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Petrology of the Lower Middle Cambrian Langston Formation, North-central Utah and Southeastern Idaho

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PETROLOGY OF THE LOWER MIDDLE CAMBRIAN LANGSTON FORMATION,

NORTH-CENTRAL UTAH AND SOUTHEASTERN IDAHO

by

Gary Jay Buterbaugh

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

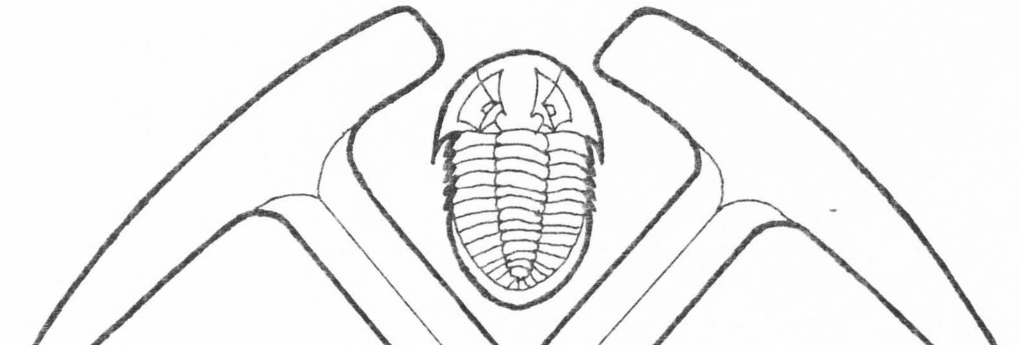
1982

This thesis is dedicated

to my wife and family.

PETROLOGY OF THE LANGSTON FORMATION

NORTH-CENTRAL UTAH AND SOUTHEASTERN IDAHO



BY
GARY JAY BUTERBAUGH
MASTER OF SCIENCE

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Last and most important, I thank my Heavenly Father for granting me the determination and ability to undertake and complete this work, and I thank Him for all my blessings.

Gary Jay Buterbaugh

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ABSTRACT

Petrology of the Lower Middle Cambrian Langston Formation,

North-central Utah and Southeastern Idaho

by

Gary Jay Buterbaugh, Master of Science

Utah State University, 1982

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Department: Geology

The Lower Middle Cambrian Langs·on Formation was studied in the Bear River Range of north-central Utah and southeasternmost Idaho and the Wellsville Mountains of north-central Utah. The depositional textures and sedimentary structures preserved within the rocks were compared with characteristics of similar modern sediments and ancient rock to determine environments of deposition, paleogeography, diagenetic alteration and pattern of dolomitization.

The rocks of the Langston Formation were divided into eleven different rock types. These eleven rock types were formed within four recognizable lithofacies: 1) upper peritidal; 2) inner carbonate shelf; 3) inner clastic shelf; and 4) outer clastic shelf.

The general depositional environment is inferred to have been a shallow subtidal to subaerial carbonate shoal complex. Clastic sediments from the east and north or northwest periodically prograded over the carbonate complex during times of relatively slow subsidence. The deposition of the Langston Formation mudrocks and carbonates occurred during the first Cambrian grand cycle.

During Langston time the study area was located near the outer edge of an equatorial epeiric sea. Clay mineralogy of the insoluble residues indicates a relatively humid climate, yet the humidity was low enough to permit precipitation of sulfate minerals.

Eogenetic diagenetic features include birdseye structures, relict evaporite structures, fibrous rim cement, compaction, and the begining of dolomitization. Mesogenetic diagenesis is characterized by dolomitization and pressure solution. Telogenetic diagenesis is limited to fracturing and calcite infilling.

Dolomitization is believed to have resulted mainly from downward reflux of hypersaline brines, as indicated by relict evaporite structures, zoned dolomite rhombs, and a general association of dolomite with upper peritidal facies. The hypersaline brines formed in the upper peritidal environment, and percolated downward through underlying porous sediments. The greater density of the hypersaline brines displaced less-dense interstitial fluids. These brines were periodically diluted by normal marine water or fresh water.

(166 pages)

INTRODUCTION

General Statement

This report summarizes a study of the environments of deposition and the diagenesis of the Middle Cambrian Langston Formation in southernmost Idaho and north-central Utah. In the area of study the Langston Formation is conformably underlain by the Lower Cambrian Brigham Quartzite and overlain by the Middle Cambrian Ute Formation.

The Langston Formation is the lowermost carbonate unit in the Cambrian stratigraphic sequence of the study area. It represents a major change in the depositional history of the Cambrian sequence. Wide distribution, fair to good exposure, vertical and lateral diversity in lithology, and its unique position in the Cambrian sequence lead to the selection of the Langston Formation for study.

Purpose of the Investigation

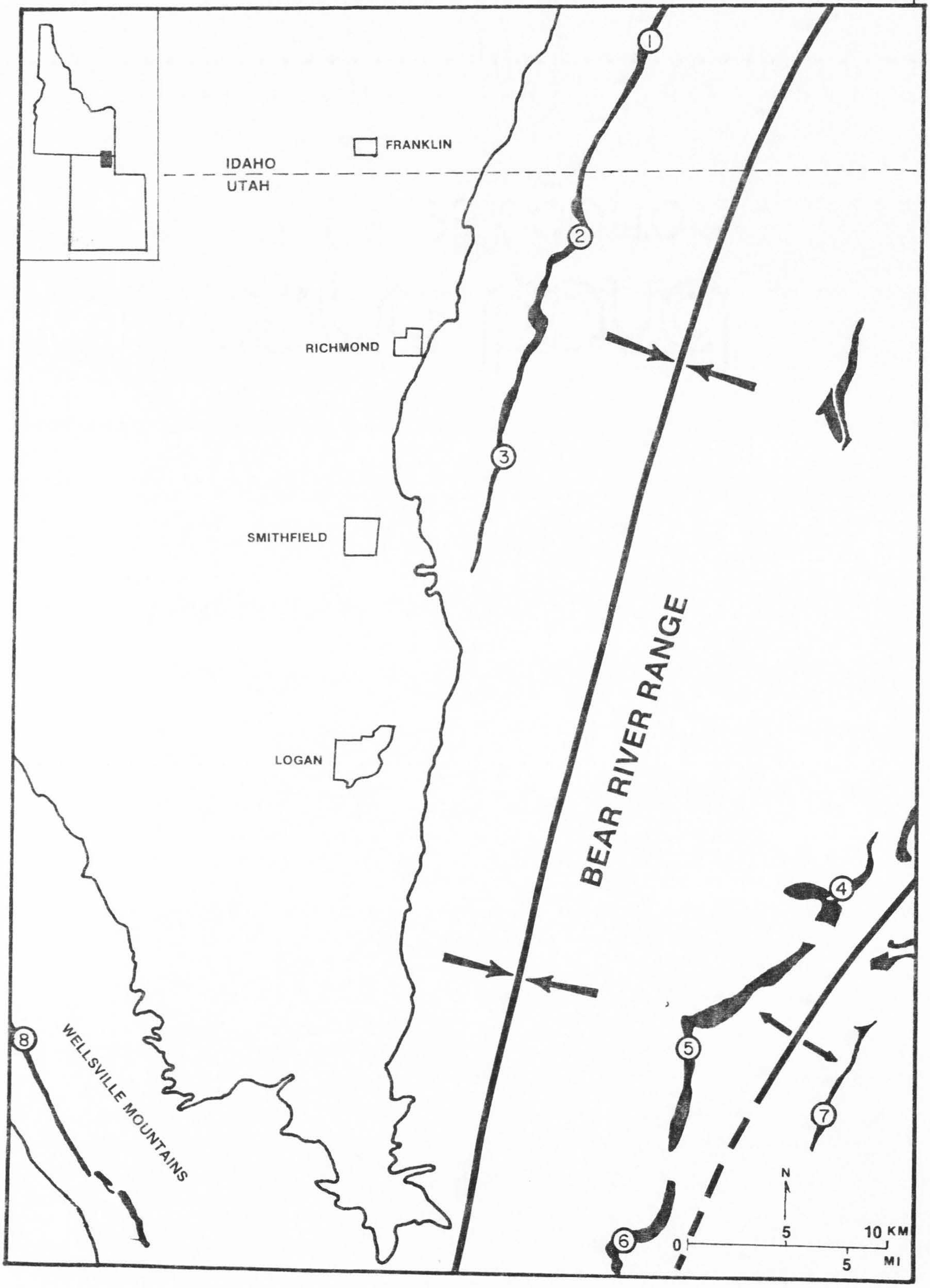
The objectives of this thesis were: (1) to determine the environments of deposition as indicated by lithology and sedimentary structures; (2) to determine the paleogeographic setting; and (3) to determine the order of diagenetic events, with emphasis on dolomitization.

Location

Six of the eight measured sections are located within the Logan Quadrangle (Fig. 1). The remaining two sections are located just outside of it, in the Preston Quadrangle to the north, and in Box Elder County to the west. The area is bounded to the north by latitude 42°02' N and on the south by latitude 41°30'N. The boundary to the east is longitude 112°04'W and to the west, longitude 111 30'W. The study area extends east-west for 42 kilometers and north-south for 62 kilometers, for a total area of 2604 square kilometers. Elevations below 5135 feet comprise approximately 2/5 of the study area and are covered by Quaternary lacustrine deposits of Lake Bonneville. At elevations above the Lake Bonneville deposits, Recent and Pleistocene deposits of drift and alluvial sediments cover many areas (Williams, 1948).

Seven of eight sections were measured in the Bear River Range. Two of the measured sections (2,8) had excellent exposure, three (3,4,5) had good exposure and three (1,6,7) had fair exposure. Four sections (1,2,3,7) were exposed on west-facing slopes, three (4,6,8) on south-facing slopes, and one on an east-facing slope. The lower contacts in four of the sections (2,4,5,8) were well exposed, graditional, and conformable. In three sections (1,3,7) the lower contacts were covered but measurable to within ± 2 meters. The upper contact in all sections except section 6, was well exposed, sharp, and conformable. The top 30% of section 6 was covered in the area measured, but in the same general area Rigo (1968) measured a middle limestone-shale unit and an upper dolostone unit.

FIG. 1 - Map showing outcrops of the Langston Formation, Logan Peak Syncline, and Strawberry Valley Anticline, north-central Utah and southeastern Idaho. Circled numbers are locations of measured sections. (adapted from Maxey, 1958)


FRANKLIN
IDAHO
UTAH
RICHMOND
SMITHFIELD
LOGAN
BEAR RIVER RANGE
WELLSVILLE MOUNTAINS
1
2
3
4
5
6
7
8
N
0
5
10 KM
5
MI

Three sections (1,2,3) were measured on the west limb of the Logan Peak Syncline. Three sections (4,5,6) were measured on the west limb of the Strawberry Valley Anticline, and one section (7) on the east limb. The last section (8), Miners Hollow, contributed most to the east-west control of the study area and is exposed on the west-facing side of the Wellsville Mountain Monocline. No faults were found within any measured section.

Extensive field reconnaissance of 14 sections showed that 6 were unsuitable for measuring due to faulting and/or very poor exposure. Most sections were easily accessible by motor vehicle and only required 2-3 kilometers of hiking and climbing to reach exposed outcrops.

Geologic Setting

The Bear River Range occupies about 3/5 of the study area and consists of two ridges separated by a depression. The front ridge is located to the west and contains Naomi and Logan Peaks. The eastern ridge is a combination of Temple Ridge and Hayes Ridge. These two ridges (the eastern ridge and the front ridge) comprise a fault block bounded on the west by the East Cache fault, and on the east by the Temple Ridge and Hayes Ridge faults. The front ridge is a topographic high superimposed on a structural low, the Logan Peak Syncline. The Strawberry Valley Anticline, to the east, runs parallel to the Logan Peak Syncline (Williams, 1948).

Field and Laboratory Methods

The field work was conducted between June 1, 1981 and October 15, 1981. Reconnaissance field work included locating possible sections for measurement using Williams' (1948) geologic map of the Logan quadrangle, and section locations described in Maxey (1958), Oriel and Armstrong (1971), and Rigo (1968). Once a section was located in the field, it was then scouted for faults, large covered intervals, or other undesireable features. Measurement and description of acceptable sections usually required 2 to 3 days.

All sections were measured with a Brunton compass and a Jacob's staff according to the methods and procedures described in Compton (1962) and Kottlowski (1965). Descriptions included section attitude, exposure, nature of contacts, topography, thickness, rock type, texture, color, bedding, organic and inorganic features, and nature of dolomitization.

The rock-color chart of Goddard (1963) was used for determining rock color. Average bedding thicknesses were recorded according to the following scheme: thin bedded = 1-5 cm; medium bedded = 5-25 cm; and thick bedded = 25+ cm. Shale thicknesses were classified according to Potter et al. (1980).

Organic sedimentary features such as pellets, onkoids, biotic components, trace fossils, and cryptalgal structures, along with inorganic sedimentary features such as peloids, pisoliths, intraclasts, ooids, mudcracks, birdseye structures, cross- and parallel- laminations were recorded. Diagenetic features such as stylolites, and fractures were also noted. Representative samples were collected within each recognizable unit, and more than one sample was collected in units with gradational changes. When a thick unit (> 15 meters) appeared homogeneous, samples were collected at approximatly 15 meter intervals. A total of 135 samples were collected. The laboratory work included preparation of cut and polished slabs of all 135 samples. Thirty-four thin sections were prepared from the samples of sections 5 and 8. Section 8, Miners Hollow, is representative of the sections in the north and west of the study area; similarly, section 5, Blacksmith Fork Canyon, is representative of the sections in the southeastern part of the area. An additional 24 thin sections were prepared from selected samples of the remaining 6 sections.

The thin sections were stained with Alizarin-red S (Friedman, 1959) to distinguish calcite from dolomite. Examination was accomplished with the use of both binocular and petrographic microscopes. Due to extensive recrystallization and dolomitization, examination with the petrographic microscope to determine original textures proved to be less than satisfactory without the aid of a light diffuser (Delgado, 1977). Delgado recommended the use of a magnesium-oxide-coated glass plate placed under the thin section to be examined. He also stated a piece of white paper would give similar results. In this study a plain white paper diffuser was used and found to be just as effective and much easier and less cumbersome to use. The binocular microscope, used with the attached light diffuser, also proved to be invaluable in determining original textures. Sandstones, mudrocks, and sandy carbonates were examined by standard petrographic techniques, but the paper diffuser was also a great aid in their study.

The amounts of acid-insoluble residues and organic matter in 135 samples were determined. The insoluble residues were isolated from the carbonate of each sample by digestion of the carbonate in 20% HCl. They were rinsed three times in tap water, then once in de-ionized water. They were then air dried until desiccation features formed and then oven-dried at 70°C for a minimum of four hours. They were then weighed. Organic matter content was determined using the insoluble residues. Organic matter was oxidized in a 30% solution of Chlorox. They were rinsed a total of 5 times, including a final rinse in de-ionized water. They were then dried and weighed in the same manner as the acid-insoluble residues.

The percentages of organic matter may have a large error factor due to the techniques used in washing the insoluble residues. During the rinsing stages, the organic matter, being less dense, floated to the surface, and large percentages may have been washed away. However, organic matter percentages compare reasonably well with average organic matter percentages found by Gehman (1962).

The mineral composition of each insoluble residue was then determined by x-ray diffraction. Oriented-sample slides were prepared by grinding the acid-insoluble residues to a size which would pass through a 60 mesh sieve. A powder-water slurry was then placed on a glass slide and allowed to dry. It was then scanned from

$2^{\circ}2\theta$ to $35^{\circ}2\theta$ at $2^{\circ}2\theta$ per minute using Ni-filtered CuK radiation at 35 Kv and 16 mA, on a Siemens Krystalloflex IV x-ray diffractometer.

In order to distinguish between the clay minerals present, 69 samples were rescanned. Sixty-four of these samples were exposed to ethylene glycol vapor for 1 hour at $60^{\circ}C$ to distinguish the montmorillonite group from chlorite and vermiculite clay minerals (Carroll, 1970). This process expands the montmorillonite structure from 15 A to 17 A, but does not affect the chlorite or vermiculite. Thirty-eight samples were heated to $550^{\circ}C$ for 1 hour to collapse the structure of any kaolinite present, this allowed identification of the kaolinite-chlorite peak (Carroll, 1970).

Paleoenvironmental and paleogeographic interpretations were aided by the use of an isopachous map, geologic sections, a fence diagram of lithofacies, and a fence diagram of total dolostone, limestone, and non-carbonate.

PREVIOUS STUDIES

In 1878, King, during exploration with the Fortieth Parallel Survey, first made mention of the undivided Cambrian rocks of the Blacksmith Fork area (King, 1878, p. 154, in Deiss, 1938).

While doing a general reconnaissance of northeast and central Utah, Walcott (1908a, p. 8) made the first description of the Langston Formation in Blacksmith Fork Canyon. He published a detailed study of the sections and faunas following his initial reconnaissance work (Walcott, 1908b, c, d). Walcott (1908d) designated Langston Creek as the type locality for the Langston Formation, but he stated that it is most readily accessible in Blacksmith Fork Canyon where he measured it. Walcott, in all publications, incorrectly identified the lower shale member of the Ute Formation as the Spence Shale. The Spence Shale member is absent in the Blacksmith Fork area.

The next study of the Langston Formation was done by Richardson (1913) near Garden City, in the Randolf Quadrangle. In this study he reaffirmed Walcott's 1908 name and definition of the Langston, and stated that the Cambrian section in the Randolf Quadrangle was essentially the same as in the Blacksmith Fork area.

Again in 1927, Walcott's names and definitions were confirmed by Mansfield (1927), in a study of southern Idaho.

Deiss in 1938, (p. 1116) stated that Walcott's original definitions of the Blacksmith Fork section " ... are nearly all so brief, incomplete and generalized that the formations cannot be recognized from them." He emended Walcott's definition of the Langston Formation and designated the type locality as North Cottonwood Canyon on the north side of Blacksmith Fork. The Spence Shale member was still included in the Ute Formation.

Williams and Maxey (1941, p. 279) defined the Langston as " ... a sequence of shales, limestones, and dolomites that, though changing laterally to some extent, constitute a satisfactory mappable (lithologic) unit. The Spence Shale is a member of the Langston Formation separated in a normal sequence from the Brigham quartzite by only a few feet of crystalline limestone." This was the first work that recognized the Spence Shale as a lower member of the Langston Formation. Williams (1948) described the Langston again from his work with Maxey.

Maxey (1958, p. 669) stated Deiss's new 'type' locality was abnormal and further stated that the base of the formation should be drawn at the first distinctive limestone bed above the lower quartzite. He then remeasured the Langston Formation one mile south of Deiss's section in South Cottonwood Canyon, off Blacksmith Fork Canyon, and excluded the basal sandstone which Deiss had included. He concluded that the High Creek section " ... is the best and most nearly typical exposure of the Langston Formation" (Maxey, 1958, p. 669).

Maxey (1958) described the interlayered and intertonguing relationship of the Cambrian shales and their upper and lower carbonate counterparts. Rigo (1968) believed the Spence Shale member to the north and the unnamed shale member to the south represent small regressive tongues within the overall transgressive sequence of the Langston Formation.

Oriel and Armstrong (1971) proposed a modification of the definition of the Langston Formation. They proposed that the term Langston be restricted to the dolostone member. The Spence Shale member was designated as a tongue of the Lead Bell Shale. The lower member was designated as the Naomi Peak Tongue of the Twin Knobs Formation, and the upper limestone was designated as a new formation, the High Creek Limestone.

These descriptions of the Langston Formation formed parts of larger works describing the Cambrian stratigraphy of the region. Maxey's 1958 definition of the Langston Formation is used in this report because it appears to be widely accepted in Utah and because the boundaries between the 'new' formations of Oriel and Armstrong are often gradational or unclear.

The paleontology of the Langston Formation, especially the Spence Shale member, has been described by Walcott (1908b, c, 1912), Robison (1969), Robison and Sprinkle (1969), Gunther and Gunther (1981), and Resser (1939).

TERMINOLOGY

General Statement

According to Leighton and Pendexter (1962) a carbonate rock is one composed of at least 50% carbonate. Carbonate rocks are further subdivided into dolostones and limestones: a dolostone contains more than 50% dolomite and a limestone contains more than 50% calcite. The modifier 'calcareous' specifies that 10 to 40% of a dolostone is calcite while the modifier 'dolomitic' specifies that 10 to 40% of a limestone is dolomite. A carbonate rock containing greater than 10% of a mineral other than dolomite or calcite is so specified in the name (e.g. quartzose dolomitic limestone).

The classification scheme of Dunham (1962) was used for textural classification. Non-mineralogic terms were also used in describing rock samples and are discused in the following sections.

Cryptalgal Structures

The classification and environmental significance of cryptalgal structures has been well documented by Logan et al. (1964) and Aitken (1967). Cryptalgal structures are by definition " ... those believed to originate through the sediment-binding and/or carbonate-precipitating activities of nonskeletal algae" (Aitken, 1967, p. 1163). Cryptalgal structures include: cryptalgalaminations; stromatolites; oncolites; and thrombolites. Stromatolites are further subdivided on the basis of their morphology and an abbreviated classification scheme is provided by Logan et al.

(1964). In this work, Aitken (1967) and Logan et al. (1964) will be used as the basis for describing rocks with cryptalgal structures.

Allochems

Folk (1962, p. 63) has defined allochems as " ... all the organized carbonate aggregates that make up the bulk of many limestones." He further divided allochems into 4 groups: 1) intraclasts; 2) ooids; 3) fossils; and 4) pellets. These four groups are defined in the following sections.

Intraclasts

The term intraclast was proposed by Folk (1962, p. 63) as an allochem which was a " ... fragment of penecontemporaneous, generally weakly consolidated carbonate sediment that has been eroded from adjoining parts of the sea bottom and redeposited to form a new sediment." They have been reworked from and deposited within the same formation. Highly reworked intraclasts would probably be classified as peloids.

Ooids and Pisolites

Wilson (1975, p. 12) defined ooids as " ... spherical multiple coated particles in which the laminae are smooth and constitute a relatively thick coating." Pettijohn (1975, p. 83) set a size limit of 0.25 to 2.00 mm in diameter. Leighton and Pendexter (1962, p. 60) defined pisolite as " ... a grain type similar to an oolite, and generally 2 mm or more diameter." Pisolites are distinguished from onkolites (or onkoids) by their concentric unbroken laminations and implied non-algal origin.

