medium grained, few oncoliths, beds average 10 cm, exposures form steep slopes	10.7
Unit 9:	Dolostone, medium light gray (N6), weathers very light gray (N8), fine grained, ooids, beds massive, average 25 cm, exposures form moderate slopes, 20 percent covered	7.6
Unit 8:	Limestone, dark gray (N3), weathers medium gray (N5), very fine to fine grained, mottled, trails and vertical burrows, stylolites, beds average 5 cm, exposures form low slopes, 15 percent covered	9.1
Unit 7:	Dolostone, medium dark gray (N4), weathers light gray (N7), medium to coarse grained, intraformational conglomerate in lower, trails in middle, ooids and oncoliths in upper, stylolites, beds average 21 cm, exposed as low slopes, 35 percent covered	59.7
Unit 6:	Limestone, grayish black (N2), weathers dark gray (N3), very fine to fine grained, few vertical burrows, many trails, mottled, beds average 9 cm, exposures form low slopes, 10 percent covered	15.7

		Thickness in meters
Unit 5:	Dolostone, medium gray (N5), weathers light gray (N7), coarse grained, beds obscure, average 30 cm, poor exposures	4.0
Unit 4:	Limestone, dark gray (N3), weathers medium dark gray (N4), very fine grained, planar or undulose cryptalgalaminae, mudcracks, beds average 3 cm, exposures form low slopes . . .	6.1
Unit 3:	Dolostone, medium dark gray (N4), weathers medium light gray (N6), medium to coarse grained, coarse calcite on weathered surface, trails and mottled, beds average 17 cm, exposures form moderate slopes	19.8
Unit 2:	Dolostone, medium light gray (N6), weathers very light gray (N8), medium grained, ooids and cross-beds in upper, stylolites, beds average 16 cm, exposures form steep slopes . .	36.0
Unit 1:	Dolostone, medium light gray (N6), weathers brownish gray (5 YR 4/1), medium grained, round intraclasts, small lenses of silt, stylolites, beds average 27 cm, often massive, exposures form steep slopes	44.2
	Total	232.7

Sharp, planar contact

Ute Formation


Mottled / Bioturbated
Resistant Calcite - Dolomite
Stromatolites
Cryptalgalaminae
Parallel Stratification
Cross - Stratification
Pellets / Peloids
Trails
Vertical Burrows
Intraclasts
Pisoliths
Oncoliths
Ooliths
Stylolites
Birdseye Structures
Mudcracks
Color
Inferred Environment
Lagoon
Tidal Flat
Lagoon
Inter-tidal
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Sample Number
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SECTION 4

Section 5

Location: Paris Canyon, measured up a south facing slope, approximately 7 miles west of Paris, Idaho, S.W. 1/4, sec. 7, T. 14 S., R. 43 E., Bear Lake County, Idaho