Fossils

Fossils are the lithified remains of once-living organisms. They may form allochems in the form of broken pieces or whole biotic units.

Pellets and Peloids

The term pellet has been used as a general term for a silt-to sand-size micritic grain, lacking internal structure, and having a general oval shape (Leighton and Pendexter, 1962). McKee and Gutschick (1969) introduced the term peloid for a grain of ambiguous origin, which may include intraclasts, pellets, skeletal components, and ooids (Pettijohn, 1975). In this paper the term pellet shall imply a fecal origin and peloid shall imply an unknown origin.

Burrows, Bioturbation, and Mottling

Burrows are trace fossils, and are distinguished from body fossils in that they " ... represent the behavior or activity by organisms rather than the actual parts, or casts and molds of body parts" (Frey, 1975, p. 15). The classification of trace fossils by Seilacher (1953, in Frey, 1975, p. 49) is used in this study.

When a sediment is "churned", the term bioturbated is applied (Moore and Scruton, 1957). In this paper the term burrowed is used to imply organic activity that has not destroyed all of the original depositional texture, while bioturbated is used to imply destruction of original depositional texture. The boundary between a burrowed and a bioturbated sediment is gradational. The texture created by bioturbation is termed mottling. A mottled texture usually results from bioturbation but is not restricted to it.

Bedding and Laminations

Bedding, as stated by Pettijohn (1975, p. 102), is characterized by rock units of a tabular or lenticular form, which contain a degree of lithologic or structural unity which in turn sets them apart from their interstratified counterparts. Pettijohn stated the lower limit for a bed is 1 cm. Similar structures less than 1 cm thick are termed laminations. There appears to be no accepted or standard classification for bedding, so bed thicknesses were measured and later defined in this report to be: 1-5 cm = thin bedded; 5-25 cm = medium bedded; and 25+ cm = thick bedded. Laminations were classified according to the modification of Potter et al. (1980) to the existing bedding-lamination schemes of Ingram (1954) and McKee and Weir (1953).

Compaction Features, Stylolites, and Pseudostylolites

Ginsburg (1957) found that initial porosities of carbonate sediments range from 40 - 70%. In contrast, ancient limestones have less than 5% porosity. This great reduction in porosity has resulted mainly from compaction (Shinn et al., 1977). Shinn et al. have found that compaction of carbonate muds can reduce original porosities by a minimum of 50%. This porosity reduction results in the production of compaction features, as shown by the molding of some structures around others. The concentration of organic matter (and clay or fine silt?) results in compaction features termed pseudostylolites (Shinn et al., 1977). The term compaction feature is used in this report to describe structures which are assumed to have formed by compaction. The term pseudostylolite is used specifically to designate a type of compaction which has the appearance of a wispy, stylolite-like structure.

Stylolites result from pressure solution, which results from late stage compaction, or more precisely, volume reduction, in carbonate rocks. Wagner (1913, in Bathurst, 1975, p. 469) was the first to explain stylolites in terms of pressure solution. The stylolites and compaction features of the Langston rocks are often closely interrelated. Compaction features often appear to serve as a nucleus or template for stylolite formation. This is shown by the crosscutting relationship of stylolites superimposed on compaction features. The same relationship exists between stylolites and clay/silt layers. The term stylolite in this report is used to imply an aggregate stylolite, rather than an intergranular stylolite (Park and Schot, 1968).

Wanless (1979) stated that stylolitization, especially non-sutured pressure solution, was reponsible for most of the volume reduction in Paleozoic carbonate rocks. He stated that the physical compaction of Shinn et al. (1977) was insignificant in volume reduction. In a reply to Wanless (1979), Pratt (1982) disclaimed the theory and supported the theory of soft sediment compaction as the major source of volume reduction. In Wanless (1982), further evidence was provided in support of the volume reduction theory. It seems probable that both processes contributed to the volume reduction in Paleozoic rocks.

Birdseye Structures

Birdseye structures, or fenestrae, are unsupported voids. They are usually associated with cryptalgal structures, but desiccation, oxidation, and lithification are also important in their formation (Logan, 1974, p. 214). Logan provided an excellent description and classification of birdseye structures and defined 3 major types: laminoid; irregular; and tubular. Two of these types, laminoid and irregular, are found in the Langston Formation.

Evaporite Textures

Precipitation of anhydrite and gypsum within a host sediment can produce unique structures and textures (Maiklem et al., 1969). The same minerals that form these unique features are highly susceptible to replacement and solution.

Anhydrite may precipitate in closely-packed nodules within the host sediment. This produces a chicken-wire anhydrite texture (Tucker, 1981, p. 163) or a nodular-mosiac (Maiklem and others, 1969, p. 196). When beds of evaporites are dissolved, the host sediment collapses to produce a brecciated texture (Maiklem et al., 1969, p. 196).

ROCK TYPES

General Statement

In order to simplify the lithologic jigsaw puzzle of paleoenvironments, rock samples were categorized into groups with similar features. Eleven rock type groups were isolated. Some variation within these groups was encountered, and subtypes were created within the rock types to accommodate these variations.

Rock Type A

Rock type A is found in all sections. In outcrop it may be exposed as small, steep cliffs or ledges, generally weathering to a shade of brownish red. It is usually thin to medium bedded and finely laminated. The maximum thickness of any one unit is 6.7 meters. This rock type may comprise up to 5% of a given section.

After Dunham (1962), this rock type is classified as an algal boundstone (Fig. 2). In all sections it is composed of dolostone, except in section 2 where there is a lateral change from limestone along the line of measurement to dolostone on either side. The dominant allochems are peloids or pellets, and intraclasts. Fossil fragments are rare and onkoids are never found.

Insoluble residue contents average 3.9% and x-ray diffraction analysis revealed their mineralogical composition to be (in order of decreasing abundance) quartz, illite, albite, microcline, and kaolinite. Hematite pseudomorphs after pyrite were found during

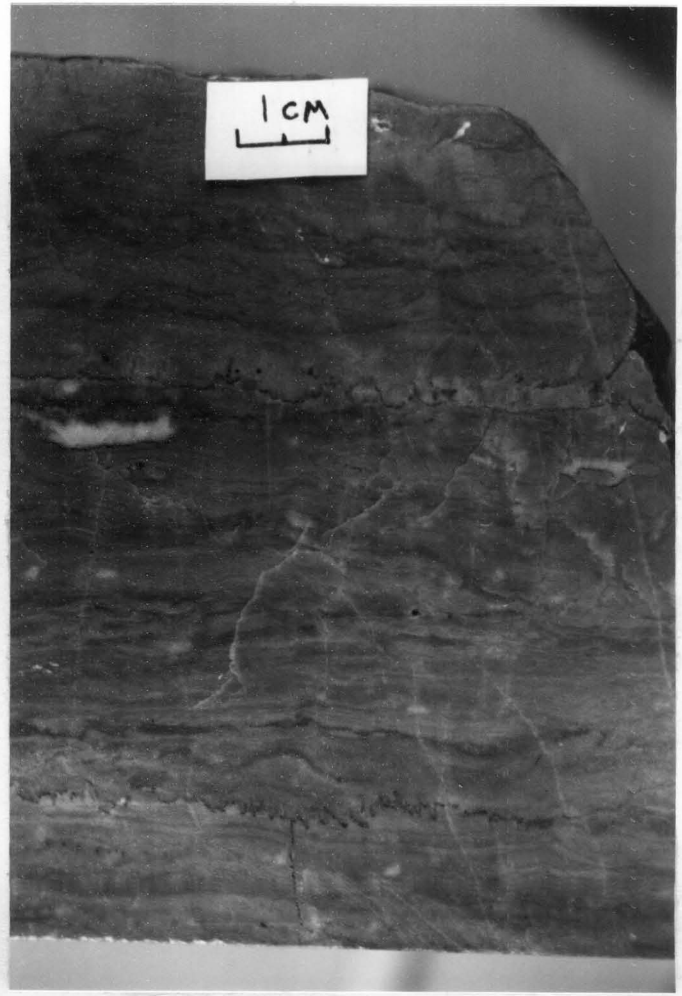


FIG. 2 - Rock Type A

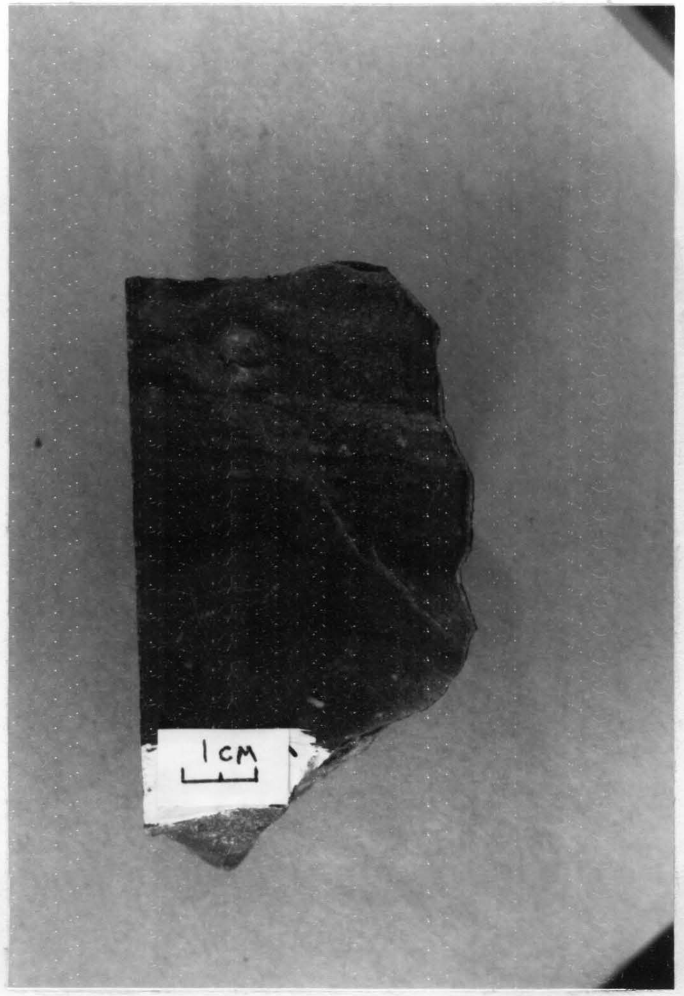


FIG. 3 - Rock Type B

petrographic examination.

Fresh color ranges from dark to light grey (N4-N6) and the organic matter content averages 0.12%.

The most characteristic sedimentary structures of this rock type are cryptalgalaminae and small stromatolites. They are similar to the structures produced by the smooth and tufted algal mats of Logan et al. (1974). The stromatolites fit in Aitken's (1967) classification scheme as Laterally Linked Hemispheroids (LLH). The cryptalgalaminae average about 1 mm thick. Within the laminations are peloids, pellets, and intraclasts which were deposited between the binding algal mats. Mud cracks are fairly common. Fine to medium laminoid and occasionally irregular birdesye structures are common in all but a few samples.

Diagenetic features are mostly limited to stylolites. Stylolitic amplitudes average 1-5 mm, but are frequently very numerous and may represent a large amount of volume loss.

Rock Type B

Rock type B is found in half of the sections (3,4,7,8) and forms steep cliffs or resistant outcrops. Bedding is highly variable and ranges from thin to thick bedded, and may be massive. The thickest exposure of this rock type forms a unit of 40 meters, and comprises up to 32% of a given section.

Type B may be a peloidal wackestone to packstone (Fig. 3), but petrographic examination of some samples reveals only a crystalline dolostone (Fig. 3). Section 2 contains rock type B as limestone along the line of measurement, but it grades laterally into dolostone. In all other sections this rock type is dolostone. Peloids or pellets are the dominant allochems, although intraclasts of rock type A are locally abundant. Rock types A and B are associated with one another, and in section 2 these are interbedded on a small scale.

Insoluble residues make up an average of 0.66% of this rock type. Quartz and illite constitute the principal minerals while microcline and albite are found in a few samples.

Rock type B ranges in color from medium dark grey to light grey (N4-N7). The mean organic matter content is 0.10%, and the organic materials appear to be concentrated in dark, wispy pseudostylolites.

Fine to medium irregular birdseye structures are present to some degree in all samples. Most samples contain pseudostylolites. Some samples contain structures which may be relict chicken-wire anhydrite (Tucker, 1981, p. 163-164) or a nodular-mosaic (Maiklem et al. 1969, p. 196). This texture results from precipitation of closely packed anhydrite nodules. Due to the present mineralogy and crystalline state of the sample, this texture can not positively be attributed to anhydrite precipitation. This texture may possibly have resulted from compaction structures forming around early-cemented areas or irregular birdseye voids.

Rock Type C

Rock type C is found in 5 of 8 sections (1,3,5,6,7). It is exposed as resistant outcrops or as steep cliffs. This rock type forms units up to 35 meters thick, and comprises up to 23% of a given section.

Peloidal-pelletal wackestones to packstones comprise the rock types with recognizable textures (Fig. 4). Due to diagenesis, many samples must be classified as crystalline carbonates. In all sections rock type C is dolostone. The major allochems are peloids-pellets.

The mean insoluble residue content is 5.6%, with the dominant minerals being quartz, illite, and albite with kaolinite, chlorite, microcline, montmorillonite, and goethite occurring locally.

Rock type C ordinarily has a uniform characteristic color of medium light grey (N6). Locally the color may vary slighty. The mean organic matter content is 0.08%. This rock type commonly has streaks and areas which are just slightly darker than the rock as a whole. These darker areas may be due to concentrations of organic matter.

Thin to coarse laminoid and irregular birdseye structures are normally present. As in rock type B, relict chicken-wire anhydrite structures may be present locally.

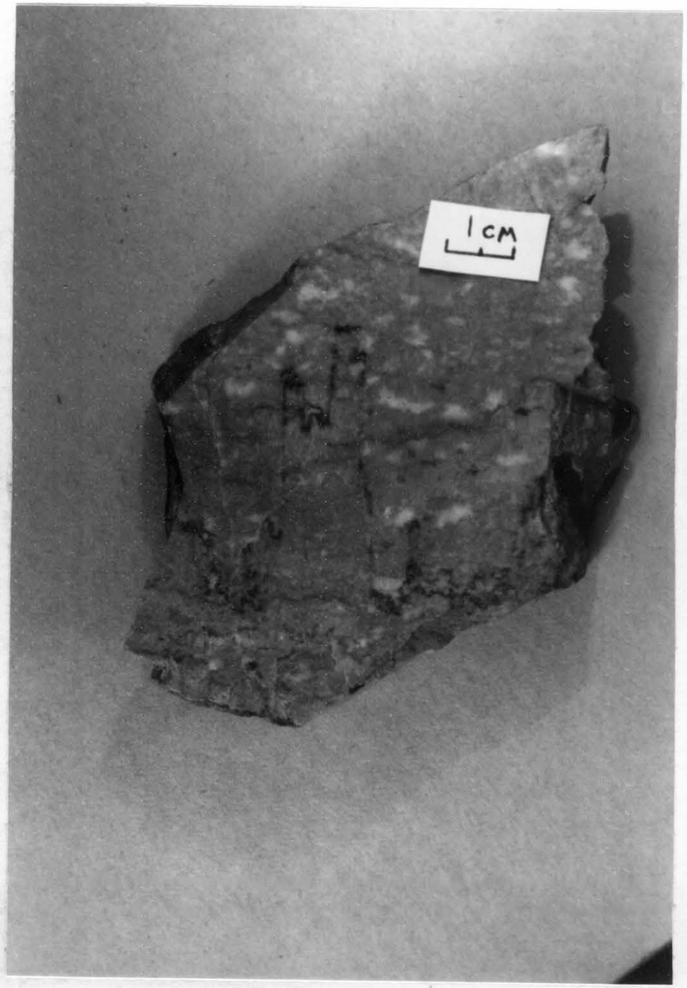


FIG. 4 - Rock Type C, showing multiple orders of stylolitization.

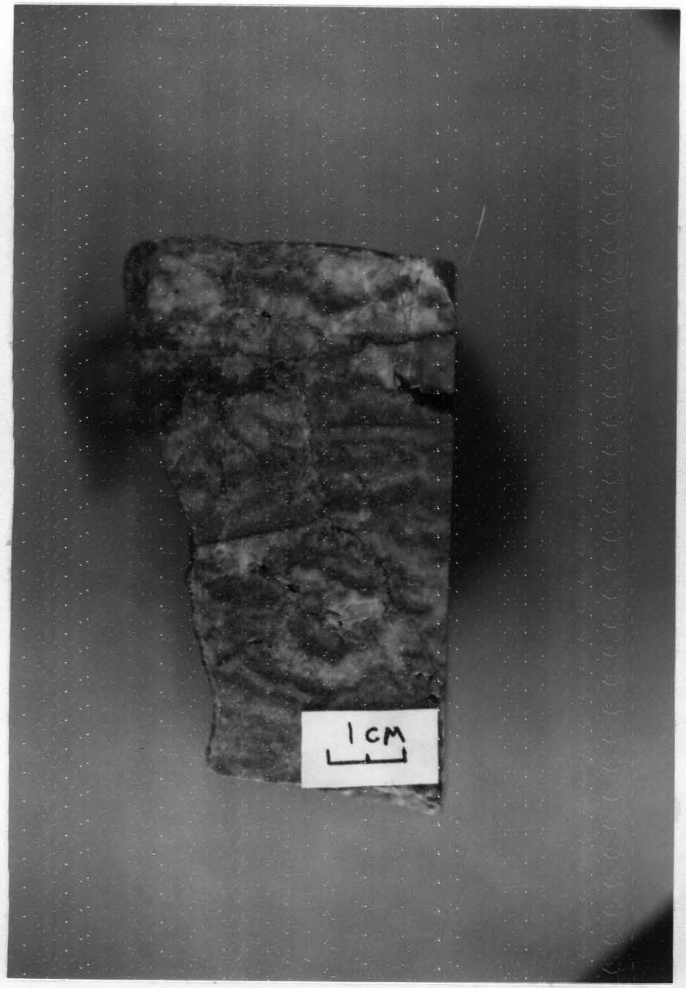


FIG. 5 - Rock Type C, Subtype 1

Rock type C subtype 1, varies from type C in that it contains disruptive evaporite structures (Fig. 5). These structures resemble disturbed bedding and most likely resulted from dissolution of gypsum or anhydrite. This type of evaporite structure is classified as brecciated, according to Maiklem et al. (1969, p. 196-197). It occurs in 4 sections and may totally or partially replace the birdseye texture.

No distinct compaction features are observable but stylolites are common.

Rock Type D

Rock type D is found in 6 of 8 sections (1,2,3,4,5,8). Rarely does it contain any bedding structure and therefore it is usually massive. It occurs in units up to 19 meters thick, and forms up to 12% of a given section.

This type is texturally a peloidal-pelletal wackestone to packstone (Fig. 6). It occurs as dolostone or calcareous dolostone. Peloids and/or pellets are virtually the only allochems, with a few onkoids occurring locally. This rock type is gradational with rock type E, and is distinguished primarily by the large amount of bioturbation. The bioturbation usually produces an indistinct to distinct mottled texture (Moore and Scruton, 1957).

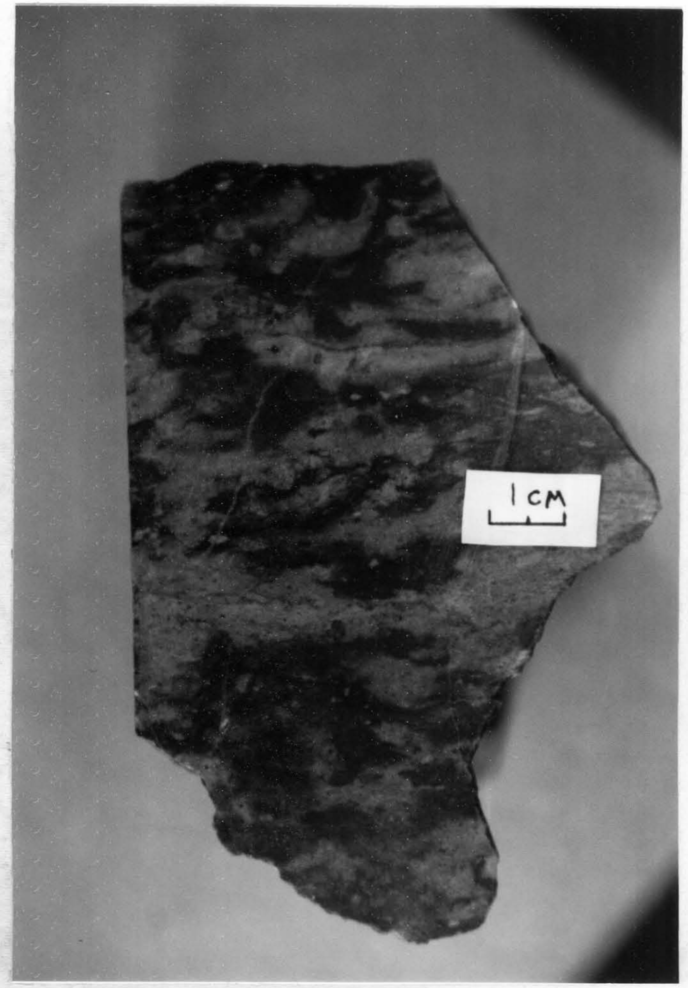


FIG. 6 - Rock Type D

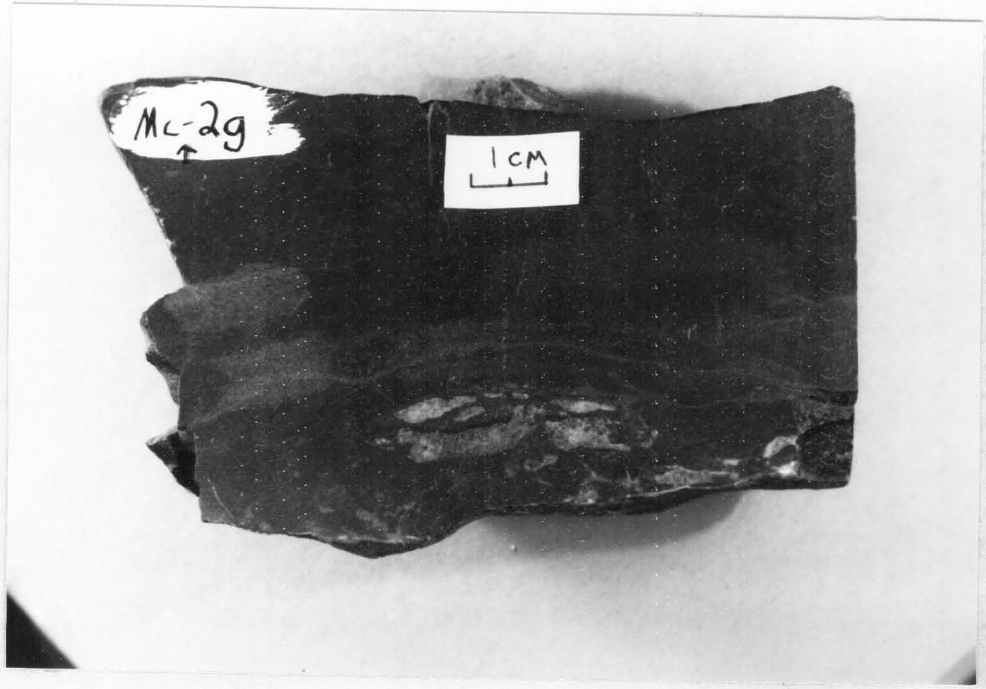


FIG. 7 - Rock Type E

Type D has an average insoluble residue content of 0.94%, which consists of quartz and illite with lesser amounts of albite and kaolinite.

Since mottling is the most characteristic feature of this rock type, there are two major colors. The darker color is usually dark grey (N3) and its lighter counterpart is often light grey (N7) or a light red to yellow variation. The average organic matter content is 0.09%. The organic material is probably concentrated within the dark areas.

Most sedimentary structures have been destroyed as a result of bioturbation. Some original layering is preserved and enhanced by compaction in some samples, but only in a disrupted and irregular form. A few burrows are superimposed on the mottled texture, indicating at least two episodes of organic activity, the latter less intense than the former.

Diagenetic features are limited mainly to compaction. Very few stylolites are found in this rock type.

Rock Type E

Rock type E is the most commonly found of the rock types and is found in all sections. It crops out in many forms, ranging from small, resistant ledges to steep, rugged cliffs. Bedding size also varies greatly, from thick to thin. It forms units as thick as 91 meters, and comprises as much as 55% of a given section.

Textural classifications vary from mudstones to packstones, but wackestones are the most common (Fig. 7). Limestones form the major portion of type E, although calcareous dolostones and dolostones are locally present in small amounts. Fossil fragments, peloids, pellets, onkoids, and intraclasts make up the suite of allochems present. Peloids and/or pellets, and onkoids usually dominate, but fossil fragments or intraclasts may predominate locally.

Insoluble residues average 3.8%, and are composed of quartz, illite, and albite with lesser amounts of microcline, orthoclase, kaolinite, chlorite, and rarely goethite and hematite.

This rock type is invariably dark grey (N3), but locally may be slighty mottled with a lighter grey (N6). The mean organic matter content of type E is 0.16%. The uniform dark color may indicate that the organic matter is evenly dispersed throughout the rock.

A few wispy pseudostylolites are present, indicating early compaction. Onkiods are often flattened parallel to bedding and may also indicate early compaction. It is equally likely that these flattened onkiods may simply reflect elongate nuclei. Many limonitic silt and clay seams are often present in the samples. When they occur as wispy stylolite-like structures, similar to concentrations of organic matter, they are classified as psuedostylolites or compaction features. Trace fossils are present in the form of feeding burrows, or <u>Fodinichinia</u> (Frey, 1975). Textural mottling occurs to a limited extent, and may have resulted from organic activity, selective dolomitization, or from areas of high iron-rich clastic concentrations. This type of mottling is classified as primary or secondary irregular layers according to Moore and Scruton (1957).

Diagenetic structures include compaction features and some stylolites along compacted silt and clay layers.

Three subtypes have been identified, based on their relative amounts of onkoids. Subtype 1 contains at least 50% onkoids and has a packstone texture (Fig. 8). It also may contain a high percentage of peloids.

Subtype 2 is similar to subtype 1 in that it contains more than 50% onkoids, but is distinguished by its grainstone texture, and the presence of fibrous rim cement concentrated on the bottom side of the onkoids (Fig. 9).

Subtype 3 contains less than 50% onkoids. The onkoids are supported in a matrix of peloids-pellets, and mud, in which the peliods-pellets form more than 50% of the matrix. This subtype is normally a wackestone, but when peloids are very abundant it is a packstone (Fig. 10).

Subtype 2 is dominated by equant onkoids with a diameter of about 1/2 cm. Fibrous-cemented oval onkoids with elongate fossil fragment nuclei are also classified in subtype 2. The onkoids of subtypes 1 and 3 are oval to slightly round with a maximum length of 2 cm.

FIG. 8 - Rock Type E, Subtype 1

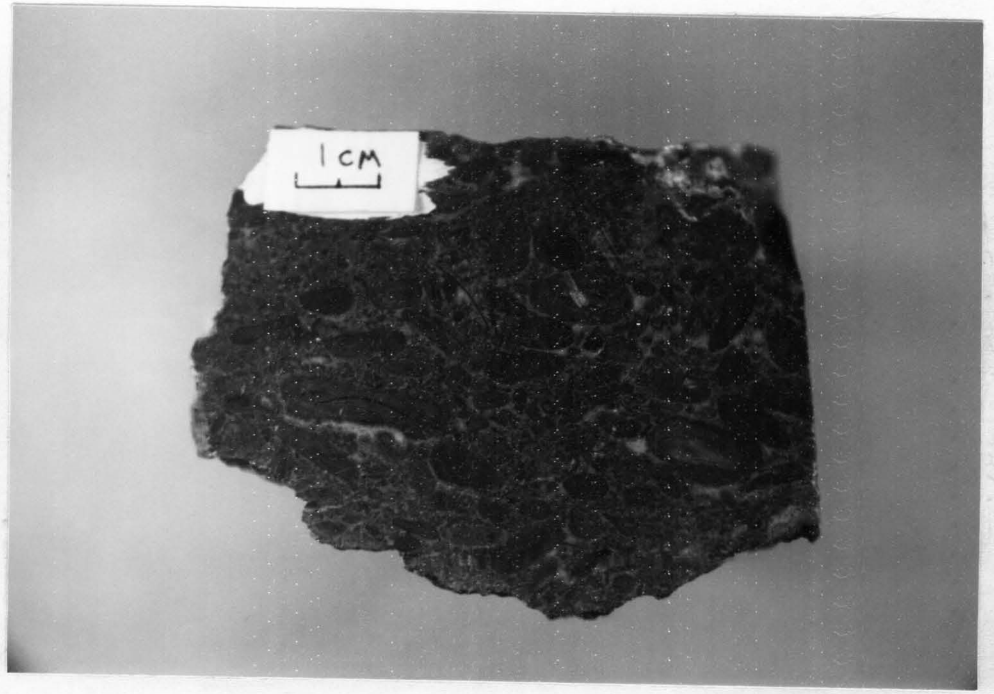


FIG. 9 - Rock Type E, Subtype 2

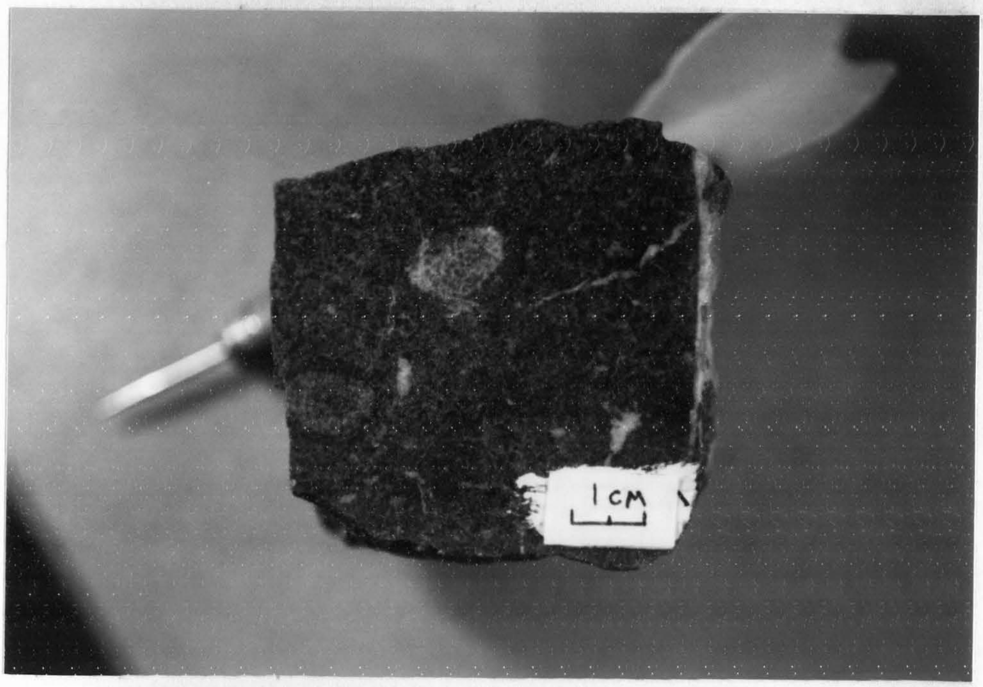


FIG. 10 - Rock Type E, Subtype 3

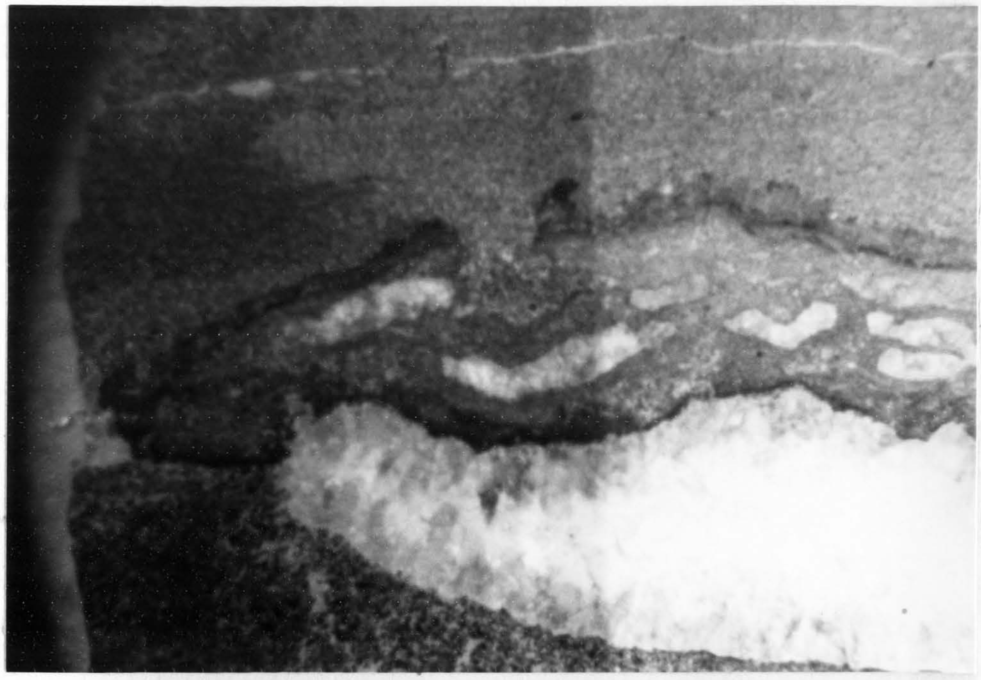


FIG. 11 - Close-up of FIG. 7, showing compaction features around spar-filled voids. Field of view = 2 cm.

One sample (Mc-2g) contains a few coarse-spar-filled voids. Petrographic examination shows a "desiccation" crack infilled with coarse peloids (Fig 11). The spar-filled voids were cemented early, as indicated by compaction features around them. These voids may have been created by evaporite growth, desiccation, gas-bubble-birdseye growth, or by burrowing.

Rock Type F

Rock type F is usually exposed as medium to thick bedded small resistant outcrops and small steep cliffs. It can form units up to 15 meters thick, and forms as much as 13% of a given section. This type is found in three of the sections (4,5,6).

Type F is classified as a packstone to grainstone (Fig. 12). It may be dolostone or dolomitic limestone. The only allochems present are peloids. Due to the destructive diagenetic effects of compaction and/or recrystallization, these peloids may originally have been pellets or ooids. Evidence in most samples suggests that pellets were the original allochems.

The allochems have a dark grey (N3-4) color and the cement is slightly lighter. This gives an overall medium to medium dark grey (N4-5) color to type F. The organic matter content averages 0.07%.

Medium to coarse laminoid birdeye structures are locally present. Rock type F is often interbedded with onkoidal subtypes of rock type E.

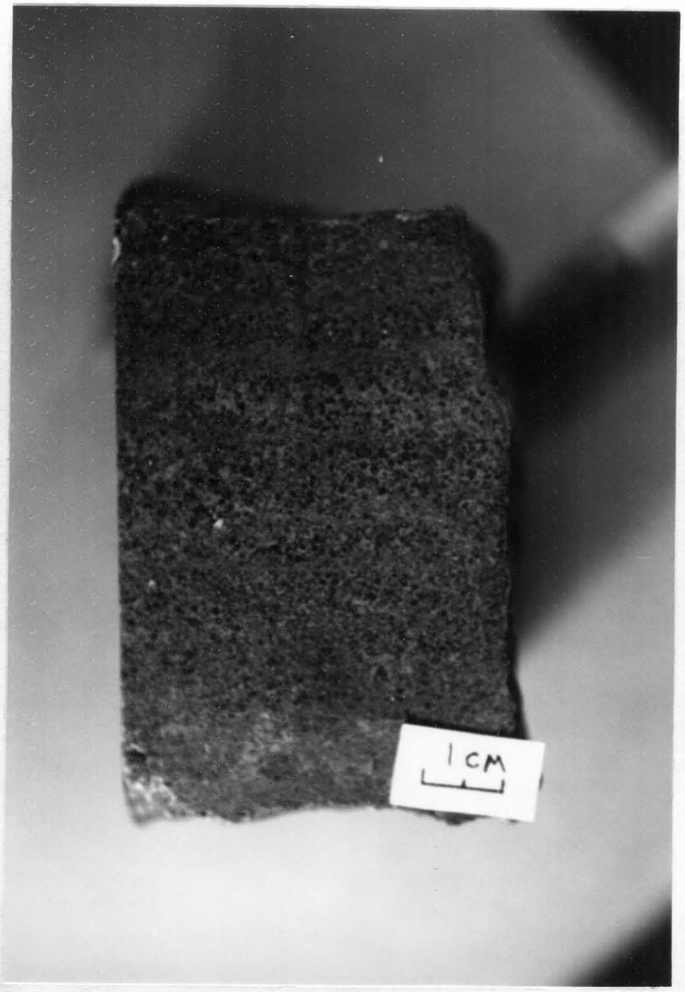


FIG. 12 - Rock Type F

FIG. 13 - Rock Type G

Rock Type G

Rock type G is found only at section 7, East Fork Canyon. It is exposed as medium bedded resistant outcrops on moderate slopes. It comprises 14% of the section in a unit 21 meters thick.

Allochems include peloids, and pisoliths. Textures range from wackestones to packstones (Fig. 13). The carbonate component is dolomite.

The average insoluble content is 28.7%, and is composed of quartz, illite, microcline, and orthoclase. These rocks have a gradational contact with the sandstones of the Brigham Group, and the high content of insoluble material is probably due to the gradational lower contact. These rocks grade upward into relatively cleaner carbonates.

Type G has an average organic matter content of 0.19% which is often concentrated in wispy pseudostylolites. The general color is medium grey (N4) slightly mottled with a light yellow-brown variation.

Type G has a slightly mottled texture produced by bioturbation. Compaction has enhanced areas of organic matter concentration, producing pseudostylolites. Stylolites often occur with pseudostylolites.

Rock Type H

Rock type H is found in unbedded, massive units which are exposed as small cliffs and ledges. It forms units up to 12 meters thick and comprises up to 9% of a given section. It occurs in sections 5 and 8.

Type H is very coarsely crystalline, with no recognizable allochems. It is classified as a crystalline dolostone (Fig. 14). Insoluble residues comprise an average of 0.72% of rock type H, and are composed of quartz, illite, albite, and orthoclase.

The color is uniformly very light grey (N8) and organic matter averages 0.07%.

The only recognizable depositional features of this rock type are medium irregular birdseye structures. Stylolites are sometimes present.

Rock type I

Rock type I is exposed as thin to medium bedded resistant ledges. It occurs in units up to 16 meters thick and forms up to 10% of a given section. This rock type is found in sections 2 and 8.

Texturally, type I is a wackestone to a packstone (Fig. 15). It is usually a silty limestone, but also includes end members of clean limestone and calcareous mudrock. Allochems include peloids, pellets, fossil fragments, whole fossils, and a few intraclacts. Insoluble residues average 28% and are composed of quartz, illite,

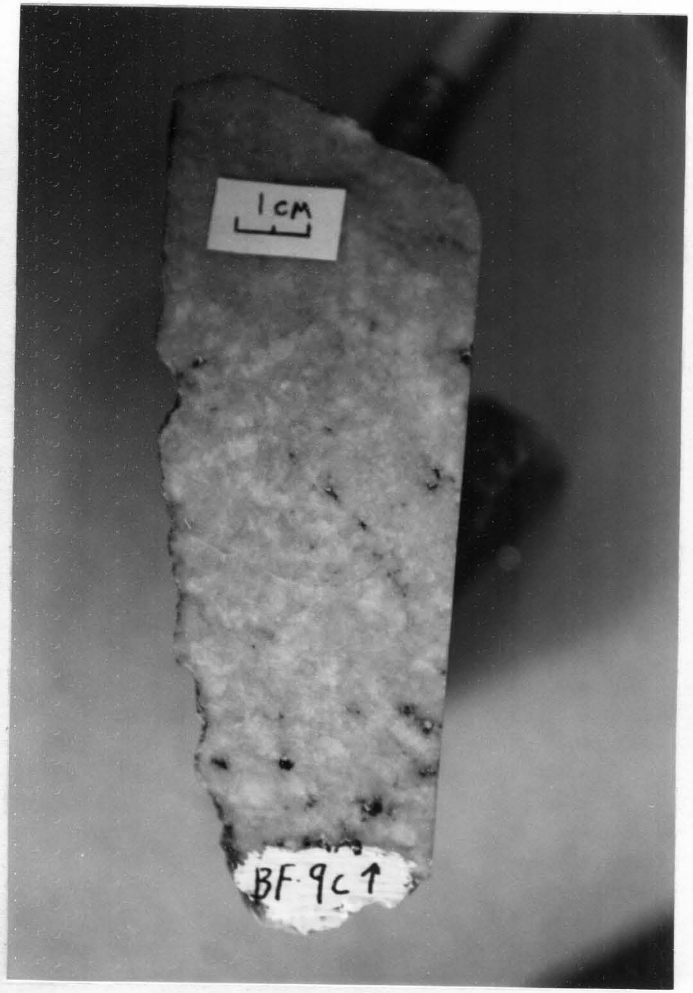


FIG. 14 - Rock Type H

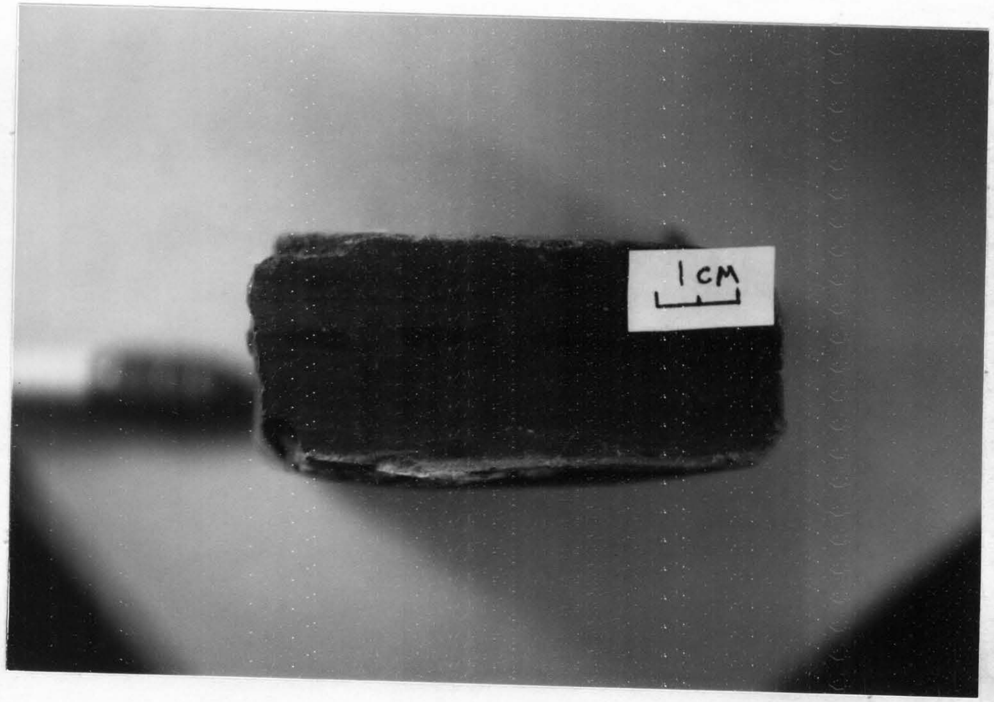


FIG. 15 - Rock Type I

albite, kaolonite, and chlorite.

The limestone layers are dark grey (N3), while the clastic areas are various shades of red or yellow. The average organic matter content is 0.53% and is probably concentrated in the carbonate layers.

Sedimentary structures include irregular laminations and interbedded thin beds of 'clean' carbonate and silty carbonate or calcareous clastics. The laminated layers (0.05mm to 5mm) are parallel to slightly wavy, and irregular. The irregularities within the laminations seem to have resulted from slight burrowing or compaction. Laminated and unlaminated layers are interbedded, and bedding ranges from thin to medium. Intraclasts of the laminated layers are found within the unlaminated layers. Whole fossils of trilobites and brachiopods are numerous.

Rock Type J

Rock type J is often exposed as weathered outcrops on mostly-covered slopes. Medium laminae are most characteristic but thin to medium beds are not uncommon. Type J comprises up to 29% of a given section, and forms units as thick as 47 meters. It is found in all sections except section 5, Blacksmith Fork Canyon.

Rock type J consists of mudrocks, more specifically, mudshales with some siltstones and clayshales (Lundegard and Samuels, 1980). The mudrocks are usually calcareous, and often contain lenses of limestone (Fig. 16). The dominant allochems are fossil fragments and peloids. Whole-body fossils and trace fossils are common. This rock type is often interbedded with rock types I and E.