Bloomington Formation

Sharp, planar contact

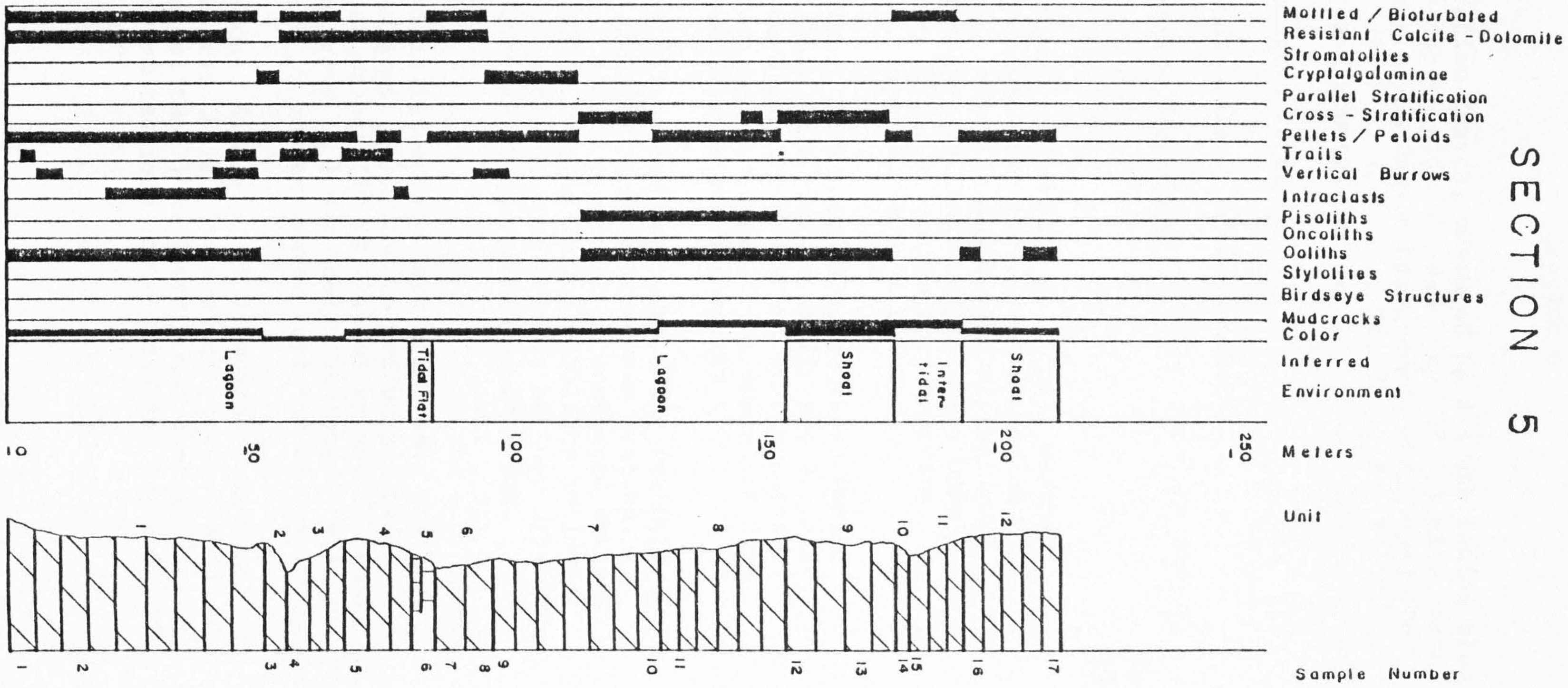
Blacksmith Formation

		Thickness in meters
Unit 12:	Dolostone, medium dark gray (N4), weathers medium light gray (N6), fine to medium grained, oolitic in upper and lower, beds average 43 cm, exposures form steep slopes	19.8
Unit 11:	Dolostone, light gray (N7), weathers very light gray (N8), fine grained, sugary texture on weathered surface, beds massive, exposures form moderate slopes	11.9
Unit 10:	Dolostone, light brownish gray (5 YR 6/1), weathers light gray (N7), very fine to medium grained with silty parts, beds average 30 cm, exposures form steep slopes	3.1
Unit 9:	Dolostone, medium gray to light gray (N5-N7), weathers medium light gray to very light gray (N6-N8), oolitic with cross-beds, beds average 30 cm, exposures form steep slopes	22.8
Unit 8:	Dolostone, medium light gray (N6), weathers medium gray (N5), medium grained, cross-beds, oolitic with few round intraclasts, beds average 40 cm, exposures form moderate slopes	25.9
Unit 7:	Dolostone, medium dark gray (N4), weathers medium light gray (N6), fine to medium grained, burrows and cryptalgal in lower, oolitic and cross-beds in upper, beds average 15 cm, exposures form low slopes	35.1

		Thickness in meters
Unit 6:	Dolostone, medium dark gray (N4), weathers medium light gray (N6), medium grained, calcite resistant on weathered surface, mottled, beds average 30 cm, exposures form moderate slopes	12.2
Unit 5:	Calcareous dolostone, medium dark gray (N5), weathers medium light gray (N6), brecciated, intraclasts angular, vuggy, beds massive, exposures form low slopes and poor	4.6
Unit 4:	Dolostone, medium dark gray (N4), weathers medium light gray (N6), medium grained, trails, intraformational conglomerate near top, beds average 14 cm, exposures form moderate slopes	13.7
Unit 3:	Dolostone, dark gray (N3), weathers medium gray (N5), fine to very fine grained, mottled, dolomite resistant on weathered surface, light brown (5 YR 5/6) silty parts, beds average 8 cm, exposures form very low slopes	12.2
Unit 2:	Dolostone, grayish black (N2), weathers medium dark gray (N4), very fine grained, planar to undulose cryptalgalaminae, beds average 3 cm, exposures form low slopes	3.7
Unit 1:	Dolostone, medium dark gray (N4), weathers light gray (N7), fine to medium grained, ooids throughout, dolomite resistant on weathered surface, vertical burrows and trails, beds average 25 cm, exposures form moderate slopes and spotty	53.3
	Total	218.3

Sharp, planar contact

Ute Formation


Mottled / Bioturbated
Resistant Calcite - Dolomite
Stromatolites
Cryptalgalaminae
Parallel Stratification
Cross - Stratification
Pellets / Peloids
Trails
Vertical Burrows
Intraclasts
Pisoliths
Oncoliths
Ooliths
Stylolites
Birdseye Structures
Mudcracks
Color
Inferred Environment
Lagoon
Tidal Flat
Lagoon
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Inter-tidal
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SECTION 5

Section 6

Location: Emigration Canyon, measured up a south facing slope on the north side of Idaho Hwy. 36 1/4 mile north of Emigration Canyon Campground, unsurveyed 1967, N.E. 1/4, N.E. 1/4, sec. 21, T. 12 S., R. 42 E., Bear Lake County, Idaho.

Bloomington Formation

Covered, probably sharp contact

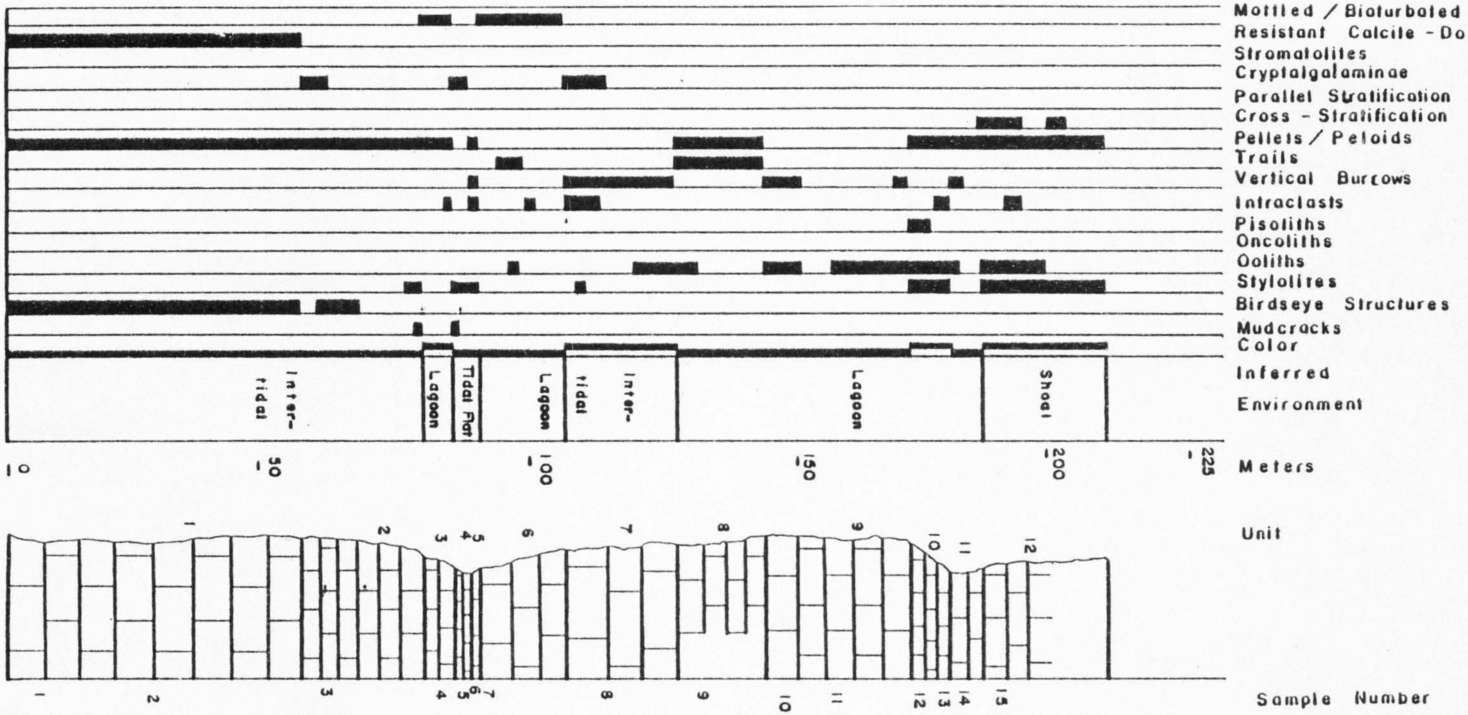
Blacksmith Formation

		Thickness in meters
Unit 12:	Limestone, medium dark gray (N4), weathers medium light gray (N6), fine to medium grained, ooids in lower, intraformational conglomerate in lower, stylolites, beds average 23 cm, exposures form moderate slopes, upper 33 percent covered	25.9
Unit 11:	Limestone, dark gray (N3), weathers medium gray (N5), fine grained, silty parts, ooids in lower, calcite resistant on weathered surface, beds average 20 cm, exposures form moderate slopes and are spotty	6.1
Unit 10:	Limestone, medium dark gray (N4), weathers light gray (N7), fine to coarse grained, coarse calcite resistant on weathered surface (fossil ?). Ooids and/or pisoliths in lower, intraformational conglomerate at top, stylolites, beds average 15 cm, exposures form low slopes	7.6
Unit 9:	Dolomitic limestone, dark gray (N3), weathers medium gray (N5), fine to medium grained, grayish orange (10 YR 7/4) silty parts, trails and burrows in lower, ooids in upper, beds average 29 cm, exposures form low slopes . . .	29.0
Unit 8:	Limestone, dark gray (N3), weathers medium light gray (N6), fine grained, trails, ooids and oncoliths(?) in lower, beds average 25 cm, exposures form low slopes, and are poor .	17.7

		Thickness in meters
Unit 7:	Limestone, medium gray (N4), weathers medium light gray (N6), fine grained, cryptalgalaminae in lower, vertical burrows, flat intraclasts, stylolites, beds average 20 cm, exposures form moderate slopes	21.3
Unit 6:	Limestone, dark gray (N3), weathers medium light gray (N6), fine grained, silty parts, trails and mottled, beds average 12 cm, exposures form low slopes	16.8
Unit 5:	Limestone, grayish black (N2), weathers medium gray (N5), fine grained, resistant calcite on weathered surface, burrows, bituminous odor on fresh surface, round intraclasts, stylolites, beds average 23 cm	1.5
Unit 4:	Limestone, dark gray (N3), weathers medium gray (N5), very fine grained, planar and undulose cryptalgalaminae, intraformational conglomerate beds, mudcracks, beds average 3 cm, exposures form low slopes and are spotty	3.4
Unit 3:	Limestone, medium dark gray (N4), weathers medium light gray (N6), fine to very fine grained, bioturbated, cryptalgalaminae(?), storm-rip-up layers near top, beds average 15 cm, exposures form moderate slopes	6.7
Unit 2:	Dolomitic limestone, dark gray (N3), weathers medium dark gray (N4), fine to coarse grained, calcite resistant on weathers surface (birdseye structures?), beds average 50 cm, massive, exposures form steep slopes	24.4
Unit 1:	Limestone, medium dark gray (N4), weathers medium light gray (N6), very fine grained, birdseye structures, parallelism of birdseyes, beds average 35 cm, massive, exposures form steep slopes	57.3
	Total	217.7

Covered, probably sharp contact

Ute Formation


Mottled / Bioturbated
Resistant Calcite - Dolomite
Stromatolites
Cryptalgalaminae
Parallel Stratification
Cross - Stratification
Pellets / Peloids
Trails
Vertical Burrows
Intraclasts
Pisoliths
Oncoliths
Ooliths
Stylolites
Birdseye Structures
Mudcracks
Color
Inferred Environment
Inter-tidal
Lagoon
Tidal Flat
Lagoon
Inter-tidal
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SECTION 6

Section 7

Location: Strawberry Creek Canyon, measured up a sotuh facing slope on the north side of Idaho Hwy. 36 approximately 6 miles north, northeast of Mink Creek, Idaho, S.E. 1/4, sec. 8, T. 13 S., R. 41 E., Franklin County, Idaho.