Insoluble residues average 82.6% and are composed of quartz, illite, mica, albite, kaolinite, microcline, and chlorite. Petrographic analysis proved some of the illite to be muscovite mica.

The average organic matter content is 0.82%. The organic matter often appears to be concentrated in layers parallel to bedding. The color varies from dark grey (N3), to yellowish grey (5Y7/2), to light olive grey (5Y5/2). Often shades of light red occur on highly weathered surfaces.

Bedding surfaces are usually wavy and often nodular. Weathering often results in fissile to flaggy plates (Potter et al. 1980).

Diagenetic effects are not too apparent. No stylolites are found. Some samples may have reached a very low grade of burial metamorphism.

Rock Type K

Rock type K is found in two sections (2,8) and is exposed as thin to thick beds. In section 2 it forms a small unit at the base of the section and grades upward into rock type E, and is also present as thin beds or layers within the limestone. It forms its thickest unit at section 2, where it is about 1 meter thick, but forms only the thin interlayered beds at section 8. It comprises less than 1% of either section.

FIG. 16 - Rock Type J

FIG. 17 - Rock Type K

It is classified as calcareous arenite, but when it is found interlayered with limestone, a single sample may be classified as a limestone depending on sampling variability (Fig. 17).

Insoluble residue ranges from 62.4% to 77.2%, and is composed of only quartz at section 2, with additional illite, albite, kaolinite, and montmorillinite at section 8. Grain sizes range from silt to coarse sand.

Color varies according to clastic content. Cleaner carbonate layers are medium grey (N5), while clastic layers are much lighter. The average organic matter content is 0.10% at section 2, and 0.82% at section 8.

Stylolites are present, especially at clastic/carbonate contacts.

INTERPRETATION OF DEPOSITIONAL ENVIRONMENTS

General Statement

A depositional environment is defined as " a natural geographic entity in which sediments accumulate" (Friedman and Sanders, 1978, p. 195). A great pool of knowledge pertaining to recent carbonate depositional environments has been accumulated within the past 2 decades. Bathurst (1975) summarized much of the work done on recent carbonate depositional environments: the Great Bahama Bank; southern Florida; the Gulf of Batabano, Cuba; the Trucial Coast and Embayment, Persian Gulf; and British Honduras. Ginsburg (1975) has edited an excellent book on tidal deposits which contains many recent examples.

Although much is known about recent carbonate depositional environments, many problems arise when trying to understand and reconstruct ancient environments. As time passes, diagenesis can slowly distort or destroy information once contained in a rock. Diagenetic processes can, therefore, cause great difficulties in the understanding of a rock's ancient depositional history, and many times these difficulties can not be overcome (Bathurst, 1975, p. 138).

Raymond (1975) stated that some organic criteria operating today may not be valid in interpretations of the Late Precambrian and Early Cambrian. Questionable criteria include: " ... 1) restricting habitats of algal stromatolites to tidal flats; 2) differentiating tidal flat from subtidal environments through the presence or absence vertical or horizontal burrows; and 3) using taxonomic diversity and abundance of individuals to discriminate between subtidal, intertidal, and supratidal environments" (Raymond, 1975, p. 364).

To further complicate matters, the paleogeography of Utah during the Cambrian was characterized by a shallow epeiric sea (Lochman-Balk, 1971; Palmer, 1971; Maxey, 1958). Friedman and Sanders (1978, p. 373) stated " ... the most striking thing about epeiric seas is that they are nowhere present in the modern world." If the present is really the key to the past, then at least some, and probably most, of the physical and chemical principles operating today must apply to the epeiric seas of the Cambrian. Friedman and Sanders (1978, p. 373) further state that the Great Bahama Bank is presently the closest modern analog of the ancient epeiric seas.

Chemical Considerations in Carbonate Production

Presently aragonite and high-Mg calcite are the main carbonate minerals produced in the seas of the world. They can be precipitated inorganically as in the Abu Dhabi lagoon or physiologically by algae and other organisms (Bathurst, 1975). Depending on the chemical circumstances, either aragonite or calcite may "gain the upper hand" as the dominant precipitant, but with time aragonite eventually is converted to calcite (Bathurst, 1975).

Precipitation of calcium carbonate is basically controlled by the following reaction:

$$CaCO_3 + H_2CO_3 = 2Ca^{+2} + 2HCO_3^-$$

(Krauskopf, 1979, p. 51). This reaction is strongly influenced by additional factors. The solubility of $CaCO_3$ in water increases with increasing CO_2 pressure, decreasing temperature, and is greater in salt water (Deer et al., 1966). The principal control is the concentration of CO_2 which affects the above reaction through the following reaction:

$$CO_2 + H_2O = H_2CO_3$$

(Bathurst, 1975, p. 231).

Dolomite, although it does not directly precipitate in large amounts in today's seas, forms a vast portion of the carbonates in the stratigraphic record (Bathurst, 1975). Many models of dolomite formation as a replacement mineral have been proposed to explain this problem, and are discussed later in the text . Tucker (1982) however, stated that some Precambrian dolomites may have been deposited as the original carbonate mineral, and furthermore that during the Precambrian, dolomite may have been the principal carbonate mineral precipitated from seawater. Was this possibly true for Lower to Middle Cambrian times also?

Langston Depositional Environments

Peritidal Complex

Peritidal refers to marginal sea areas which are subject to the effects of tidal fluctuations. A peritidal complex can be divided into four zones: 1) areas that are always covered by water; 2) areas that are covered and uncovered during every tide; 3) areas that are covered and uncovered during some tides; and 4) areas that are covered by water only during the highest tides. Zone 1 is the subtidal zone, zones 2 and 3 are the intertidal zone, and zone 4 is the supratidal zone (Friedman and Sanders, 1978, p. 540). The term upper peritidal in this report refers to zones 2 through 4, those zones not always covered by water.

Upper peritidal flats have low to moderate, smooth gradients (0.8 to 0.1 m/km), with well-defined tidal zonation. The upper intertidal and supratidal zones are rarely flooded but are subjected to marine influences by tidal groundwaters and storm floods (Logan et al., 1974, p. 141).

Upper Peritidal Zone. - Shinn et al. (1965) defined the supratidal zone as an area above normal high tide but periodically flooded by spring tides and storm tides. The upper intertidal zone is that area which is covered and uncovered by some, but not all tides, while the lower intertidal zone is that area which is covered by all tides (Friedman and Sanders, 1978, p. 540).

Palmer and Halley (1979, p. 45) stated that in all major carbonate mud-producing-areas, the intertidal and supratidal zones display very similar characteristics and that they are often difficult to separate. They found algal boundstones, pellets, mudcracks, birdseyes, interbedded grainstones, lime mudstones, onkolitic lime mudstones, and occasionally shales in the peritidal deposits of the Cambrian Carrara Formation.

Lucia (1972), in a study of Permian deposits, described irregular laminations, lithoclasts, desiccation features, LLH-stromatolites, and quartz silt beds in the supratidal zone. At Andros Island, Shinn et al. (1965) found laminated packstones, algal mats, mud cracks, lithoclasts, birdseyes, and dolomite to be characteristic of the supratidal environment. Illing et al. (1965) in a study of the Persian Gulf found the supratidal environment to contain mudstones to packstones, birdseyes, disrupted laminations, few marine organisms, gypsum crystals and dolomite. Within the intertidal zone, Shinn et al. (1965) found burrowed pellet packstones, algal mats, gypsum crystals, and dolomite. Wilson (1975) described birdseyes, mudcracks, storm layers, intraclasts, burrows, and trails as features commonly associated with intertidal deposits.

Logan et al. (1974, p. 141) stated " ... the intertidal-supratidal platform is the main habitat of algal mats...". They further stated (p. 184) that most cryptalgal structures are formed in the lower to middle intertidal zones. The supratidal zone is characterized by blister and film mats. The upper intertidal zone is characterized by blister, film, gelatinous, tufted, and pustular algal mats. The lower intertidal zone is characterized by gelatinous, tufted, pustular, smooth, and colloform algal mats.

Shinn (1968, p. 215) stated that birdseye structures are preserved in supratidal sediments, sometimes in intertidal sediments, and never in subtidal sediments. He concluded that in the absence of any diagnostic structures other than birdseyes, a supratidal environment can be inferred. Logan (1974) implied that birdseye structures can occur in the upper subtidal to supratidal environments, with fine laminoid birdseyes restricted to the lower intertidal zone.

Tucker (1981, p. 163-164) stated that today's gypsum-anhydrite cycle occurs in the high intertidal and supratidal zones. Chicken-wire anhydrite textures are typical textures of many ancient sulfate deposits. In the upper supratidal zone anhydrite is precipitated as thin beds or layers of coalesced nodules. Wilson (1975, p. 85) described evaporite solution breccias and light rock colors as supratidal features. Dolomitization of carbonate particles is commonly associated with gypsum precipitation (Tucker, 1981, p. 163).

Rock type C has a uniform light color of about medium light grey (N6). Peloids are abundant. Fine to coarse irregular birdseyes and relict chicken-wire anhydrite are abundant locally. Some of the medium irregular birdseye structures testify to the past presence of pustular algal mats (Logan et al., 1974). This rock type is inferred to have been deposited in the middle intertidal to lower supratidal zones.

Subclass 1 of rock type C contains brecciated evaporite structures and was likely deposited in the supratidal zone.

Rock type B is usually darker than type C, ranging from medium dark grey to light grey (N4-N7). It contains many peloids, fine to medium irregular birdseyes, wispy irregular pseudostylolites, and possible relict chicken-wire anhydrite structures. The pseudostylolites have resulted from concentrations of organic matter, and give a wispy, irregularly laminated appearance to the rock. Similar structures have been produced by Shinn et al. (1977). These pseudostylolites are interpreted to have resulted from the concentration of organic matter in algal mats during compaction. This rock type is inferred to have formed in the upper intertidal environment.

Rock type A usually contains cryptalgalaminae, small LLH-stromatolites, pellets, intraclasts, mudcracks, and fine to medium laminoid birdseyes. It is usually dolostone. Fossil fragments and onkoids are very rare to absent. It is often interbedded with grainstones to wackestones. Rock type A is inferred to have formed in the lower to upper intertidal zones.

Rock type H contains only medium irregular birdseye structures. Dolomitization has destroyed all other original sedimentary features. Shinn (1968) stated that the presence of only birdseyes indicates a supratidal origin. However, Logan et al. (1974) found that medium irregular birdseyes may form within an intertidal pustular algal mat.

Therefore, this rock type may have formed in either the intertidal or supratidal zone.

Subtidal Zone

The subtidal zone comprises all the area below the mean low tide level. Wilson's (1975) facies 6 through 8 comprise most of the subtidal environments in this report. A great variety of depositional textures can occur and burrowing may be very prominent. Burrowed pellet packstones to wackestones are common (Shinn et al., 1965; Illing et al., 1965).

Agitated Shoal. - Wilson (1975) described a shoal environment in agitated water in his standard facies belt 6. Belt 6 is characterized by depths of 5 to 10 meters to below sea level. High energy provides a well-oxygenated environment, and at the same time produces an inhospitable environment for most marine life. Standard microfacies 13 (Wilson, 1975) of belt 6 is characterized by onkoids formed in a very shallow water, moderately high energy environment.

Subtype 2 of rock type E is characterised by moderate to well-sorted onkoids with a grainstone texture. The bottom side of the onkoids are cemented with a fibrous rim cement. This rock type probably formed in a high energy agitated shoal environment within an inner carbonate shelf.

Restricted Marine Shoal. - These quiet water shoals are found in Wilson's (1975) belts 7 and 8, which are shallow water environments with moderate circulation. Salinities may be normal to hypersaline. Sediments may be exposed subaerially at times. Standard microfacies 16 (SMF-16) is a peloidal grainstone which was deposited in water with only slight movement. SMF-16 may grade into a peloidal wackestone, and may contain thick, graded laminae and birdseye structures.

Rock type F is a peloidal packstone or grainstone which occasionally contains medium to coarse laminoid birdseyes and centimeter-thick laminations. This rock type probably was deposited in a restricted marine shoal within an inner carbonate shelf sea.

Open Marine Platform or Inner Shelf Sea. - Wilson (1975) described facies 7 as a shallow marine environment with moderate circulation and variable salinities. Such environments are located in open lagoons, and bays behind the outer platform edge. Standard microfacies 19 is a " ... laminated to bioturbated pelleted lime mudstone-wackestone grading occasionally into pelsparite" (or peloidal grainstone) " with fenestral fabric." (Wilson, 1975, p. 68). Standard microfacies 22 (SMF-22) contains onkoidal wackestones or packstones. SMF-22 is characteristic of quiet water sedimentation in shallow back reef environments.

Wilson (1975) also characterized facies 7 as containing clastic sediments in well-segregated beds. Potter et al. (1980) characterized the clastic sediments in marine inner shelves as being a few to tens of meters thick, commonly fine to silty muds, which may contain fecal pellets. Colors may be grey, green, brown, and black. The biotic assemblage is characterized by open marine fauna, and trace fossils may be abundant. Deposition results "from suspension or biogenic pelletization along protected, low-energy coasts, but also on open coasts when the mud supply is great" (Potter et al., 1980, p.63). The clastic sediments are usually found landward and interfinger with the carbonate sediments seaward. Potter et al. (1980) gave the same general definition for outer shelves, except the deposition occurs farther from shore, below wave base.

Rock type D is characterized by peloidal wackestones to packstones with distinct, and sometimes indistinct, mottled textures. This mottling resulted from bioturbation. Rock type D was probably deposited in a shallow, low energy inner shelf sea.

Rock type E is a mudstone to packstone, containing peloids, fossil fragments, pellets, onkoids, and intraclasts. The color is normally dark grey (N3). Burrows are usually present and some slight bioturbation occurs locally. Peloids are the dominant allochems, with onkoids and fossil fragments dominating locally.

Rock type E was deposited in a shallow, low energy inner shelf sea. Subtype 1 and 3 of rock type E were deposited in a shallow, moderate energy, inner shelf sea close to the outer restricting platform.

Rock type G contains peloids and pisoliths with a wackestone/packstone texture. Pseudostylolites are numerous, and probably reflect compactional concentration of organic matter and clastic sediments. The average insoluble content is 28.7%. This high insoluble content may reflect either a nearby clastic source or a large influx of clastic sediment at some distance. The pisoliths are most likely onkoids with their primary structure destroyed by dolomitization. The high clastic content and well-rounded pisoliths or onkoids indicate deposition in a shallow, low to moderate energy inner shelf sea during a period of slow subsidence as clastic deposits migrated seaward from an eastern source area.

Rock type I is a peloidal wackestone to packstone, with fossil fragments and intraclasts abundant locally. Insoluble residues average 28%. Depending on clastic content, rock type I may grade into rock type E. Any one sample may be dominated by clastic sediment or carbonate sediment, with carbonates generally dominating. Rock type I represents a change from an environment of carbonate-dominated sedimentation (inner carbonate shelf) to one of clastic-dominated sedimentation (outer clastic shelf). The limestone was often deposited as lenses within the clastic areas. This rock type was probably deposited below wave base at the boundary of the inner and outer shelf during a period of slow subsidence.

Rock type J contains mudrock with peloids, fossil fragments, trace fossils, and relatively numerous whole body fossils. Bedding is often wavy and nodular, reflecting low energy. The mudrocks are often calcareous or they may contain carbonate lenses. This reflects a diminishing, fluctuating, carbonate-producing environment, and the appearance of type J in the north and southeast parts of the study area reflects the progradation of clastic sediments from the two major source areas toward the carbonate bank. This model is very similar to the model proposed by Palmer and Halley (1979) for the Carrara Formation. Rock type J, of the upper shale member of sections 4,6, and 7, is inferred to have been deposited in a shallow, low energy inner shelf sea in the southeastern part of the section and in a shallow low energy outer shelf sea in the north and western area of study. Deposition occurred during a period of slow subsidence.

Rock type K is a calcareous sandstone which grades upward into limestones with sandy layers. Depending on sampling location, this rock type may have more or less than 50% clastic material. When it occurs as limestone with sandy layers, burrows infilled with sandstone are evident. It is found only within the Naomi Peak Limestone member. This rock type reflects a period of fluctuation between a depositional environment dominated by clastic sedimentation and one of carbonate sedimentation. It was deposited in a shallow, inner shelf sea during a period of fluctuating subsidence.

Open Shelf or Outer Shelf Sea. - Wilson (1975) described facies 2 as having water depths of tens to a few hundred meters, good circulation, oxygenated, and of normal marine salinity. Shales and/or carbonates may be deposited in facies 2. Bedding may be burrowed, thin to medium, and wavy to lenticular.

Wilson (1975) stated that the carbonates and shales occur in well-segregated beds. Potter et al. (1980) characterized the clastic sediments in the outer shelf as being a few to tens of meters thick, commonly fine to silty muds, which may contain fecal pellets. Colors may be grey, green, brown, and black. The biotic assemblage is characterized by open marine fauna and trace fossils may be abundant. Deposition results " ... from suspension and biogenic pelletization below wave base" (Potter et al., 1980, p. 63). The clastic or mud deposition is controlled by wave energy and clastic supply. When the clastic supply is limited then carbonate sediments are deposited. It should be pointed out that the descriptions of the mudrocks or shales of the inner and outer shelves by Wilson (1975) and Potter et al. (1980) are very similar. Aitken (1978, p. 523) stated, while describing the paleogeographic elements of the Cambrian depositional grand cycles, that " ... it is not known whether the open basin was oceanic or part of an epicratonic sea."

The Spence Shale, which occurs in sections 1,2,3, and 8, is characterized by thin to medium, wavy to lenticular bedding, with open marine fauna, and often trace fossils. Color varies from shades of green to black. The source area for the Spence Shale is to the north or northwest and is different from that of the southeastern unnamed shale member as indicated by their stratigraphic relationships and differences in insoluble residue mineralogy. It is proposed that the Spence Shale was deposited in a relatively shallow outer clastic shelf sea.

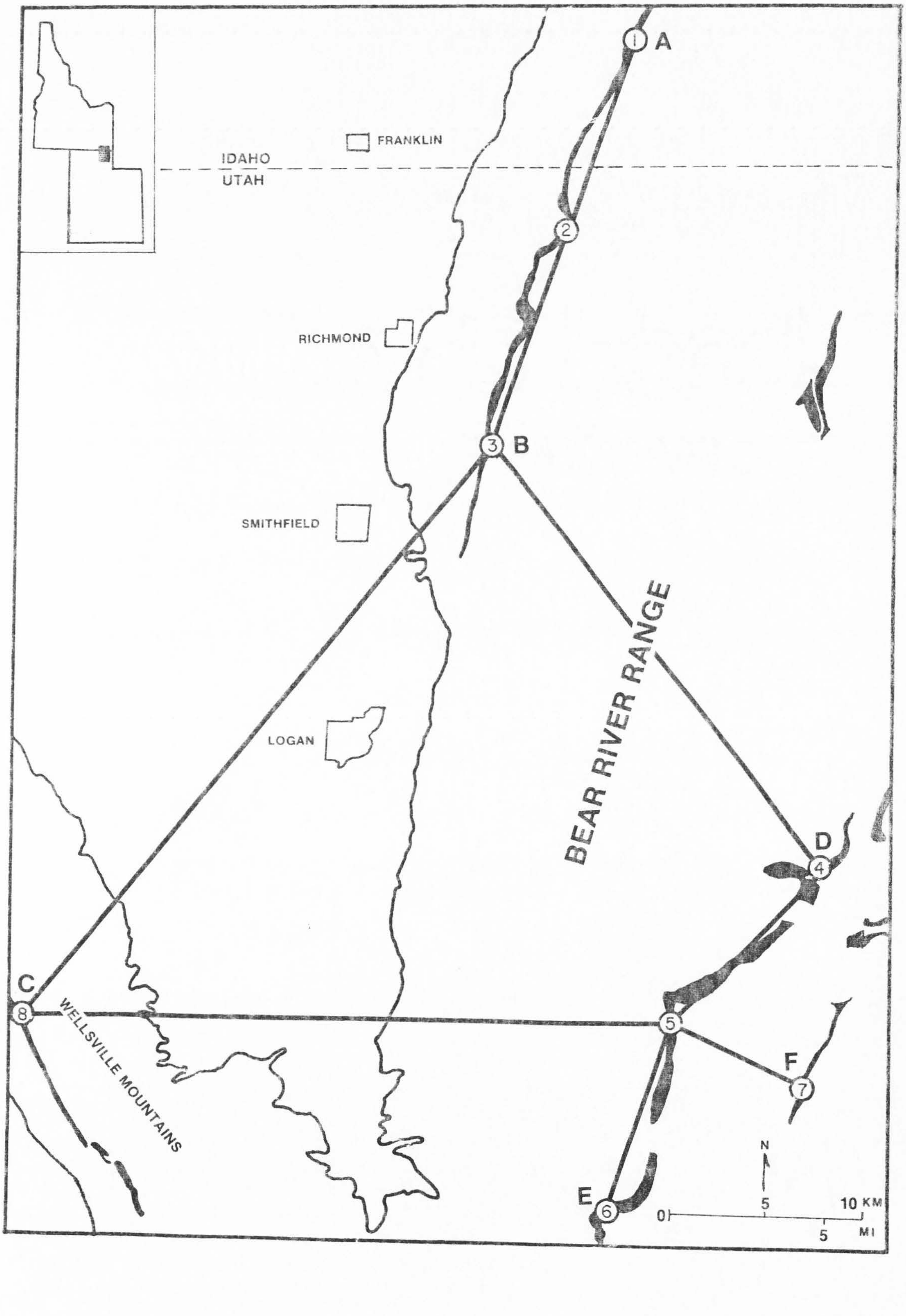
Rock type I probably resulted from the gradational relationship between the inner and outer shelves, and was probably deposited near the boundary of the outer clastic shelf facies and the inner carbonate shelf facies.

See figure 18 for a summary of the characteristics of environments, and figures 19, 20, 21, 22, and 23 for the distribution of environments in the study area.

FIG. 18 - Generalized diagram of depositional environments with facies and related information. MHW = mean high water level, MLW = mean low water level.