Bloomington Formation

Covered, probably sharp contact

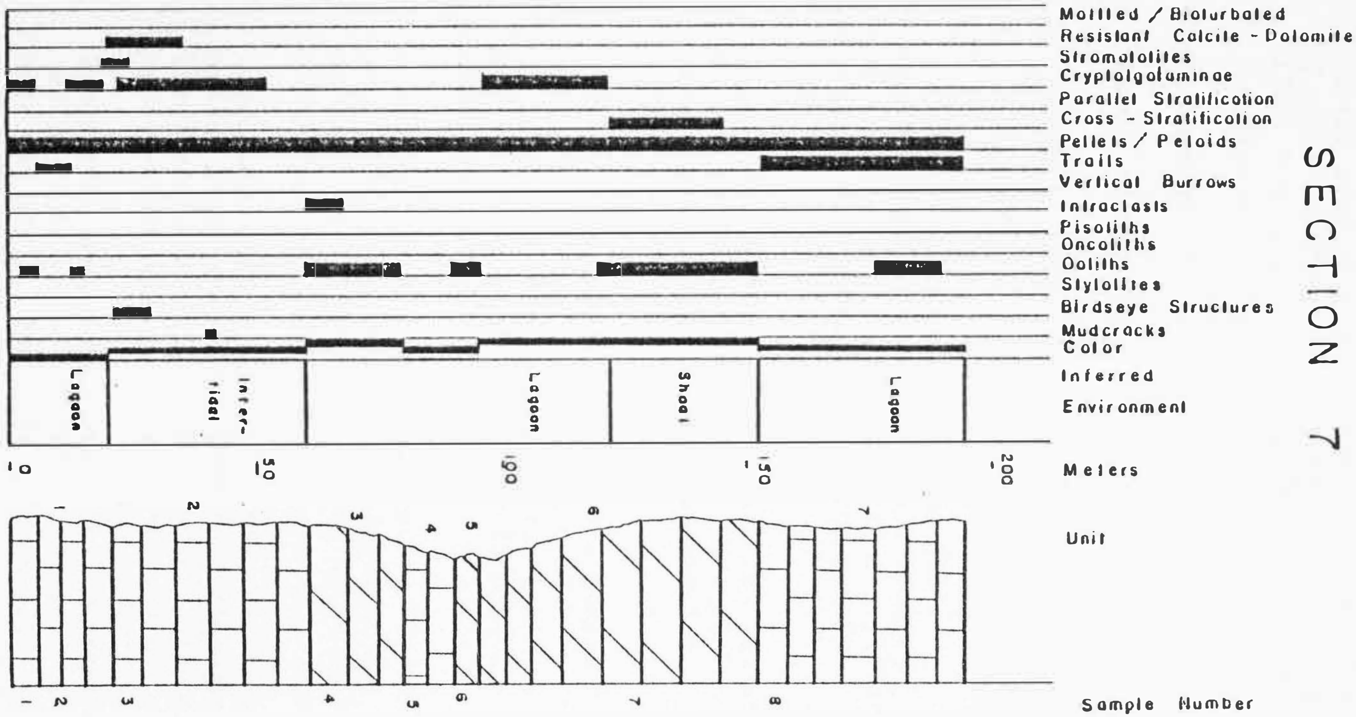
Blacksmith Formation

		Thickness in meters
Unit 7:	Limestone, medium gray (N5), weathers medium light gray (N6), very fine to fine grained, mottled and bioturbated, trails, ooids in upper, beds average 10 cm, exposures form moderate slopes	41.1
Unit 6:	Dolostone, medium light gray (N6), weathers medium gray (N7), medium grained, slightly mottled, cross-bedded and oolitic in upper, beds average 25(?) cm, exposures form moderate slopes	50.3
Unit 5:	Dolostone, medium gray (N5), weathers medium light gray (N6), fine to medium grained, mottled, ooids, exposures form steep slopes .	9.1
Unit 4:	Limestone, medium dark gray (N4), weathers medium gray (N5), very fine grained, parallel laminae on weathered surface, beds average 15 cm, exposures form very low slopes	12.2
Unit 3:	Dolostone, medium light gray (N6), weathers medium gray (N5), medium grained, ooids, few intraclasts, beds appear massive	19.8
Unit 2:	Limestone, medium gray (N5), weathers light gray (N7), planar and undulose cryptalgalaminae, small domal stromatolites(?), birdseye structures (?), mottled in spots, mudcracks (?), beds average 10 cm, exposures form steep slopes	38.1

		Thickness in meters
Unit 1:	Dolomitic limestone, dark gray (N3), weathers medium gray (N5), fine to very fine grained, few ooids, cryptalgalaminae in lower, trails, beds average 17 cm, exposures form steep slopes	19.8
	Total	190.4

Covered, probably sharp contact

Ute Formation


SECTION 7

Mottled / Bioturbated
Resistant Calcite - Dolomite
Stromatolites
Cryptalgalaminae
Parallel Stratification
Cross - Stratification
Pellets / Peloids
Trails
Vertical Burrows
Intraclasts
Pisoliths
Oncoliths
Ooliths
Stylolites
Birdseye Structures
Mudcracks
Color
Inferred Environment
Lagoon
Inter-tidal
Lagoon
Shoal
Lagoon
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Sample Number
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Section 8

Location: Oneida Narrows, measured up a north facing slope to the east of a private access road approximately 3 miles southeast of Treasurton, Idaho, unsurveyed 1967, S.W. 1/4, N.E. 1/4, Sec 5, T. 14 S., R. 40 E., Franklin County, Idaho

Bloomington Formation

Sharp, planar contact

Blacksmith Formation

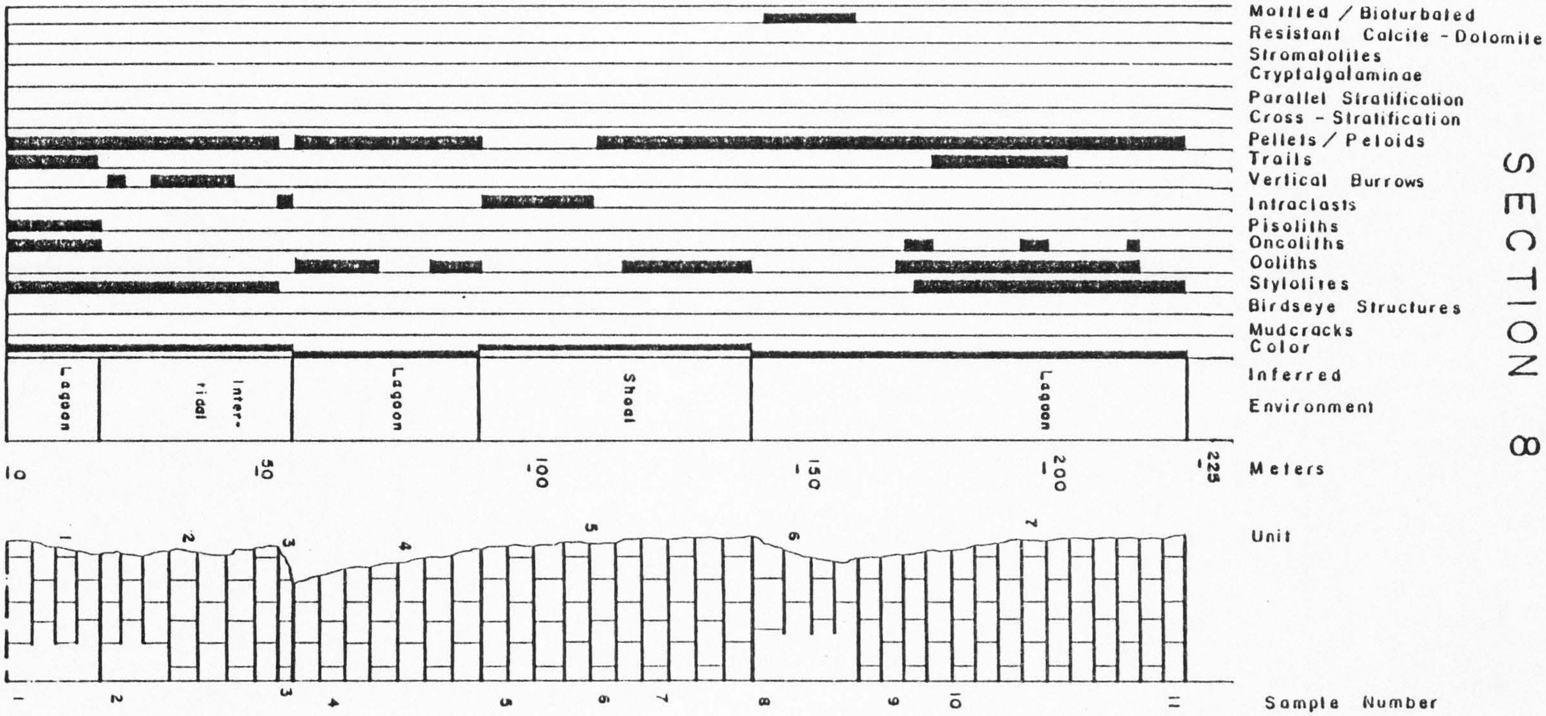
		Thickness in meters
Unit 7:	Dolomitic limestone, dark gray (N3), weathers medium dark gray (N4), fine to medium grained, ooids, oncoliths, stylolites, trails, beds average 18 cm, top poorly exposed	64.9
Unit 6:	Limestone, dark gray (N3), weathers medium dark gray (N4), fine grained, bioturbated, beds average 20 cm, exposures form low slopes and are poor	21.3
Unit 5:	Dolomitic limestone, medium dark gray (N4), weathers pinkish gray to medium light gray (5 YR 8/1 to N6), fine to medium grained, brecciated in middle, oolitic in upper, beds often massive	53.2
Unit 4:	Limestone, dark gray (N3), weathers medium gray (N5), fine to medium grained, ooids, calcite, resistant on weathered surface, beds average 15 cm	37.2
Unit 3:	Limestone, medium dark gray (N4), weathers medium light gray (N6), fine to medium grained, brecciated, large calcite veins throughout, beds massive and poorly exposed	2.4
Unit 2:	Limestone, medium dark gray (N4), weathers medium light gray (N6), fine grained, vertical burrows, stylolites, beds average 25(?) cm, much talus, exposures form moderate slopes and are poor	35.1

		Thickness in meters
Unit 1:	Limestone, medium dark gray (N4), weathers medium light gray (N6), fine to medium grained, ooids, oncoliths, stylolites, trails throughout, bituminous odor on fresh surface, beds average 20 cm, exposures form moderate slopes	18.3
	Total	232.4

Covered, probably sharp contact

Ute Formation

SECTION 8


Mottled / Bioturbated
Resistant Calcite - Dolomite
Stromatolites
Cryptalgalaminae
Parallel Stratification
Cross - Stratification
Pellets / Peloids
Trails
Vertical Burrows
Intraclasts
Pisoliths
Oncoliths
Ooliths
Stylolites
Birdseye Structures
Mudcracks
Color
Inferred Environment
Lagoon
Inter-tidal
Lagoon
Shoal
Lagoon
Meters
10
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Unit
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Sample Number
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11

Section 9

Location: Beaver Basin, measured west to east on a south facing slope approximately 5 miles southwest of Turner, Idaho, S. 1/2, N.E. 1/4, sec. 34, T. 10 S., R. 39 E., Bannock County, Idaho