Diagrammatic Cross Section				
Facies	Outer Clastic Shelf Sea	Upper Peritidal	Inner Carbonate Shelf Sea	Inner Clastic Shelf Sea
Rock types	J, I	A, B, C, H	D, E, F	J, K, G
Lithology	Mudshales, and silty mudstones	Wackestone/packstone, and algal boundstones	Mudstones to grainstones	Mudshales, silty wackestones, and sandstones
Color	Green to black	N6-N8	N2-N5	Green to black
Allochems	Peloids and fossils	Peloids, pellets, intraclasts, and rare fossil fragments.	Peloids, pellets, intraclasts, fossil fragments, onkoids, and pisoliths	Peloids and fossils
Sedimentary Structures	Parallel to lenticular laminations, and burrows	Birdseyes, mudcracks, cryptalgal structures, relict evaporites.	Bioturbation and/or burrows	Parallel to lenticular laminations, and burrows.
Insoluble residue	55.3%	3.4%	1.7%	62.3%

FIG. 19 - Location of geologic sections


FRANKLIN
IDAHO
UTAH
RICHMOND
SMITHFIELD
LOGAN
BEAR RIVER RANGE
WELLSVILLE MOUNTAINS
A
B
C
D
E
F
1
2
3
4
5
6
7
8
N
0
5
10 KM
5
MI

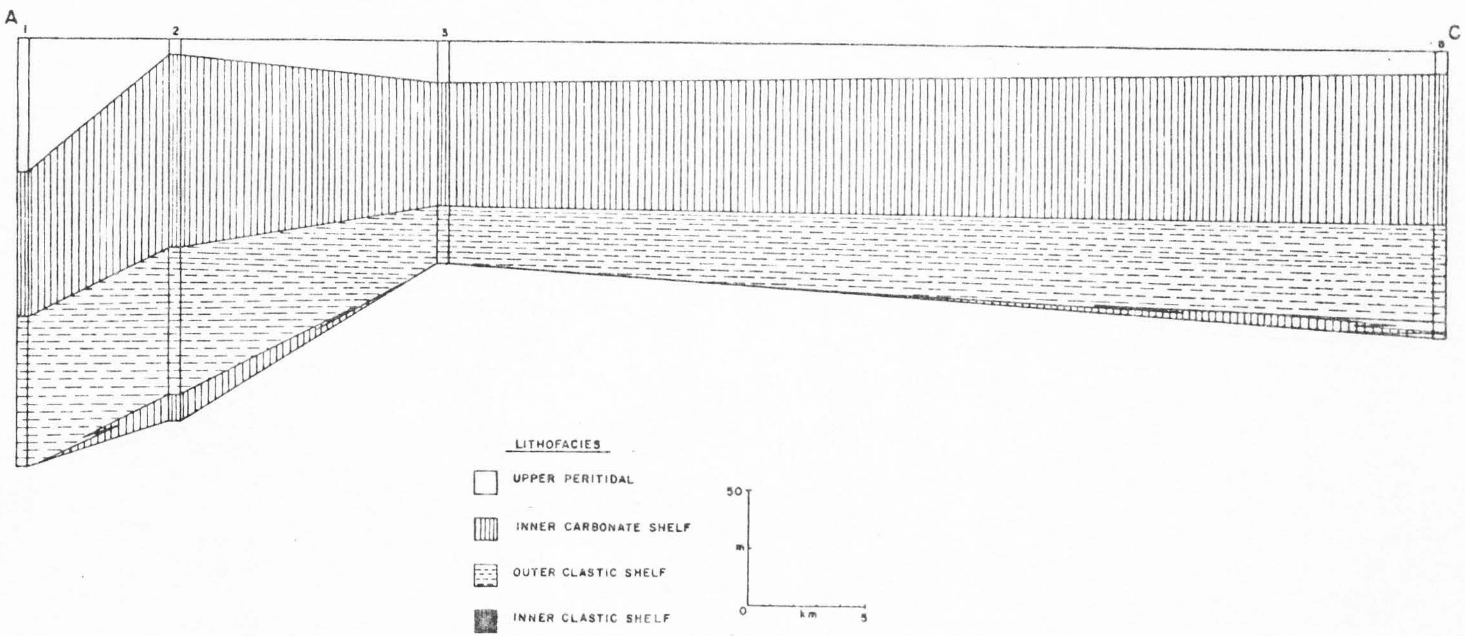


FIG. 20. - North-south geologic section of the inferred depositional environments of the Langston Formation: north and west areas.

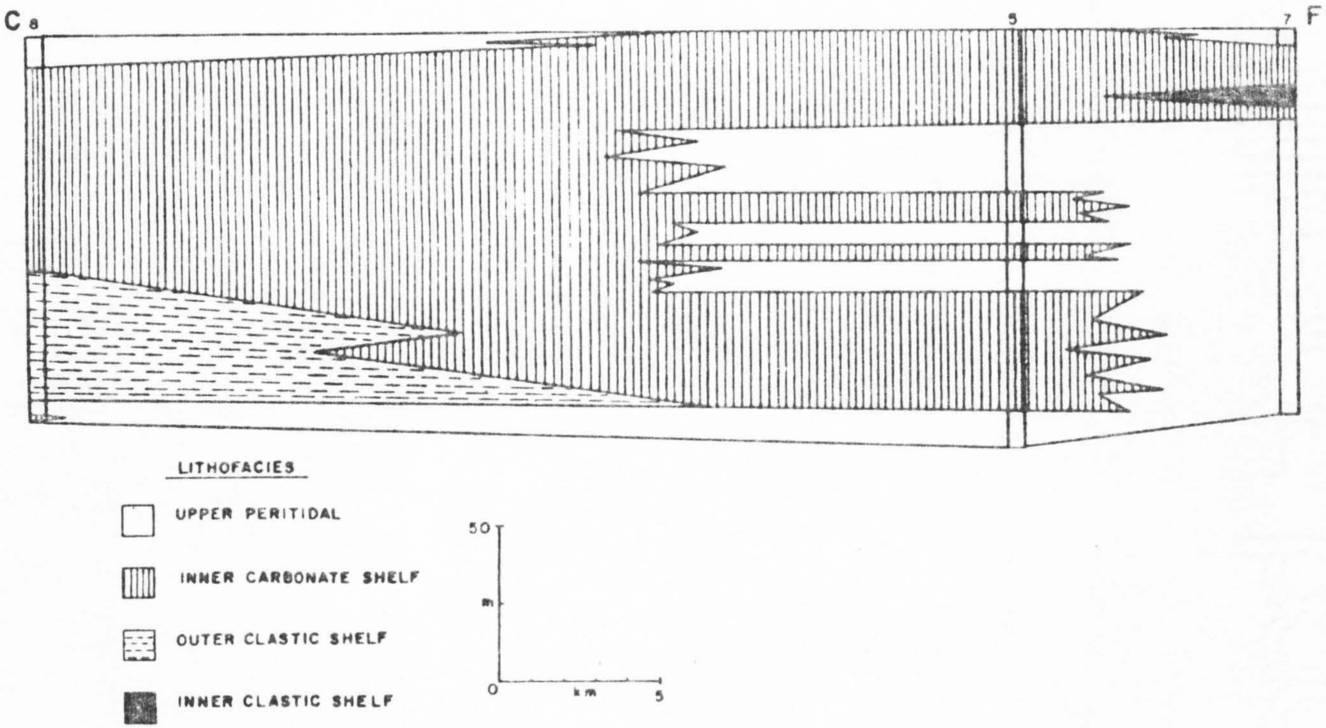


FIG. 21 - West-east geologic section of the inferred depositional environments of the Langston Formation. Numbers indicate measured sections.

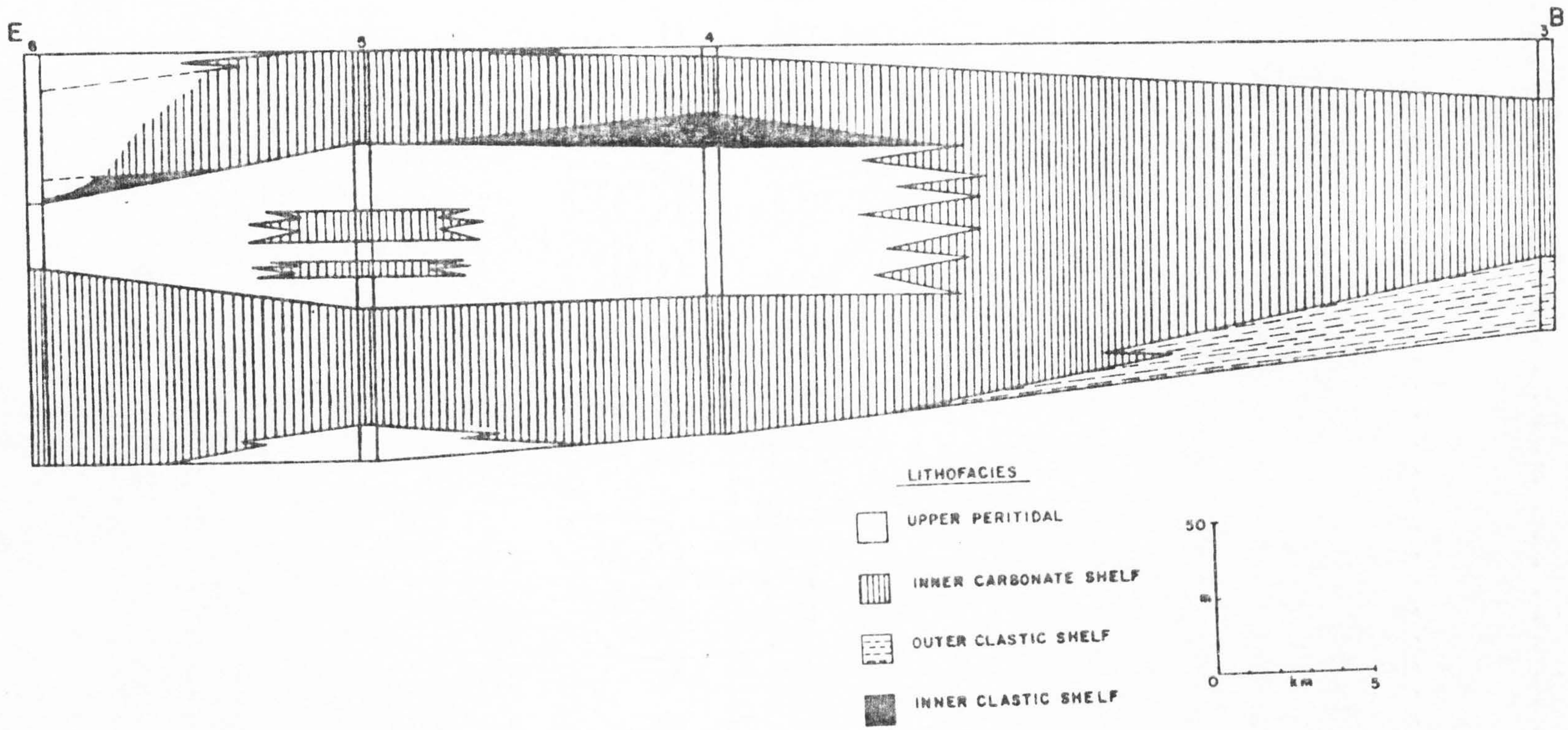
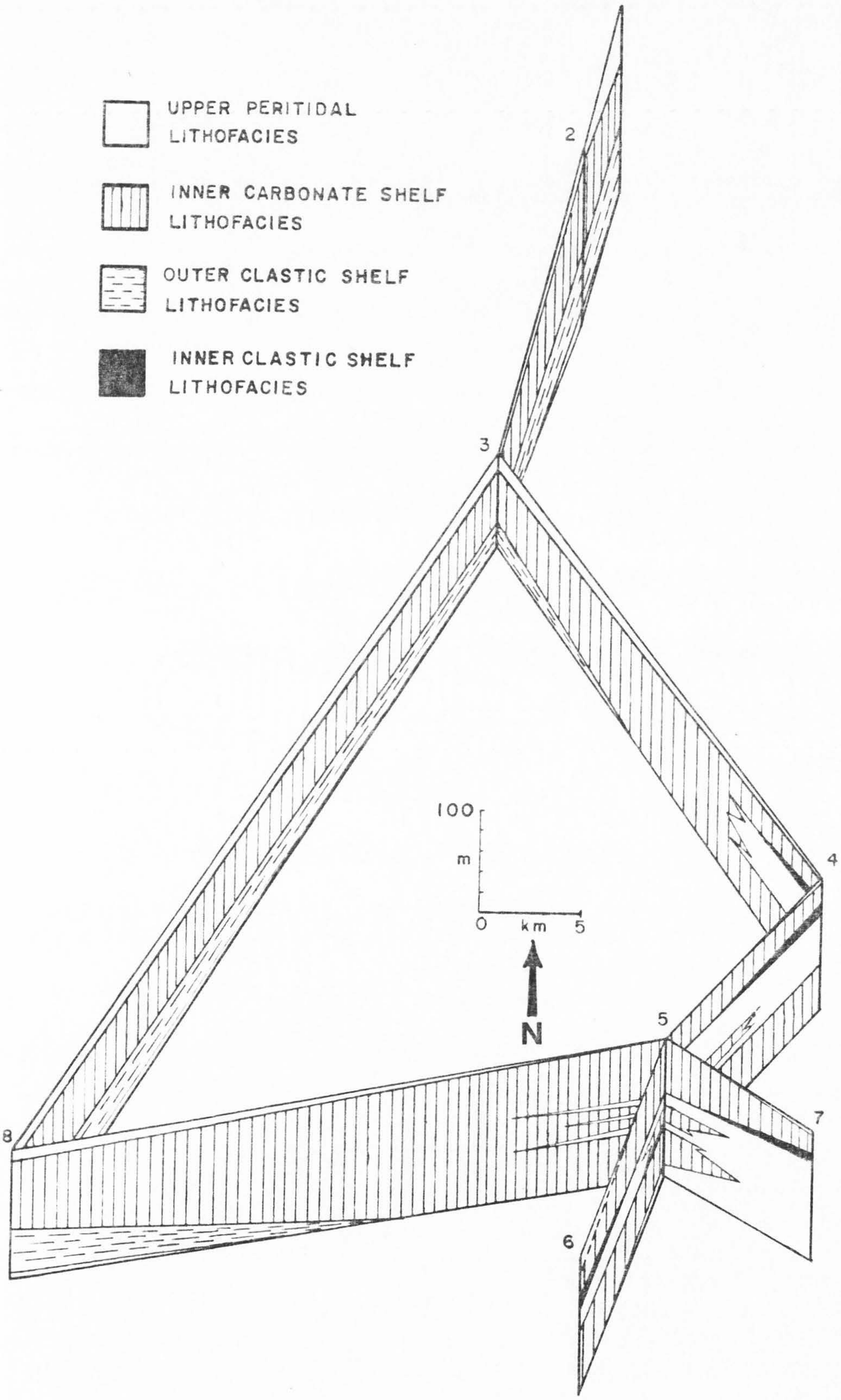


FIG. 22 - South-north geologic section of the inferred depositional environments of the Langston Formation: southeastern area. Numbers indicate measured sections.

FIG. 23 - Fence diagram of the Langston Formation, north-central Utah and southeasternmost Idaho. Numbers indicate measured sections.


UPPER PERITIDAL LITHOFACIES
INNER CARBONATE SHELF LITHOFACIES
OUTER CLASTIC SHELF LITHOFACIES
INNER CLASTIC SHELF LITHOFACIES
1
2
3
4
5
6
7
8
100
m
0
km
5
N

ANALYSIS OF INSOLUBLE RESIDUE

"The small amount of terrigenous or biogenic siliceous clastic materials in carbonate sediments may be very significant in environmental interpretation" (Wilson, 1975, p. 90). The analysis of the insoluble residues of the Langston Formation has provided some useful information. Data are in Appendix A.

Quartz is found in all samples and is the dominant mineral species (based on x-ray diffraction peak heights) in all but one sample. Illite and/or mica is found in 95% of the samples, and shares the position of second most abundant along with one of the K-feldspars or kaolinite. Albite is found in 62% of the samples, microcline in 22%, and orthoclase in 6%. Kaolinite is found in 35% of the samples, chlorite in 12%, and montmorillonite in 2%. A small portion of the insoluble residue consists of iron minerals: goethite, 5%; and hematite, less than 1%. Hematite was found in many samples through petrographic methods, but probably constitutes such a small portion of the mineralogy that it could not be detected by x-ray diffraction methods. Limonite, an amorphous or cryptocrystalline iron hydroxide (Deer et al., 1966), is found concentrated along fractures or in silty layers in many samples.

Analysis of the mineralogy of the Spence Shale member and the unnamed shale member indicates that the sediments were derived from two different source areas. Both shales contain quartz and illite, but the dominant feldspar in the Spence Shale is albite, while the dominant feldspar in the unnamed shale is microcline. This general relationship holds true for the insoluble residues of the carbonates: the north and east sections, which contain the Spence Shale, are characterized by an abundance of albite and the southeastern areas are usually low in albite and richer in microcline. The distribution of the two shales and the relationships of the insoluble residues indicate two different areas for the source of the clastic sediments: one to the north or northwest, and one to the east or southeast. This conclusion is in agreement with the findings of Palmer (1971) and Williams (1948).

Environmental interpretation using minerals is valid only if the following assumptions are valid: 1) clay mineral formation is directly related to climatic parameters; 2) clay minerals have pre-burial stability; 3) and clay minerals have post-burial stability (Singer, 1980, p. 303). Singer further stated that all of the assumptions have only a limited probability. Krumbein and Sloss (1963) indicated that the illite group is the most abundant in ancient and modern sediments. Illite is particularly abundant in calcareous marine sediments (Grim, 1968, p. 548). It is the dominant clay mineral in shales and mudstones (Deer et al., 1966). Rateev et al. (1969) showed the distribution of illite in world oceans to be concentrated near detrital source areas and that there is no latitudinal control. The above indicates that illite should be abundant in marine sediments with a proper source area.

Singer (1980) and Carroll (1970) stated that kaolinite is the product of a high-leaching, humid tropical environment. Kaolinite is especially concentrated along the equator (Rateev et al., 1969).

Singer (1980) and Carroll (1970) also stated that montmorillonite is produced in areas of less intense weathering in temperate or arid climates. Worldwide oceanic montmorillonite is often concentrated near the equator in spots but also in areas with volcanic sources (Rateev et al., 1969). Chlorite has a minimum concentration along the equator and increases in concentration toward the poles (Rateev et al., 1969). Montmorillonite and chlorite would not be expected to make up a large percentage of the clays in a sediment deposited in a warm, non-volcanic, equatorial sea.

The Langston sediments are dominated by illite and kaolinite with minor amounts of chlorite and montmorillonite. This clay mineral assemblage indicates that the Langson Formation was deposited in a warm to hot humid climate. This is in agreement with paleoequatorial studies (Rowland, 1981; Ziegler et al., 1979).

PALEOGEOGRAPHIC RECONSTRUCTION

Paleomagnetic and faunal studies of the Cambrian Period indicate that the equator ran northward very near or through Utah (Rowland, 1981; Ziegler et al., 1979). Stratigraphic studies indicate a marine transgression slowly covered Utah with shallow seas (Maxey, 1958, p. 685). Insoluble residue analysis indicates the climate in the study area was warm to hot, and humid. Eventually in Late Cambrian time, essentially all of the state was covered by a shallow warm tropical sea. This environment was ideal for carbonate production.

The creation of this epeiric sea introduced new and unique environments of deposition to the Cambrian scene. As Middle Cambrian time approached, a broad, linear, north-trending, peritidal carbonate shoal complex developed toward the edge of the Cordilleran miogeosyncline. This complex separated a deeper water outer basin from a wide, shallow water inner basin (Kepper, 1972; Aitken, 1978; Bush and Fisher, 1981; Palmer and Halley, 1979). In its infancy (during the Langston deposition) it was probably analogous to the 'Stephen-type' shoal complex of Aitken (1978). This shoal complex was narrow (usually less than 20 km wide) and discontinuous. This allowed an unhindered tidal exchange, yet it restricted high energy events in the inshore basin. As time progressed, the shoal complex matured into Aitken's 'Sullivan type' shoal complex. This shoal complex was often 400 km wide and was breached only in a few locations. This type of shoal complex hindered tidal exchange and generated a tidal resonance which lead to a large tidal range. This Cambrian carbonate shoal complex has been found in Cambrian studies in northern Washington, northern Idaho, and northwestern Montana by Bush and Fischer (1981).

Robison (1960) has shown that Cambrian stratigraphy can be divided into an inner detrital belt, a middle (relatively clean) carbonate belt, and an outer detrital belt. The middle carbonate belt and the inner detrital belt comprise the epeiric sea described by Shaw (1964). Shaw stated that the Paleozoic epeiric seas had an average depth of 27 meters over thousands of square miles. He concluded that with these dimensions the average bottom slopes ranged from 0.02 to 0.1 meters per kilometer (0.1 to 0.5 feet per mile).

Aitken (1978) related these belts to grand cycles during the Cambrian. Grand cycles were responsible for the intertonguing relationship between the carbonate sediments and the clastic sediments during the Cambrian. Grand cycles began with the appearance of an inner detrital facies which graded upward into a middle carbonate shoal complex, and then terminated abruptly with the deposition of another inner detrital facies, initiating the next cycle. These cycles are defined to be 300 to over 1000 feet thick and must span one to three trilobite assemblage-zones (Aitken, 1978).

Rigo (1968) believed the shale members of the Langston Formation represent small regressive tongues within the overall transgressive sequence. However, in most sections measured for this study, the shale members of the Langston and Ute Formations abrupty overlie peritidal deposits. A subtidal clastic deposit conformably overlying a peritidal carbonate deposit hardly represents a regression! Palmer and Halley (1979) found a similar example and developed a model related to Aitken's depositional grand cycles. Their model related the clastic and carbonate deposition to changing rates of shelf subsidence. The Langston Formation qualifies as a grand cycle and probably represents the first and lowermost Cambrian grand cycle.

The Langston Formation was deposited in an area bordering the Cordilleran miogeosyncline during the Lower Middle Cambrian as indicated by trilobite assemblages. Furthermore, it was deposited partially as part of a peritidal carbonate shoal complex, inland basin, and partially part of the outer seaward basin. Specifically, the middle carbonate unit was deposited on a peritidal shoal complex or middle carbonate belt as indicated by a low insoluble residue content in the carbonates and a general shoaling upward sequence. The Spence Shale member (the lower shale member) in the north and west of the study area was deposited in the outer detrital belt. The upper unnamed shale members in the southeastern part of the study area were deposited in the inner detrital belt.