Bloomington Formation

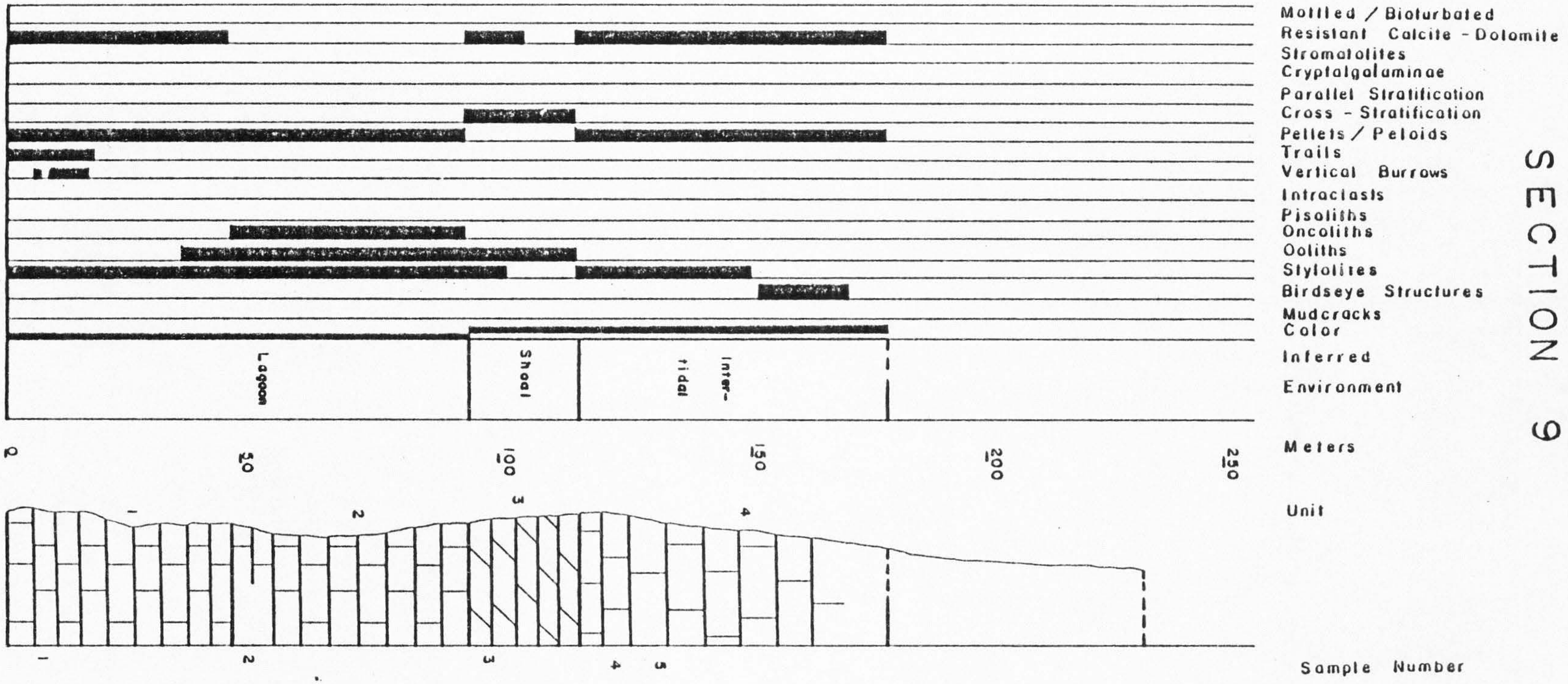
Covered, probably sharp contact

Blacksmith Formation

		Thickness in meters
Unit 5:	Covered, float fine grained limestone (?)	53.3
Unit 4:	Limestone, medium dark gray (N4), weathers medium light gray (N6), very fine grained, birdseye structures filled with calcite, stylolites, beds average 39 cm, often massive, exposures form steep slopes	65.5
Unit 3:	Dolostone, medium gray (N5), weathers light to very light gray (N7-N8), medium grained, oolitic throughout, parallel and cross-bedding, stylolites, beds average 25 cm, exposures form steep slopes	21.3
Unit 2:	Limestone, dark gray (N3), weathers medium gray to medium light gray (N5-N6), fine to medium grained, bituminous odor on fresh surface, few oncoliths, stylolites, cross-beds near top, beds average 15 cm, exposures form moderate slopes	47.2
Unit 1:	Limestone, dark gray (N3), weathers medium light bray (N6), fine grained, trails and vertical burrows near base, calcite resistant on weathered surface (fossil ?), reddish brown (10 YR 4/6) silty parts, stylolites, beds average 20 cm, exposures form moderate slopes	50.3
	Total	237.6

Sharp, planar(?) contact

Ute Formation


Mottled / Bioturbated
Resistant Calcite - Dolomite
Stromatolites
Cryptalgalaminae
Parallel Stratification
Cross - Stratification
Pellets / Peloids
Trails
Vertical Burrows
Intraclasts
Pisoliths
Oncoliths
Ooliths
Stylolites
Birdseye Structures
Mudcracks
Color
Inferred Environment
Lagoon
Shoal
Inter-tidal
Meters
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100
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Unit
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Sample Number
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SECTION 9

Section 10

Location: Water Canyon, measured up a south facing slope approximately 5 miles southwest of Grace, Idaho, S.W. 1/4, S.W. 1/4, sec. 23, T. 10 S., R. 41 E., Caribou County, Idaho, field assistant Matt Hare.

Bloomington Formation

Covered, probably sharp contact

Blacksmith Formation

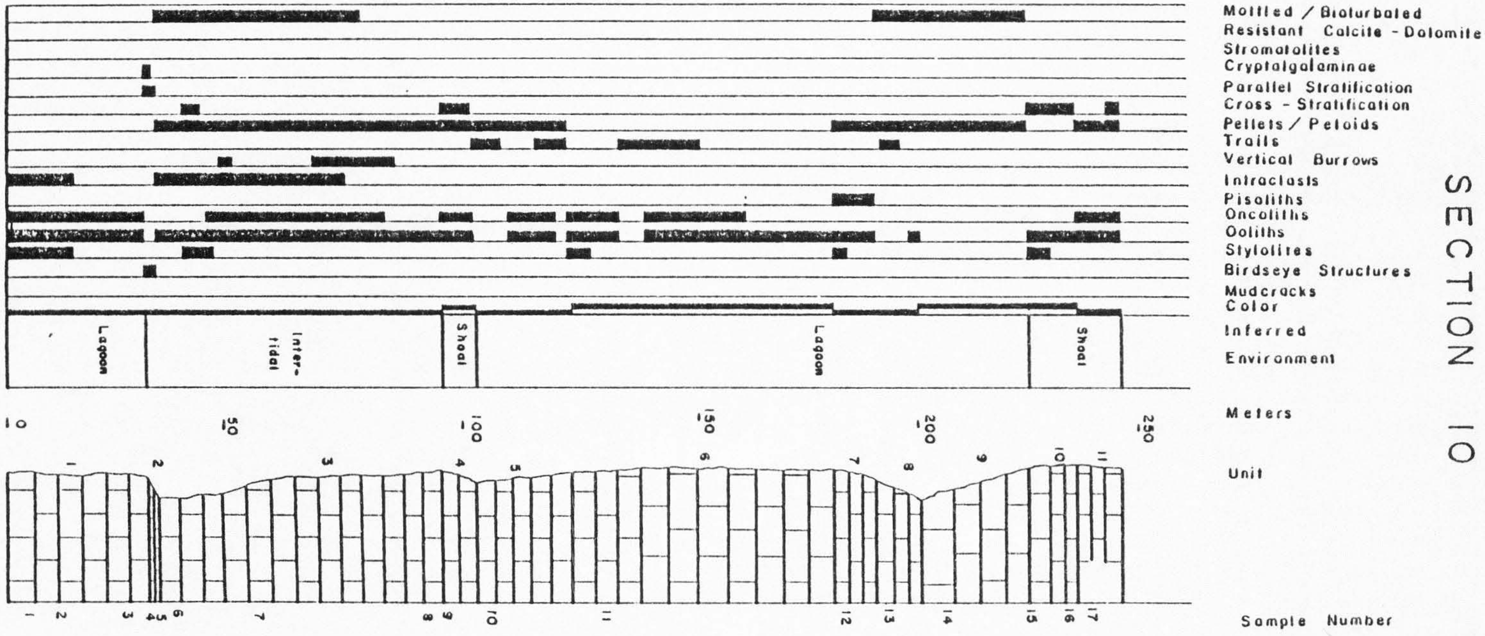
		Thickness in meters
Unit 11:	Limestone, dark gray (N3), weathers medium gray (N5), fine to medium grained, ooids and oncoliths throughout, cross-bedded near top, beds average 20 cm, much talus covering contact, exposures form steep slopes	9.1
Unit 10:	Limestone, medium gray (N5), weathers light gray (N7), medium grained, oolitic and cross-bedded throughout, stylolites, beds average 25 cm, exposures form steep slopes	10.7
Unit 9:	Limestone, medium dark gray (N4), weathers medium light gray (N6), fine to medium grained, ooids near base, bioturbated, beds average 15 cm, exposures form steep slopes	24.4
Unit 8:	Limestone, dark gray (N3), weathers medium dark gray (N4), very fine to medium grained, silty parts, bioturbated trails in middle, ooids in upper, beds average 8 cm, exposures form steep slopes and thin ledges	10.7
Unit 7:	Limestone, dark gray (N3), weathers medium gray (N5), fine to medium grained, ooids and oncoliths(?), throughout, stylolites, beds appear massive	9.1
Unit 6:	Limestone, medium dark gray (N4), weathers light gray (N7), medium to fine grained, ooids oncoliths throughout, trails in middle, stylolites, beds average 30 cm, exposures form steep slopes	59.4

		Thickness in meters
Unit 5:	Limestone, dark gray (N3), weathers medium gray (N5), fine to medium grained, grayish orange(10 YR 7/4) silty parts, trails, ooids, and oncoliths, beds average 5 cm, exposures form steep slopes	21.0
Unit 4:	Limestone, medium dark gray (N4), weathers medium light gray (N6), medium grained, ooids and oncoliths throughout, beds average 17 cm, exposures form steep slopes	7.0
Unit 3:	Limestone, dark gray (N3), weathers medium gray (N5), fine to coarse grained, bioturbated, stylolites, ooids, oncoliths, intraclasts, vertical burrows, beds average 7 cm, exposures form moderate slopes	63.4
Unit 2:	Dolomitic limestone, light brownish gray (5 YR 6/1), weathers moderate yellowish brown (10 YR 5/4), very fine to fine grained, planar cryptalgalaminae, LLH stromatolites, parallel laminae, birdseye structures filled with calcite, beds average 2 cm, poor exposures	1.5
Unit 1:	Limestone, dark gray (N3), weathers medium light gray (N6) fine to medium grained, ooids, oncoliths, stylolites, intraclasts in lower, beds average 15 cm, exposures form moderate slopes	32.0
	Total	248.3

Sharp, planar contact

Ute Formation

SECTION 10


Mottled / Bioturbated
Resistant Calcite - Dolomite
Stromatolites
Cryptalgalaminae
Parallel Stratification
Cross - Stratification
Pellets / Peloids
Trails
Vertical Burrows
Intraclasts
Pisoliths
Oncoliths
Ooliths
Stylolites
Birdseye Structures
Mudcracks
Color
Inferred Environment
Lagoon
Inter-tidal
Shoal
Lagoon
Shoal
Meters
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Unit
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9
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Sample Number
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Section 11

Location: Nelson Canyon, measured up a south facing slope approximately 1-1/2 miles southeast of Soda Point, N.W. 1/4, sec. 20, T. 9 S., R. 41 E., Caribou County, Idaho.