There were two major terrigenous source areas during Langston time. To the northwest of the study area in western Idaho or northwestern Utah sediments were shed into the outer detrital belt (Williams, 1948, p. 1157; Palmer, 1971, p. 61). Some of these sediments were eventually deposited as the Spence Shale. A problem arises in transporting the sediments from a northern source area to a southern depositional environment at a time when prevailing currents should have been traveling northward (westward during the Cambrian). It is proposed that the geography must have been such as to create reverse currents passing by and transporting sediments from the northern source area to the southern site of deposition (Fig. 24).

To the east was a positive area of Precambrian rocks (possibly the present day Uinta Mountains) which shed sediments into the inner detrital belt (Williams, 1948, p. 1157; Palmer, 1971, p. 61). Some of these sediments were deposited as the upper unnamed shale members in the southeastern part of the study area.

Subsidence was not uniform throughout the study area. Figure 25 shows that the Langston thickens to the north, and is fairly uniform in the south. Section 3, Smithfield Canyon, is extremely thin compared to the other sections. The isopachous map indicates that subsidence was greatest in the northern area and fairly uniform in the southern area, but at section 3, either subsidence was at a minimum or the area was characterized by a topographic high.

The fence diagram and lithofacies cross sections (Figures 19-23) show that in early Langston time the peritidal complex was located to the southeast, and the Spence Shale was accumulating in the north and west. This likely occurred while subsidence was slow; then as subsidence increased, carbonate production dominated the area and built a shoaling complex to the north and west. Toward the end of Langston time subsidence slowed again, as represented by the progradation of inner detrital belt clastic sediments over the peritidal deposits in the southeastern area. The areas to the north and west must have been farther from their clastic source since the shales are absent. Finally, Langston deposition was concluded (the

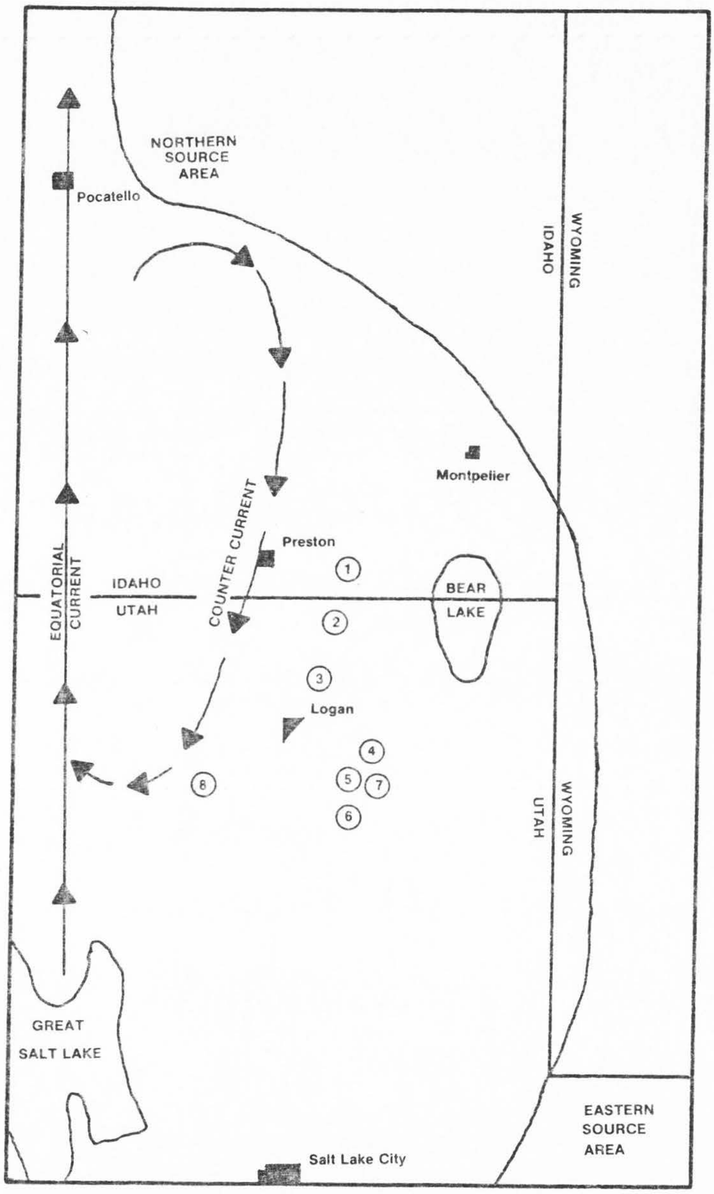
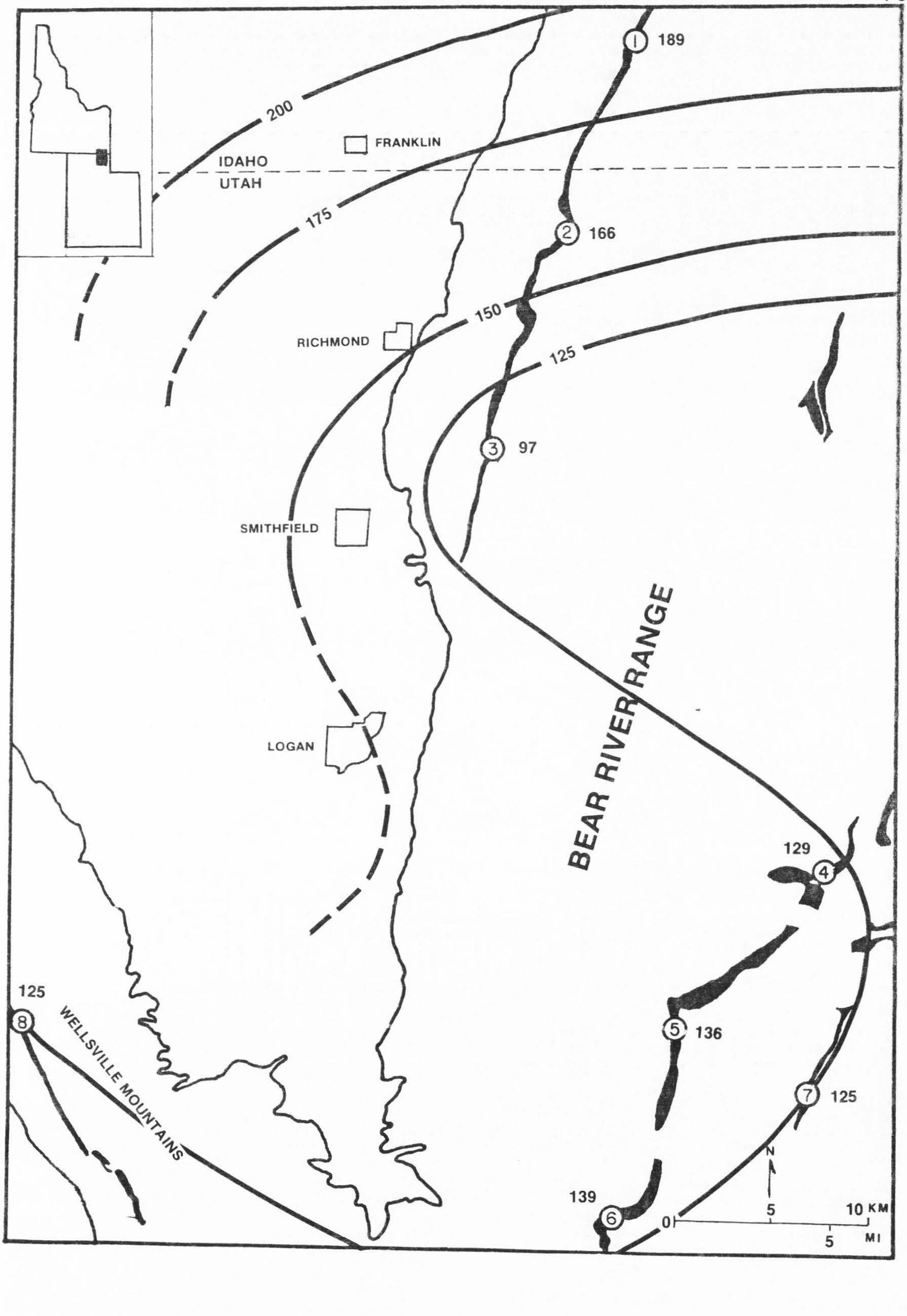


FIG. 24 - Proposed model of paleogeography showing possible relationship between the equatorial current, counter current, and northern source area.

FIG. 25 - Isopachous map of the Langston Formation, north-central Utah and southeastern Idaho. Contour interval = 25 meters.



IDAHO
UTAH
FRANKLIN
RICHMOND
SMITHFIELD
LOGAN
200
175
150
125
1 189
2 166
3 97
4 129
5 136
6 139
7 125
8 125
BEAR RIVER RANGE
WELLSVILLE MOUNTAINS
N
0
5
10 KM
5 MI

end of a grand cycle) when subsidence slowed to the point where the shales and siltstones of the Ute Formation were deposited over the whole area.

DIAGENESIS

General Statement

Diagenesis of the carbonates can be divided into cementation, solution, aggrading neomorphism, degrading neomorphism, compaction, and dolomitization. Dolomitization will be discussed in a section by itself. Diagenesis may occur in the eogenetic, mesogenetic, and/or the epigenetic environment. Eogenetic diagenesis occurs within the first 100 meters of burial and within 10^3 to 10^6 years after deposition. The water of this environment is connate which may circulate freely to the surface. Mesogenetic diagenesis is synonymous with burial diagenesis, occurs at depths of 1 to 10,000 meters, and takes place 10^3 to 10^8 years after deposition. Ascending altered pore $\pm$ juvenile waters characterize this environment. Telogenetic diagenesis occurs at depths of 1 to 3000 meters, and may take place 10^3 to 10^9 years after deposition. Meteoric waters dominate this environment, and diagenesis may take place above or below the water table (Choquette and Pray, 1970).

Cementation

Carbonate sediments may contain 40 to 70% porosity when deposited, yet ancient carbonates usually have porosities of less than 5%. Therefore the pore space was either filled with cement or considerable compaction occurred (Bathurst, 1975, p. 416).

The Langston Formation shows little evidence for large amounts of cementation. Dolomitization and/or recrystallization have distorted or destroyed much of the original depositional and eogenetic structures. Subtypes 1 and 2 of rock type E have fibrous rim cements. This type of cementation is characteristic of cementation in intertidal to subtidal environments (Scholle, 1978). The fibrous cementation was followed by a coarse mosaic cementation within the voids bounded by the fibrous isopachous cement. This indicates 2 stages of cementation: one early, which partially filled the original pore space and prevented compaction; and one later, possibly after considerable burial, which infilled the remaining pore space. The later stage may have occurred in either the eogenetic or mesogenetic environment.

Rock type F is a peloidal packstone, and is moderately to well sorted. Early submarine cementation likely filled the pores of these rocks, but evidence for or against has been destroyed by dolomitization and/or recrystallization.

Many samples contain voids or birdseye structures which are filled with cloudy, radial fibrous spar. This type of cement may represent alteration of early formed original submarine aragonite cement (Scholle, 1978). Some of these spar-filled voids show prominent compaction features, also indicating early cementation of sediments.

A third, but relatively unimportant, stage of cementation occurred in the telogenetic environment. This stage was simple infilling of fractures, often accompanied by iron-staining.

Some early cementation definitely occurred in the Langston Formation as seen in some samples, but later diagenetic events such as neomorphism and dolomitization destroyed most of the evidence needed to distinguish cement from original matrix in many samples. Often radiaxial carbonate mosaics occur within recrystallized samples. Cotter (1966) suggested that this texture may have resulted from the recrystallization of early fibrous aragonite cement. Pingitore (1971), Glover and Pray (1971), and many others have cited examples of early submarine cementation. It is most probable that most of the cementation in the Langston took place in the eogenetic environment.

Aggrading Neomorphism

Aggrading neomorphism, or grain growth, may involve only one element of a rock, such as syntaxial overgrowths on echinoderm fragments, or it may encompass all or most of a rock, such as the formation of a coarse mosaic (Pettijohn, 1975).

In the samples examined, both types are found. Syntaxial overgrowths on echinoderm fragments are common, especially in rock types E and D. The formation of a coarse crystalline mosaic is most prominent in rock types B and C, but occurs in most samples to some degree. Dolomitization appears to be the root of this destructive neomorphic process, as is shown in some of the dolomitic limestones.

In these rocks, well-defined and recognizable primary depositional features within the calcite portion become obliterated as they grade into the coarser dolomite areas. Often the 'ghost' of a single peloid can be seen within one dolomite rhomb. This diagenetic process is often associated with dolomite, and therefore most likely occurred during the dolomitizing process which probably began in the eogenetic environment and continued into the mesogenetic environment.

Degrading Neomorphism

Degrading neomorphism, or micritization, results in a reduction of overall crystal size (Pettijohn, 1975). Micritization of the rims of many onkoids and large peloids is common. Bathurst (1966) attributed micritic envelopes to the infilling of algal borings by micritic carbonate mud. Total micritization is most common in the limestones of rock type D and E. Micritization predates cementation as indicated by micritic rims contained within envelopes of fibrous cement. Degrading neomorphism must have occurred in the eogenetic environment.

Compaction

Compaction features are often very evident in some of the Langston samples, but in others there is little or no evidence for compaction. Shinn et al. (1977) have demonstrated that carbonate muds are capable of at least 50% compaction. They also demonstrated that pseudostylolites can be created through the compaction of sediments.

Rock types B, C, D, and E often contain some evidence of compaction. Pseudostylolites are common, and areas of early cementation show draped features above them.

Rock type A, cryptalgalaminated boundstone, contains no evidence of compaction, but it seems probable that, as the algal mats were buried and decomposition of the algal filaments occurred, some compaction must have occurred.

Park and Schot (1968) described a stylolite classification based on two factors: 1) pure geometry; and 2) relation to bedding plane. The geometric classification is subdivided into six catagories: 1) simple wave-like type; 2) sutured type; 3) up-peak type; 4) down-peak type; 5) sharp-peak type; and 6) seismogram type. The Langston Formation stylolites generally fall within catagories 2 or 5. The bedding plane classification is subdivided into 6 catagories also: 1) horizontal; 2) inclined; 3) horizontal-inclined-crosscutting; 4) vertical; 5) interconnecting network; and 6) vertical-inclined-crosscutting. The Langston Formation stylolites generally fall within catagories 1 and 5. These two catagories are both parallel to bedding.

Evidence for large amounts of cementation is lacking, and evidence for compaction is common. These facts lead to the conclusion that compaction played a key role in reducing the volume of original pore space. Compaction began in the eogenetic environment and probably continued into the mesogenetic.

Stylolitization or pressure solution is extensive. Bathurst (1975, p. 459) stated that volume reductions of 20 to 35% are commonplace. Stylolite amplitudes of 1mm to 1cm are common, but amplitudes of up to 6cm do occur. One sample shows 3 orders of stylolitization (Fig. 4). Most stylolitized samples contain less than 1 or 2 percent insoluble residues in unstylolitized area, yet stylolitic concentrations of insoluble residues are often extremely dense. Stylolitization usually requires overburdens of 600 to 900 meters, which places the process in the mesogenetic environment (Dunnington, 1967, cited in Bathurst, 1975). The stylolitization within the Langston Formation is assumed to have occurred in the mesogenetic environment.

The final diagenetic events include fracturing and subsequent infilling with calcite or iron-stained calcite. Hematite pseudomorphs after pyrite are common. Upon uplift into the fresh water environment, oxidation of pyrite supplied the source of iron for staining of calcite fractures and porous clastic areas. The iron stain may be hematite, limonite, and/or goethite.

DOLOMITIZATION

General Statement

"Clearly because of the variety of dolomite types that exist in nature, a single process of dolomitization does not exist and there is no one unique model to explain all dolomite" (Zenger et al. 1980, p. 1). Within the last decade or so, a large amount of information about dolomite, and its occurrence, has been published. Comparisons are made in the following section between the published literature and the evidence found in this study.

Dolomite of the Langston Formation

The dolomites of the Langston Formation are partially, but not totally, facies-controlled. There is a significant relationship between dolomite occurrence and upper peritidal deposits. Dolomite is also found in subtidal deposits which are below upper peritidal deposits. The dolomitization contact often cuts across the bedding surfaces of subtidal units. Figure 26 shows this relationship. The upper peritidal deposits of section 2 are undolomitized along the line of measurement, but within a few meters in either direction they are dolomitized, as are some of the subtidal deposits. This must represent a very local environment unfavorable to dolomitization during the Langston time. On the other hand, at section 8, all the upper peritidal and subtidal deposits (75 m) above the Spence Shale are dolomitized. Since most of the dolomitization is related to the upper peritidal deposits, a model for their dolomitization shall be

FIG. 26 - Photograph of cross-cutting dolomitization contact.

discussed first.

Dolomite formation is commonly referred to one of two major models, either formation in asociation with evaporites (Friedman, 1980; Zenger, 1972; and many others) or formation as a result of mixing of fresh and sea water (Hanshaw et al. 1971; Badiozamani, 1973; Folk and Land, 1975; and others). The mixing model proposes that mixtures of 5% to 35% seawater in fresh water will be undersaturated with respect to calcite but still supersaturated with respect to dolomite. It does not require the high Mg/Ca ratios of other models, instead it needs ratios of only 1:1 (Folk and Land, 1975). The upper peritidal deposits represent the emerged portion of a carbonate shoal complex. This complex was on the outer edge of a wide epeiric sea. It was therefore many miles from any large, constant source of fresh water. For this reason it is assumed that the Dorag, or mixing model, could not have operated.

The Langston Formation did not have a large source of fresh water available but the upper peritidal environments could have provided solutions with high Mg/Ca ratios. Therefore a process similar to the seepage reflux models of Adams and Rhodes (1960) and Deffeyes et al. (1965) is suggested for dolomitization of the Langston (Fig. 27). The seepage reflux model requires an evaporative concentration of saline brines in upper peritidal environments. As salinities increase, sulfates such as gypsum and anhydrite would precipitate out of solution and drive up Mg/Ca ratios in the solution. These saline, Mg-rich, dense fluids are then gravity-driven into lower limestone sediments. As they pass through

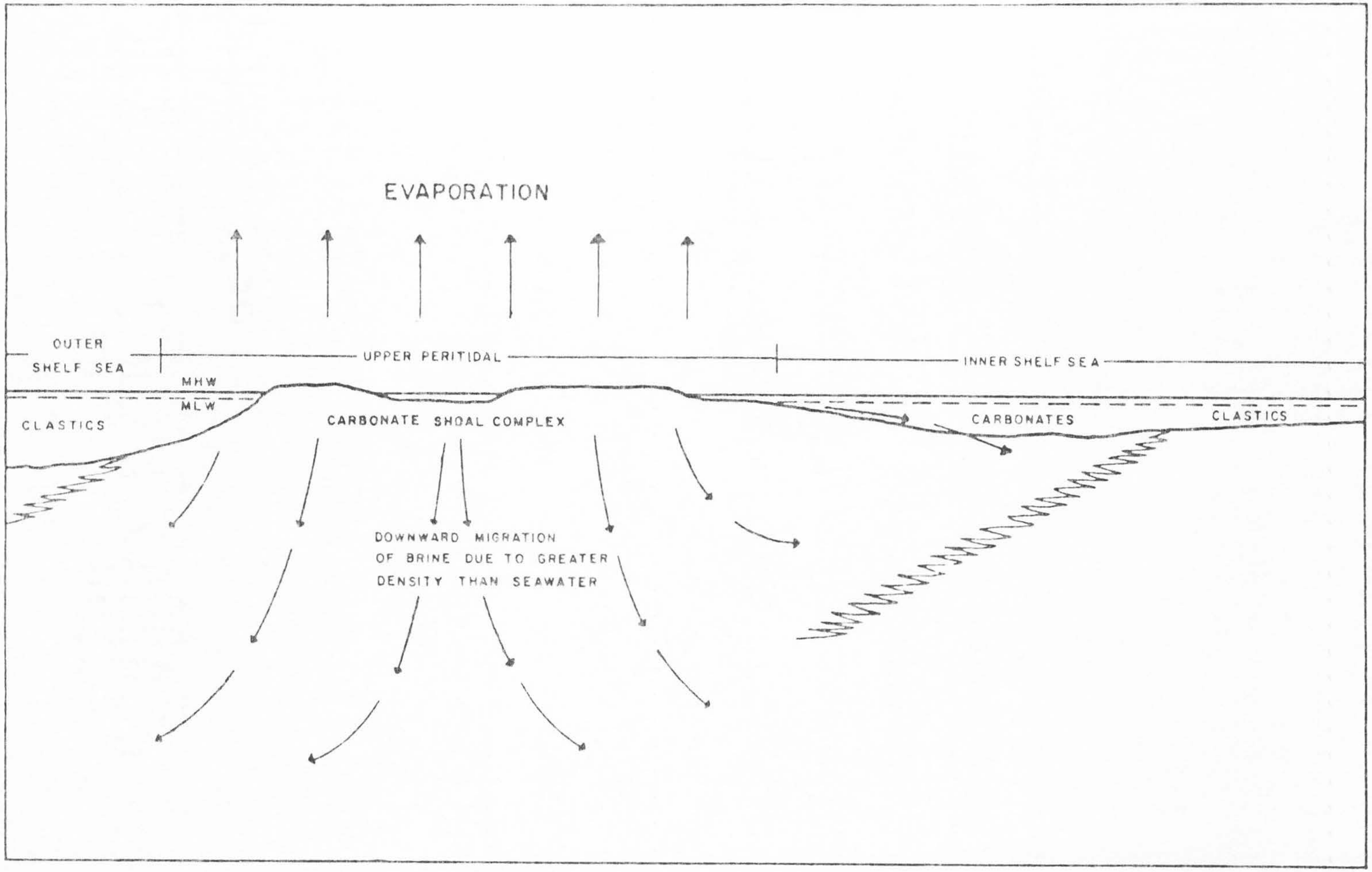


FIG. 27 - Diagram of modified seepage-reflux model for dolomitization of the Langston Formation.

MHW = mean high water level, MLW = mean low water.

those sediments, favorable conditions are created for the replacement of relatively unstable aragonite and calcite by more stable dolomite.

Evidence for a seepage reflux process is very abundant. The dolomite of the Langston Formation is almost always found in upper peritidal lithofacies, it is usually found below the upper peritidal lithofacies in the uppermost part of subtidal deposits, but is almost never found in subtidal lithofacies unassociated with upper peritidal lithofacies. Adams and Rhodes (1960) implied that dolomite is commonly associated with evaporites and shallow marine limestones. Evidence for evaporation in the Langston is common in the upper peritidal deposits. Gypsum casts are found, although they may occasionally be confused with birdseye structures. Relict chicken-wire anhydrite is locally common, and even solution breccias of once-bedded sulfates are found. Presence of sulfates is also inferred from the presence of many euhedral pyrite pseudomorphs. It has been proposed that the sulfur for the pyrite formation was provided by the dissolution of the sulfate evaporites (Braun and Friedman, 1969, p. 118). Desiccation features such as mudcracks and laminoid birdseyes are also common. This evidence leads to the conclusion that much of the Langston Formation represents environments in which extensive evaporation took place.

The paleoclimate during the Langston time was warm and humid based on the clay mineralogy. The paleolatitude places Utah in an equatorial setting during Langston time (Rowland, 1981; Ziegler et al., 1979). Could sulfates precipitate in this type of climate? Kinsman (1976) has found repetitive carbonate/sulfate layers in the

Permian Castile Formation of the Delaware Basin. Smith et al (1973, as cited by Kinsman, 1976) have determined the paleolatitude of the Delaware Basin to have been 5 - 10 N during the Permian. Kinsman stated that thea gypsum-anhydrite evaporite facies can precipitate in relative humidities as high as 93%. It therefore does not seem unreasonable to have produced evaporites in the Langston upper peritidal deposits.

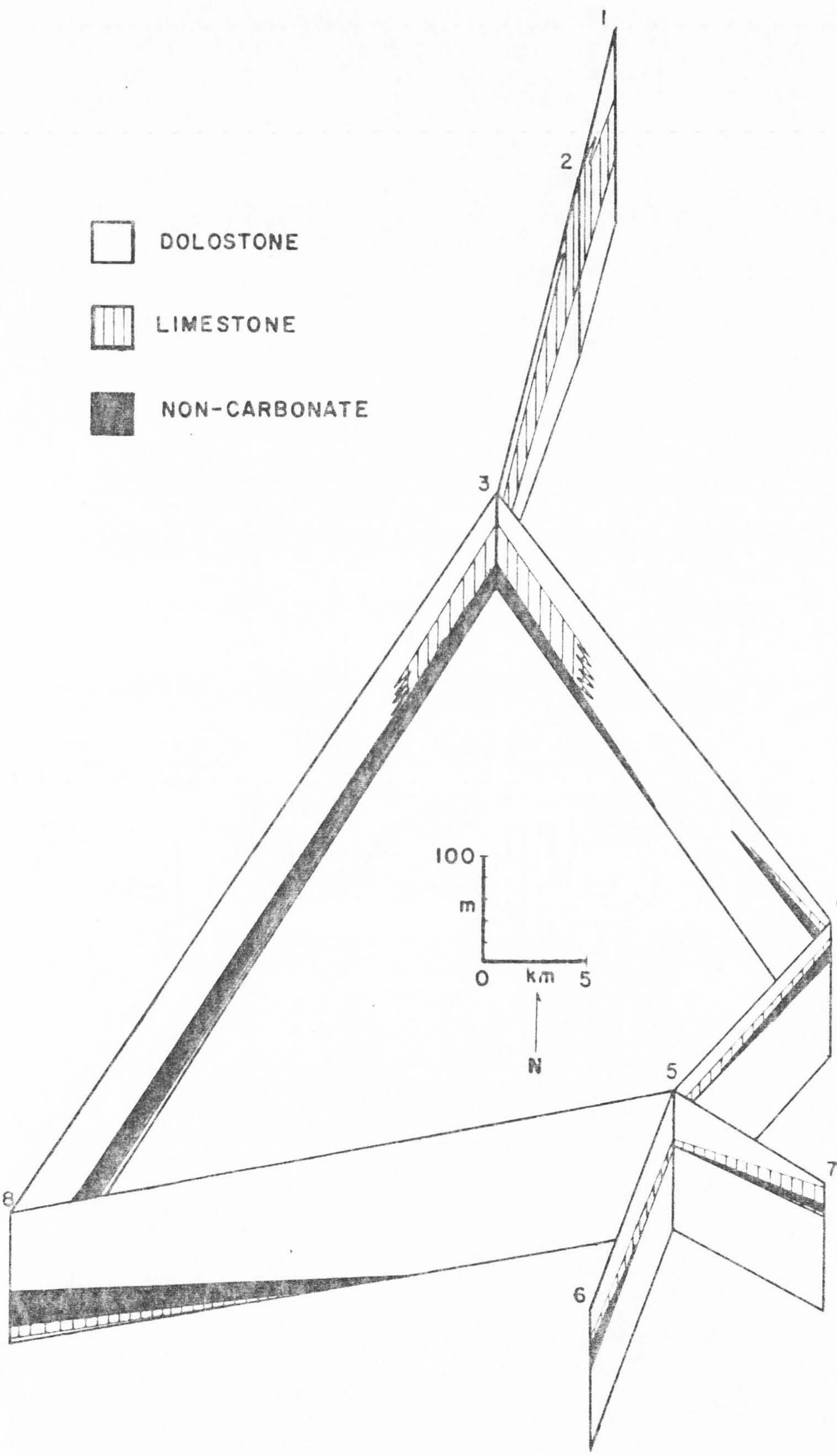
These peritidally produced, Mg-rich, dense fluids then filtered downward through the permeable substrates and dolomitized the relatively unstable aragonite and Mg-calcite. The downward migration of the fluids is well demonstrated in a few samples with obviously high original permeabilities. One dolomite sample from section 8 contains burrows which are coarsely dolomitized around their light colored peripheries for a distance of 2 to 10 times their diameter (FIG. 28). The coarsely dolomitized burrowed areas show distinct compaction features which formed around them but are themselves uncompacted, indicating one stage of dolomitization occurred before compaction. The darker areas, which show compaction features, are also dolomite but are not coarsely crystallized. This represents a later stage of dolomitization, possibly by Mg-rich interstitial fluids after compaction. Some of the mottled dolostones are more coarsely dolomitized in their lighter areas which probably represent the reworked portions of the rock. These two types of examples represent primary conduits for the seepage reflux brines. Other evidence for seepage reflux dolomitization of non-peritidal sediments is found in the cross-cutting relationships between bedding surfaces

FIG. 28 - Photograph showing early dolomitized burrows with compaction features around them.

and dolomite contacts. This is best exemplified in section 3 (Fig. 26) where dolomitized subtidal deposits, approximately 10 meters below upper peritidal deposits, have an irregular contact with undolomitized subtidal beds of identical lithologies.

One characteristic of the seepage reflux brines is that their compositions change and their dolomitizing potential diminishes away from their evaporative source (Adams and Rhodes, 1960). Field stratigraphic relationships demonstrate this well (Fig. 29). In sections 4 through 7, large upper peritidal dolomite deposits are found, and almost all of the subtidal carbonate deposits below them are dolomitized also. In sections 1 through 3, thin peritidal deposits occur at the top of the sections and dolomitization is restricted to the uppermost subtidal deposits below them. Section 8 also has a thin upper peritidal deposit at the top of the section, but the carbonates are dolomitized down to the impermeable shales. This must have resulted from dolomitizing fluids seeping down from the upper peritidal deposits at the top and from dolomitizing fluids migrating west from the thicker upper peritidal deposits in the east. These westward-migrating brines originated as the downward-seeping brines came in contact with less permeable layers and began migrating away from their source. They flowed west and aided in the dolomitization of section 8, but their dolomitizing potential must have diminished before they reached the northern sections.

FIG. 29 - Fence diagram showing relationship between, and the distribution of, dolostone, limestone, and non-carbonate rocks within the study area.


DOLOSTONE
LIMESTONE
NON-CARBONATE
1
2
3
4
5
6
7
8
100
m
0
km
5
N

There is evidence that the dolomitizing fluids were not always constant. The presence of alternating zones of dolomite, ferroan dolomite, and calcite within the dolomite rhombs (Fig. 30) suggests that the interstitial solutions were quite variable. Katz (1971) has found that zoned dolomite crystals result from dilution of interstitial brines with normal sea water or fresh water within the eogenetic environment. The ferroan dolomite was deposited as Fe/Mg ratios increased under reducing conditions. During periods of high turbulence, well-oxygenated waters diluted the dolomitizing fluids and oxidized the ferroan dolomite to produce the hematite-stained zones now present. Calcian dolomite and polycrystalline calcite zones were deposited as the dolomitizing brines were diluted also. The calcian dolomite (which can only be detected by electron-probe analysis) was deposited upon increase of Ca/Mg ratios, and the polycrystalline calcite was deposited as Ca/Mg ratios increased further. This depositional process was actually a dedolomitizing process. Katz further stated that zoned dolomite crystals are replacement products of a calcium carbonate sediment which was dolomitized before lithification.

One sample (Mh-3) contains many vugs infilled with zoned dolomite crystals and further infilled with quartz and quartz euhedra. The vugs may have resulted from either birdseye formation or sulfate precipitation and dissolution. Many euhedral crystals of hematite after pyrite are also found, suggesting dissolution of sulfate in a reducing environment. The presence of quartz within the vugs indicates a change in the interstitial fluid compostion.

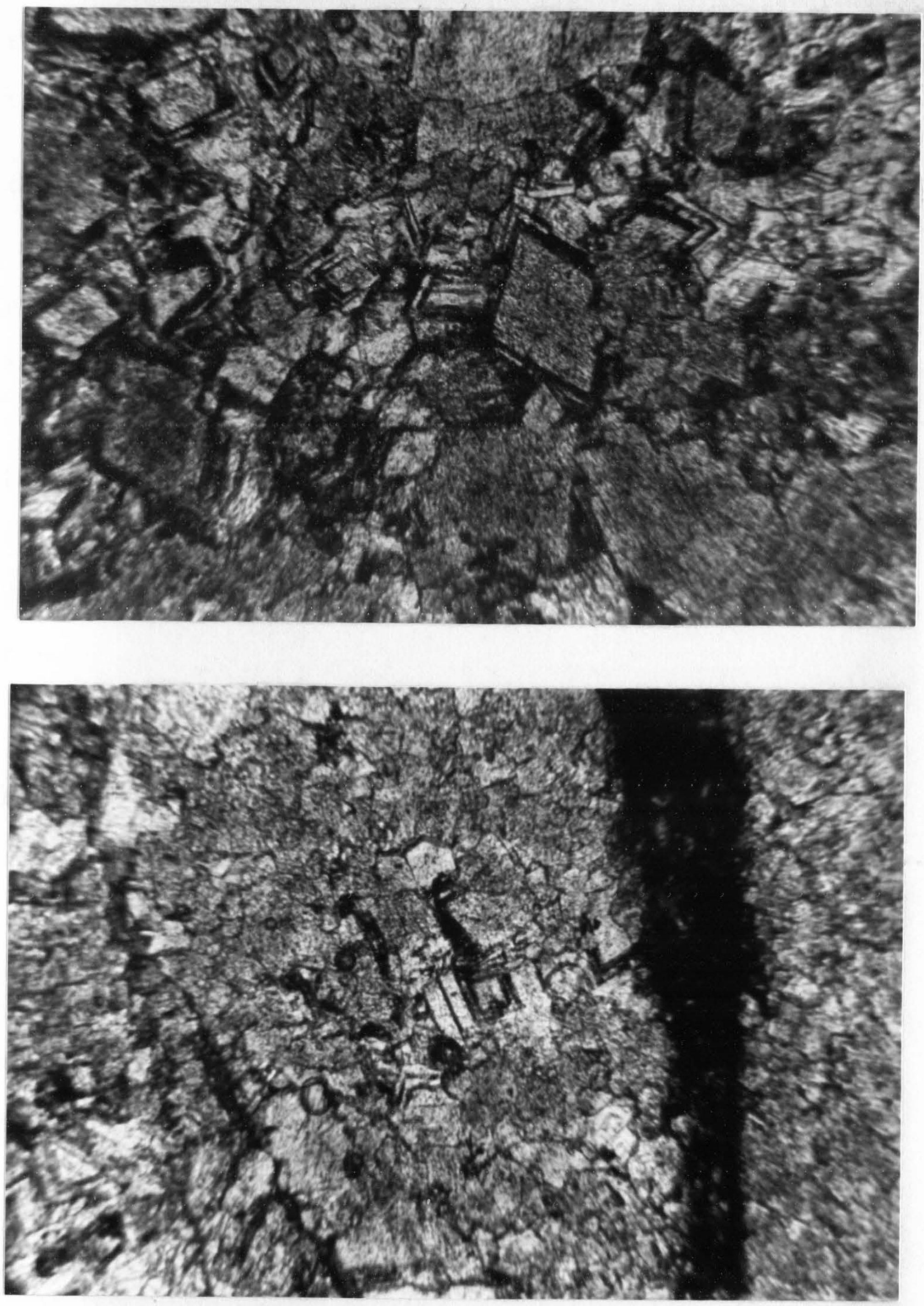


FIG. 30 - Two photographs of zoned dolomite rhombs. Field of view for both photographs = 1.8 mm.

Friedman and Shulkla (1980) have found authigenic quartz euhedra in sulfate solution vugs.

Wanless (1979, 1982) stated that pressure solution can supply the needed Mg for dolomitization. In this model, dolomitization is initiated and concentrated along areas of volume reduction by pressure solution. The crystals are zoned due to inclusions of clay and ferrous iron. The zoned dolomite rhombs of the Langson Formation contain dolomite, ferrous dolomite, and calcite. The dolomite rhombs in Wanless (1979, 1982) had no calcite. The Langston dolomite rhombs are not necessarily concentrated near stylolites. For these reasons Wanless' model of dolomitization was rejected for the Langston Formation.

The zoned dolomite crystals of the Langston Formation probably formed in birdseye vugs and/or sulfate solution vugs as indicated by their euhedral cores and rhombohedral inner zones. Precipitation stopped as the crystals grew in contact with each other.

Although seepage reflux appears to have been responsible for most of the dolomitization, a few other processes may have been operating.

Cryptalgal boundstones are found near the top of the dolomite portion in most sections. Gebelein and Hoffman (1973) have proposed that sediment binding Mg-rich algae may have been responsible for the dolomitization of alternating layers within algal boundstones. The decomposition of these Mg-rich algae produced local environments favorable to dolomitization within the algae-rich laminae. Most of the Langston algal boundstones are all dolomite, therefore the mineralogical evidence alone does not support Gebelein and Hoffman's model. However, there is a noticeable textural difference between some laminae. Alternating layers of coarse and finer crystals are found within the samples. This may indicate that early dolomitization did occur in the algal-rich layers, and then other processes later dolomitized the rest of the rock.

Another process may have operated in the Naomi Peak member of section 8. The Naomi Peak member contains upper peritidal and subtidal carbonates, and it is capped by the impermeable Spence Shale member above. The dolomitization in this area is very irregular. The lower contact grades into limestone to the north, and many large limestone lenses occur in the dolomite portion. Dolomitization surfaces often cross-cut bedding surfaces. The presence of peritidal deposits suggests that seepage reflux was the main dolomitizing process. The limestone lenses may have been less permeable to the seepage reflux brines or may have contained solutions more unfavorable to dolomite formation. Gebelein et al. (1980) have found lenses of fresh water beneath elevated ridges on tidal flats. The lenses and areas of limestone in the Naomi Peak member may have remained undolomitized as a result of chemically unfavorable interstitial solutions, although it is probably more likely that the seepage reflux brines were just not potent enough to dolomitize all of the carbonates in the area.

SUMMARY OF ENVIRONMENTAL AND DIAGENETIC EVENTS

The Lower Middle Cambrian Langston Formation is characterized by shallow subtidal to upper peritidal carbonate sequences and subtidal clastic sequences. Four major lithofacies were recognized: 1) upper peritidal; 2) inner carbonate shelf; 3) inner clastic shelf; and 4) outer clastic shelf. The distributional relationship between these facies probably was controlled mainly by fluctuating subsidence rates, but fluctuations in the clastic source area and sea level fluctuations may also have been important periodically.

The Langston Formation represents the first of the Cambrian grand cycles. In early Langston time subsidence was relatively slow. This allowed a large carbonate shoal complex to develop on the southeastern part of the study area. To the west and north of this complex, clastic sediments were accumulating in the outer shelf. These sediments were derived from the north or northwest and formed the Spence Shale. The Spence Shale deposition ended as subsidence increased. The upper peritidal deposits were eventually covered by inner carbonate shelf sediments. Finally, toward the end of Langston time subsidence began to slow again. The carbonate shoal complex shifted to the northwest, and clastic sediments from an eastern source prograded over the carbonates in the southeastern part of the section. These clastic sediments accumulated for a relatively short period of time, and inner carbonate shelf sediments were quickly deposited above them. Lastly, upper peritidal deposits were deposited throughout most of the section. This progradation of upper peritidal sediments over the area represents the end of the Langston deposition. The Langston Formation was then covered by the clastic sediments of the Ute Formation, representing the end of the first Cambrian grand cycle.

Eogenic diagenetic features include relict evaporite structures, birdseye structures, and compaction features. Dolomitization and possibly pressure solution began in the eogenetic environment, and probably continued into the mesogenetic environment. Diagenesis in the telogenetic environment was dominated by fracturing and infilling by calcite. Some fracturing and infilling may have also taken place in the late mesogenetic environment.

Dolomitization is thought to have resulted from a process similar to the seepage reflux model. Hypersaline brines flowed downward from upper peritidal sediments into the inner carbonate shelf sediments below. Favorable chemical conditions were created to bring about the replacement of calcium carbonate sediments by dolomite. Sediments containing algal mats may have been dolomitized as a result of algal concentration of Mg. The dolomitizing brine composition was not always constant, due to periodic dilution by normal marine water and/or fresh water.

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APPENDICES

Appendix A

Petrographic, Insoluble Residue, Organic Matter, and X-ray Data

Explanation

Samples are described according to one of three recognized classification schemes: 1) carbonates by Dunham (1962); 2) mudrocks by Lundegard and Samuels (1980); 3) sandstones by Folk (1968).

Sample descriptions consist of two fundamental parts: the basic rock name (limestone, mudrock, sandstone), and the compositional or textural classification term (packstone, mudshale, arkose) with appropriate modifiers.

Grain descriptions in thin sections include sphericity, roundness, size (maximum, minimum, average), and type of grains.

Sphericity:		Roundness:
	P	Platy A Angular
6:1		
	Bl	Bladed SA Subangular
2:1		
	SE	Subequant SR Subround
1 1/2:1		
	E	Equant R Rounded

(Terminology of Folk, 1968)

Samples are listed in order of their stratigraphic position; the lowermost sample is listed first. The symbol * in front of the sample number indicates the description is that of a thin section and those without are descriptions of polished slabs.

The mineralogical composition of the insoluble residues of the samples is listed in order of decreasing peak height.

Maple Creek - Section 1					
Sample Number	Unit	Rock Name	Percent Organic	Percent Insoluble	Insoluble Residue Composition
1a'	1	Mudrock: lenticular, medium laminated, trilobite- (agnostid), and feeding-trail-bearing, mudshale	----	----	----
1a	1	Mudrock: wavy, thin to medium bedded vertical burrow-bearing, siltstone	0.47	89.07	quartz, orthoclase, mica, albite
1b	1	Mudrock: parallel to wavy, medium bedded, thin curving cross laminated siltstone	0.39	93.06	quartz, microcline, mica, albite
1c	1	Mudrock: parallel to wavy, medium laminated mudshale	0.39	93.68	quartz, mica, kaolinite, microcline, albite
1d	1	Mudrock: parallel to wavy, medium laminated mudshale with limestone nodules	0.94	84.31	quartz, mica, albite, microcline
1e	1	Mudrock: wavy, very thin bedded mudshale with limestone nodules	0.20	79.78	quartz, mica, albite, microcline, kaolinite

2c	2	Limestone: burrowed, brecciated, peloidal wackestone with silty limonitic compaction features and stylolites	0.14	4.32	quartz, illite, chlorite, kaolinite, orthoclase
2b	2	Limestone: intraclast-bearing, peloidal wackestone with silty limonitic compaction features	0.18	4.61	quartz, illite, anorthclase
2a	2	Limestone: burrowed, peloidal wackestone with silty compaction features	0.19	5.22	quartz, illite, microcline
2d	2	Limestone: burrowed, peloidal wackestone with silty compaction features	0.08	4.80	quartz, kaolinite, chlorite, albite
2e	2	Limestone: burrowed, peloidal wackestone with silty limonitic psuedostylolites and stylolites	0.11	1.89	quartz, illite, albite, kaolinite
2f	2	Limestone: burrowed, pelletal wackestone with silty pockets and stylolite	0.13	1.37	quartz,illite, kaolinite, chlorite, albite

*2g	2	Limestone: SE-E, SR-R, (0.1mm,0.03mm 0.07mm), desiccation crack-bearing, pelletal packstone	0.20	1.73	quartz, illite, kaolinite, albite, chlorite
2h	2	Limestone: brachiopod-bearing, pelletal packstone with silty compaction features	0.14	1.10	quartz, illite albite, kaolinite
*3a	3	Dolostone: SE-E, SR-R, (2mm,0.08mm 0.25), bioturbated, pelletal wackestone/ packstone with organic-rich compaction features	0.04	0.98	quartz, illite, kaolinite
3b	3	Dolostone: peloidal crystalline carbonate	0.06	0.32	quartz, illite, kaolinite
*3c	3	Dolostone: gypsum cast-bearing, vuggy, peloidal wackestone	0.13	0.41	K-feldspar, quartz, illite
3d	3	Dolostone: medium irregular birdseye-rich, limonitic, peloidal wackestone	0.10	0.56	quartz, illite, kaolinite, chlorite
3e	3	Dolostone: coarse crystalline, fine laminoid birdseye-rich, peloidal wackestone with stylolites	0.11	0.74	illite, quartz, kaolonite, chlorite

3f	3	Dolostone: intraclast-, mudcrack-, and fine irregular birdseye-bearing, cryptalgalaminated boundstone with stylolites	0.04	0.64	quartz, illite, albite
*3g	3	Dolostone: fine laminoid birdseye-rich, ?peloidal crystalline carbonate with ?relict chicken wire anhydrite and stylolites	0.11	17.89	quartz, illite