Bloomington Formation

Sharp, planar contact

Blacksmith Formation

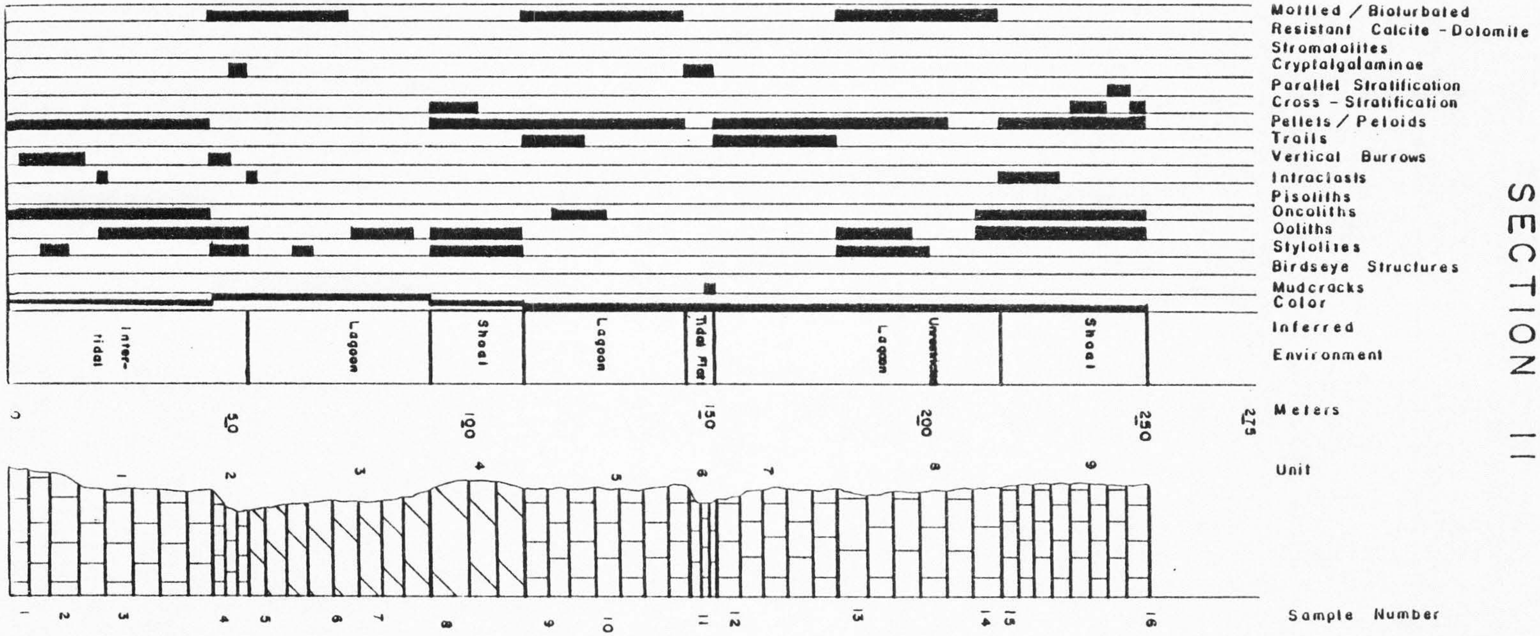
		Thickness in maters
Unit 9:	Limestone, dark gray (N3), weathers medium dark gray (N4), medium to coarse grained, ooids, oncoliths, cross- and parallel lamination, round intraclasts in lower, beds average 14 cm, exposures form steep slopes, poorly exposed at top	33.5
Unit 8:	Dolomitic limestone, dark gray (N3), weathers medium dark gray (N4), fine to medium grained, ooids in lower, stylolites, mottled, beds average 20 cm, exposures form steep slopes and thin ledges	36.6
Unit 7:	Dolomitic limestone, dark gray (N3), weathers medium dark gray (N4), very fine to fine grained, trails, silty parts, beds average 4 cm, exposures form moderate slopes	27.4
Unit 6:	Dolomitic limestone, dark gray (N3), weathers light gray (N7), very fine grained, planar cryptalgalaminae, mudcracks(?), beds average 3 cm, exposures form low slopes	6.1
Unit 5:	Dolomitic limestone, dark gray (N3), weathers medium gray (N5), fine to coarse grained, trails, oncoliths, mottled, beds average 5 cm, exposures form low slopes	36.6
Unit 4:	Limestone, medium dark gray (N4), weathers light gray (N7), medium grained, ooids, cross-bedding, stylolites, beds average 20 cm, exposures form steep cliffs and ledges	21.3

		Thickness in meters
Unit 3:	Calcareous dolostone, medium light gray (N6), weathers pinkish gray (5 YR 8/1), medium to coarse grained, ooids in upper, mottled, beds appear massive	41.1
Unit 2:	Limestone, medium dark gray (N4), weathers medium gray (N5), fine to medium grained, few cryptalgalaminae, mottled, ooids, stylolites, vertical burrows, beds average 12 cm, exposures form low slopes	7.6
Unit 1:	Limestone, medium gray (N5), weathers light gray (N7), fine to coarse grained, vertical burrows, intraclasts, stylolites, beds average 17 cm, poorly exposed at base	45.7
	Total	255.9

Covered, probably sharp contact

Ute Formation

SECTION II


Mottled / Bioturbated
Resistant Calcite - Dolomite
Stromatolites
Cryptalgalaminae
Parallel Stratification
Cross - Stratification
Pellets / Peloids
Trails
Vertical Burrows
Intraclasts
Pisoliths
Oncoliths
Ooliths
Stylolites
Birdseye Structures
Mudcracks
Color
Inferred Environment
Inter-tidal
Lagoon
Shoal
Lagoon
Tidal Flat
Lagoon
Unrestricted
Shoal
Meters
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200
250
275
Unit
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4
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Sample Number
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