High Creek - Section 2					
Sample Number	Unit	Rock Name	Percent Organic	Percent Insoluble	Insoluble Residue Composition
*1a	1	Sandstone: BL-SE, SA-SR, (1.5mm, 0.005mm, 0.25mm), echinoderm- and trilobite fragment-bearing, calcareous, quartz arenite with stylolites	0.10	77.2	quartz
1c	1	Limestone: hematite- and limonite-bearing, trilobite fragment-rich, burrowed, wackestone with compaction features and stylolites	0.17	16.97	quartz, illite, albite
*1d	1	Limestone: P-E, SA-R, (1cm,0.05mm, 0.11mm), algal tubule (Girvenella)-, echinoderm fragment-bearing, trilobite fragment-rich, burrowed, pelletal dolomitic packstone with stylolites, compaction features, and quartz silt limonitic pockets	0.05	0.76	quartz, illite
*1b	1	Limestone: P-E, A-R, (1.5cm,0.005mm,?), ostracod-, and echinoderm fragment-bearing, pelletal, trilobite fragment-rich dolomitic wackestone/packstone with stylolites and quartz silt limonitic layers and pockets	0.09	1.07	quartz, illite, albite

*2a	2	Limestone: P-E, SA-SR, (0.15mm,0.005mm, 0.60mm), hematite-bearing,silty, trilobite fragment-rich, fossiliferous, peloidal, ?oolitic, burrowed, laminated to lenticular packstone	0.76	21.11	quartz, illite, kaolinite, albite
2b	2	Limestone: hematite-bearing, silty, fossiliferous, peloidal, parallel to lenticular bedded wackestone/packstone	0.60	38.75	quartz, illite, albite, kaolinite
3a	3	Mudrock: parallel to lenticular, medium laminated, non-calcareous mudshale	0.25	86.72	quartz, illite, albite
3b	3	Mudrock: parallel, medium laminated, trilobite-bearing, calcareous mudshale	0.15	78.49	quartz, kaolinite, illite, albite
3c	3	Mudrock: lenticular, thick laminated, trilobite- and horizontal burrow-bearing, mudshale	0.51	88.16	quartz, illite, kaolinite, albite
3d	3	Mudrock: lenticular, thick laminated, trilobite-bearing, slightly calcareous mudshale	0.05	83.85	quartz, illite, kaolinite
3e	3	Mudrock: wavy to parallel, thin bedded, slightly calcareous mudshale	0.15	84.47	quartz, illite, kaolinite, ?albite

*3f	3	Mudrock: BL-SE, SR-R, (0.08mm,?, 0.03mm), organic-, trilobite fragment-rich, silty, slightly calcareous, mudshale	1.97	87.63	quartz, illite, kaolinite, ?albite
5a	5	Limestone: trilobite fragment-bearing, burrowed, peloidal wackestone with silty limonitic pseudostylolites	0.22	8.04	quartz, illite, kaolinite, chlorite, ?albite
6a	6	Limestone: parallel laminated, peloidal wackestone with silty limonitic pseudostylolites and stylolites	0.12	3.79	quartz, illite, albite
7a	7	Limestone: trilobite fragment-bearing, intraclastic, peloidal, pisolitic, fibrous-cemented packstone/grainstone	0.15	0.75	quartz, illite, ?albite
8a	8	Limestone: bioturbated peloidal wackestone	0.21	1.95	quartz, illite, ?albite
8b	8	Dolostone: bioturbated peloidal wackestone	0.11	0.94	quartz, illite, ?albite

8c	8	Limestone: BL-E, SR-R, (2.5cm,0.2mm, 2.5mm), intraclastic, ?fibrous-cemented grainstone with silty stylolites	----	----	----
9a	9	Limestone: peloid-, intraclast-, mudcrack-bearing, thin laminoid and irregular birdseye-rich, cryptalgalaminated boundstone with stylolites	0.07	2.58	quartz, illite, ?albite
9b	9	Dolostone: medium laminoid and irregular birdseye-rich stromatolitic (LLH), cryptalgalaminated boundstone with stylolites	0.11	2.32	quartz, illite

Smithfield Canyon - Section 3					
Sample Number	Unit	Rock Name	Percent Organic	Percent Insoluble	Insoluble Residue Composition
1a	1	Mudrock: parallel to wavy, medium laminated, calcareous mudshale	0.65	87.98	quartz, illite, kaolinite, albite
1b	1	Mudrock: parallel, thick laminated, calcareous, mudshale	----	87.50	quartz, illite, albite
1c	1	Mudrock: parallel, medium laminated, non-calcareous, mudshale	1.18	84.46	quartz, illite, albite, kaolinite, ?microcline
2a	2	Mudrock: wavy to lenticular, thick laminated, calcareous, mudshale	0.66	85.07	quartz, illite, kaolinite, albite, chlorite
*2b	2	Mudrock: wavy to lenticular, thin to medium laminated, trilobite-bearing, peloidal, calcareous, mudshale	0.38	80.72	quartz, mica, kaolinite, albite, chlorite
2c	2	Mudshale: wavy to lenticular, thin to medium laminated, calcareous, mudshale	0.81	84.88	quartz, illite, kaolinite, albite, chlorite

*6a	6	Limestone: BL-E, SR-R, (4.0mm, 0.05mm, 0.10mm), echinodern and trilobite fragment-rich, pelletal, peloidal, dolomitic packstone	0.17	2.23	quartz, illite, kaolinite, albite
7a	7	Limestone: burrowed, peloidal wackestone	0.15	1.58	quartz, illite, kaolinite, albite
*8a	8	Limestone: E, R, (0.5mm, 0.1mm, 0.4mm), burrow-bearing, silty, peloidal, wackestone with stylolites	0.22	3.21	quartz, illite, kaolinite, albite
8b	8	Limestone: burrow-bearing, silty, peloidal, wackestone with stylolites	0.22	1.93	quartz, illite, kaolinite, albite
8c	8	Dolostone: burrow-bearing, silty, peloidal, wackestone with stylolites	0.10	2.37	quartz, illite, ?albite
9a	9	Dolostone: highly bioturbated, peloidal wackestone with stylolites	0.07	0.30	quartz, illite, ?albite
10a	10	Dolostone: relict chicken-wire anhydrite-bearing, peloidal, wackestone with stylolites	0.09	0.54	quartz, illite, albite

*10b	10	Dolostone: medium irregular birdseye-rich, peloidal, wackestone with stylolites	0.10	0.62	quartz, illite, ?albite
10c	10	Dolostone: medium irregular birdseye-rich, peloidal, wackestone with stylolites	0.01	0.77	quartz, illite, albite

Left Fork - Section 4

Sample Number	Unit	Rock Name	Percent Organic	Percent Insoluble	Insoluble Residue Composition
1a	1	Dolostone: gypsum cast-bearing, bioturbated packstone	0.14	13.15	quartz, microcline, illite
1b	1	Dolostone: medium laminoid birdseye-bearing, peloidal packstone	0.01	2.33	quartz
1c	1	Dolostone: onkoidal, peloidal packstone	0.07	2.35	quartz, illite, microcline, kaolinite
1d	1	Dolostone: peloidal, onkoidal packstone	0.05	0.79	quartz, illite, microcline
1e	1	Dolostone: bioturbated, peloidal, wackestone with compaction features	0.07	0.93	quartz, illite
2a	2	Dolostone: medium irregular birdseye-, and peloid-bearing, bioturbated wackestone wit stylolites and compaction features	0.08	0.35	quartz, illite
*3a	3	Dolostone: crystalline carbonate with pseudostylolites, stylolites and relic chicken-wire anhydrite	0.08	0.77	quartz, illite

*3b	3	Dolostone: crystalline carbonate with medium irregular birdseyes infilled with concentrically banded dolomite and relict chicken-wire anhydrite	0.01	0.79	quartz, illite,
3c	3	Dolostone: fine to medium irregular birdseye-bearing, peloidal mudstone/ wackestone with pseudostylolites and stylolites	0.13	0.41	K-feldspar, quartz, illite, microcline
3d	3	Dolostone: medium irregular birdseye-bearing, limonitic mudstone with stylolites and pseudostylolites	0.05	0.79	quartz, illite
4a	4	Dolostone: intraclast-, mudcrack-bearing, stromatolitic (LLH), cryptalgalaminated boundstone with stylolites	0.06	2.42	quartz, illite, ?albite
*5a	5	Dolostone: SE-E, R, (0.22mm,0.05mm, 0.12mm), hematite- and limonite-bearing peloidal packstone with pseudostylolites and stylolites	0.04	0.94	quartz, illite, ?K-feldspar
6	6	Mudrock: float, parallel to lenticular medium laminated, trilobite- and annelid-pellet-filled burrow-bearing mudshale	1.38	87.83	quartz, illite, microcline

*7a	7	Limestone: BL-E, R (2cm,0.07mm,4.0mm), ?trilobite-, calcisphere-, archaeocyathid-, echinoderm-, and brachiopod-bearing, fibrous calcite cemented, peloidal, dolomitic grainstone	0.14	2.14	quartz, illite
8a	8	Dolostone: poorly sorted, sparry, peloidal, onkoidal, calcareous grainstone	0.08	1.59	quartz, illite
8b	8	Dolostone: onkoid-bearing, bioturbated, peloidal, calcareous wackestone/packstone with silty layers and pockets, and stylolites	0.15	0.80	quartz, illite, ?K-feldspar
8c	8	Dolostone: thin laminoid birdseye-intraclast-, and peloid-bearing, stromatolitic (LLH), cryptalgalaminated boundstone with stylolites	0.10	4.42	quartz, illite,

Blacksmith Fork - Section 5					
Sample Number	Unit	Rock Name	Percent Organic	Percent Insoluble	Insoluble Residue Composition
*5a	1	Dolostone: BL-E, A-SR, (0.18mm, 0.03mm, 0.12mm), medium laminoid birdseye-rich, silty, wackestone	0.06	5.83	quartz, plagioclase, microcline
*5b	1	Dolostone: BL-SE, A-SR, (0.27mm, 0.05mm, 0.24mm), gypsum cast-rich, silty, wackestone with stylolites	0.07	38.70	quartz, montmorillonite
*6a	2	Dolostone: SE-E, A-SA, (0.12mm, 0.05mm, 0.10mm), peloid-bearing, silty, medium crystalline carbonate with stylolites	0.13	5.46	quartz, microcline, illite
*6a'	2	Dolostone: SE-E, SA-R, silt-bearing, peloidal and onkoidal wackestone	0.12	2.74	quartz, illite
*8a	4	Dolostone: E, SR-R, (1.0 cm, 0.1 mm, 0.02 mm), pisolitic, ?onkoidal, and peloidal, bioturbated packstone	0.24	4.10	quartz, illite
*8b	4	Dolostone: T-E, SR-R, (1.8 cm, 0.09 mm, 0.15mm), trilobite fragment- and silt-bearing, pisolitic and peloidal, wackestone with stylolites	0.09	2.57	quartz, illite, kaolinite

*9a	5	Dolostone: vuggy crystalline carbonate	0.01	0.90	quartz, illite, albite
*9b	5	Dolostone: SE, SR, (0.12 mm, 0.06 mm, 0.10 mm), laminoid birdseye- bearing, bioturbated, ?peloidal, wackestone	0.01	1.12	quartz, illite, albite
*9c	5	Dolostone: vuggy, euhedral quartz-bearing, medium to thick irregular birdseye-rich, crystalline carbonate	0.03	.052	quartz
*11a	7	Dolostone: B-SE, A-SR, (3 cm, 0.05 mm, 0.18 mm), trilobite fragment-, mudcrack-, intraclast-bearing, thin laminoid to irregular birdseye-rich, silty, stromatolitic (LLH), peloidal, cryptalgalaminated boundstone with stylolites	0.06	9.88	quartz, illite, K-feldspar, kaolinite
*13a	9	Limestone: ?ooid-bearing, intraclast-trilobite, archaeocyathid-, and echinoderm-fragment-rich, dolomitic wackestone	0.48	6.52	quartz, illite, orthoclase, albite
*14a	10	Limestone: B-E, SR-R, (1 cm, 0.01mm, 0.2 mm), intraclast-, onkoid-, silt-, trilobite-fragment-, and peloidal, wackestone/packstone	0.09	4.87	quartz, illite, goethite

*15a	11	Dolostone: archaeocyathid- and trilobite-fragment-bearing, burrowed, onkoidal, and peloidal, wackestone with stylolites	0.03	1.61	quartz, illite, hematite
*15b	11	Dolostone: E-SE, R-SR, (0.25 mm, 0.05 mm, 0.18 mm), bioturbated, peloidal packstone with stylolites	0.14	1.18	quartz, illite, albite
*15c	11	Dolostone: E-SE, R-SR, (0.5 mm, o.o5 mm, 0.20 mm), bioturbated peloidal wackestone with stylolites	0.05	0.65	quartz, illite, kaolinite

East Fork - Section 6					
Sample Number	Unit	Rock Name	Percent Organic	Percent Insoluble	Insoluble Residue Composition
2a	1	Dolostone: silty to sandy, peloidal, pisolitic, calcareous packstone with stylolites	0.14	21.45	quartz, illite, microcline, orthoclase
2I	1	Dolostone: hematite (pseudomorph after pyrite)-bearing, silty to sandy, limonitic, peloidal wackestone/packstone with pseudostylolites and stylolites	0.35	47.76	quartz, microcline, illite
2b	1	Dolostone: silty to sandy, slightly bioturbated, peloidal wackestone with stylolites	0.25	35.85	quartz, microcline
4II	2	Limestone: burrowed, peloidal packstone with limonitic stylolites	0.23	3.22	quartz, orthoclase, illite, microcline, albite
*4III	2	Limestone: BL-E, SR-R, (0.85mm,0.01mm, 0.12mm), trilobite fragment-bearing, burrowed, silty, dolomitic pelletal packstone with stylolites and silty dolomite pockets	0.17	6.79	quartz, illite, orthoclase, microcline, albite, kaolinite

4I	2	Limestone: trilobite fragment-bearing, peloidal, onkoidal, fibrous-cemented grainstone	0.11	1.46	quartz, illite, orthoclase, microcline, albite
6a	4	Dolostone: peloidal packstone	0.06	2.32	quartz, illite
6I	4	Dolostone: peloidal, onkoidal packstone with stylolites	0.17	2.45	quartz, illite, microcline
*6II	4	Dolostone: SE-E, R, (1mm,0.25mm, 0.50mm), pelletal packstone/grainstone	0.08	2.04	quartz, illite, microcline
*6b	4	Dolostone: SE-E, SR-R, (0.7mm,0.08mm, 0.5mm), thin irregular birdseye-rich, peloidal packstone	0.01	1.99	quartz, illite
7a	4	Dolostone: medium laminoid and irregular birdseye-rich, peloidal wackestone with stylolites and ?relict chicken-wire anhydrite	0.11	1.77	quartz, illite, chlorite, kaolinite

8a	5	Dolostone: mudcrack-bearing, stromatolitic (LLH), peloidal, cryptalgalaminated boundstone with stylolites	0.14	9.39	quartz, illite, albite
9a	5	Dolostone: mudcrack-, intraclast-bearing, stromatolitic (LLH), peloidal, cryptalgalaminated boundstone with stylolites	0.20	12.28	quartz, illite, microcline, ?albite

Hardware Ranch - Section 7					
Sample Number	Unit	Rock Name	Percant Organic	Percent Insoluble	Insoluble Residue Composition
*1a	1	Dolostone: E, R, (4 mm, 0.35 mm, 0.8 mm), limonitic, peloidal, grainstone with stylolites	0.06	0.76	quartz, goethite, illite
*1c	1	Dolostone: SE-E, SR-R, (1 mm, 0.09 mm, 0.22 mm), relict chicken-wire anhydrite-bearing, peloidal, packstone with compaction features	0.05	1.15	quartz, illite
1d	1	Dolostone: thin to medium laminoid birdseye- and intraclast-bearing, cryptalgalaminated boundstone	0.02	0.82	quartz, illite
*1e	1	Dolostone: ?peloidal, crystalline carbonate with stylolites	0.15	1.50	quartz, illite
*1f	1	Dolostone: coarse laminoid ?birdseye-bearing, peloidal crystalline carbonate	0.02	0.82	quartz, illite
1g	1	Dolostone: coarse crystalline, medium laminoid birdseye-bearing, ?peloidal packstone	0.15	0.84	quartz, illite, goethite

1h	1	Dolostone: coarse crystalline, coarse irregular birdseye-bearing, mudstone	0.05	1.09	quartz, illite, goethite
2a	2	Limestone: onkoid-bearing, slightly bioturbated, burrowed, limonitic, peloidal, wackestone with compaction features	0.13	1.53	quartz, goethite, illite
2b	2	Mudrock: lenticular, medium laminated, trilobite-bearing, mudshale	2.95	90.18	quartz, illite, ?microcline
2c	2	Limestone: ?fossil fragment-bearing, onkoidal, peloidal, burrowed, wackestone with hematite stained stylolites	0.14	1.81	quartz, illite, goethite
2d	2	Dolostone: hematite crystal-bearing, intraclastic, and stromatolitic (LLH), cryptalgalaminated boundstone and intraclastic wackestone	0.17	8.90	quartz, illite, microcline, ?albite

Miners Hollow - Section 8					
Sample Number	Unit	Rock Name	Percent Organic	Percent Insoluble	Insoluble Residue Composition
*1	1	Dolostone: coarse laminoid birdseye-, pisolite-, and hematite (pseudomorph after pyrite)-bearing, euhedral quartz crystal-bearing and peloidal, wackestone/ packstone	0.04	3.03	quartz, illite, albite, kaolinite, montmorillonite
*2	1	Limestone: pyrite-, pisolite-, trilobite and echinoderm fragment-bearing, burrowed, mottled, peloidal, dolomitic, wackestone	0.15	8.23	quartz,illite, albite, kaolinite, microcline
*3	1	Dolostone: E, R, (0.19 mm, 0.05 mm, 0.12 mm), medium irregular birdseye-rich, silty, peloidal wackestone	0.03	4.53	quartz, illite, albite
*4	1	Dolostone: SE-E, A-SR, (0.15 mm, 0.05 mm, 0.9 mm), silty, burrowed, ?peloidal wackestone with stylolites	0.85	62.41	quartz, illite, albite
5	2	Mudrock: lenticular, medium laminated, trilobite fragment-bearing, calcareous, mudshale	0.72	80.59	quartz, illite, albite, kaolinite

*6	2	Limestone: SE-E, SR-R, (0.07 mm, 0.04 mm, 0.05mm), intraclast- and trilobite fragment-bearing, silty, limonitic, laminated, peloidal, mudstone/wackestone	0.23	24.53	quartz, illite, albite, kaolinite, chlorite
7	3	Mudrock: wavy, thin laminated, trilobite fragment-bearing, calcareous, mudshale	1.01	75.18	quartz, illite, kaolinite, albite, chlorite
8	3	Mudrock: lenticular to parallel, thin laminated, trilobite fragment-bearing, calcareous, mudshale	1.09	80.17	quartz, illite, kaolinite, albite, chlorite
9	3	Mudrock: parallel to wavy, thin to medium laminated, trilobite fragment and brachiopod-bearing, calcareous, mudshale	1.02	75.83	quartz, illite, kaolinite, albite, chlorite, microcline
*10	3	Mudrock: parallel to wavy, medium laminated, trilobite fragment-bearing, peloidal, calcareous, and dolomitic, mudshale	0.74	66.61	quartz, illite, kaolinite, albite, chlorite
*11	4	Mudrock: parallel to wavy, thin to medium laminated, trilobite fragment-bearing, peloidal, calcareous, mudshale	0.55	51.10	quartz, illite, kaolinite, albite

*12	4	Limestone: BL-E, SA-R, (6 mm, 0.01 mm, 0.10 mm), fossiliferous, silty, peloidal, dolomitic, wackestone	0.21	29.70	quartz, illite, kaolinite, albite
13	4	Mudrock: parallel to wavy, medium laminated, fossiliferous, calcareous, mudshale	1.20	81.40	quartz, illite, albite, microcline
*13.5	4	Dolostone: BL-E, SA-R, (2.5 mm, ?, 0.14 mm), echinoderm and trilobite fragment-bearing, limonitic, calcareous, wackestone with stylolites, compaction features, and fractures	0.25	21.05	quartz, illite, albite
*14	5	Dolostone: SE-E, RS-R, (10 mm, 0.05 mm, 0.10 mm), very highly fractured, peloidal, calcareous, wackestone/packstone	0.03	1.08	quartz, illite, albite
*15	5	Dolostone: SE-E, SR-R, (0.25 mm, 0.05 mm, 0.15 mm), hematite-stained, mottled, peloidal, wackestone with compaction features and silty layers	0.14	2.10	quartz, illite, albite
*16	5	Dolostone: SE-E, SR-R, (0.14 mm, ?, 0.09 mm), burrowed, mottled (non-biotic), peloidal, wackestone with compaction features, and stylolites	0.10	0.76	quartz, illite, orthoclase, albite

*17	5	Dolostone: SE-E, SR-R, (0.09 mm, ?, 0.07 mm), bioturbated, mottled, ?peloidal, wackestone with compaction features, stylolites, and dolomite rhombs with alternating calcite bands	0.07	0.61	quartz, illite, albite
*17.5	5	Dolostone: SE-E, SR-R, (0.20 mm, 0.05 mm, 0.15 mm), ?birdseye-bearing, slightly bioturbated, peloidal, wackestone with stylolites and compaction features	0.22	1.12	quartz, illite, albite
*18	5	Dolostone: E, R, (1.5 cm, 0.08 mm, 0.70 mm), ooid-, intraclast-, and peloid-bearing, onkoidal, wackestone/packstone with compaction features and stylolites	0.10	0.19	quartz, illite, albite
*19	5	Dolostone: SE-E, SR-R, (1.0 mm, 0.05 mm, 0.09 mm), mottled, peloidal wackestone	0.10	0.44	illite, quartz
*20	5	Dolomite: SE-E, SR-R, (1.0 mm, 0.08 mm, 0.15 mm), very thick laminated, peloidal, calcareous, wackestone with stylolites and alternating dark grey (N3), fine crystalline laminations and moderate yellowish brown (10 YR 5/4) medium crystalline laminations	0.10	1.66	quartz, illite, albite, orthoclase

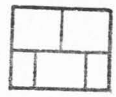
*21	6	Dolostone: thin to medium laminoid and medium irregular birdseye-bearing, calcareous, crystalline dolostone with stylolites	0.17	0.74	quartz, illite, albite, orthoclase
*22	6	Dolostone: BL-E, SA-R, (1.0 mm, 0.05 mm, 0.10 mm), hematite- and medium laminoid and fine irregular birdseye-bearing, intraclastic, peloidal, stromatolitic (LLH), cryptalgalaminated boundstone and wackestone with stylolites	0.34	2.16	quartz, illite, albite

Appendix B

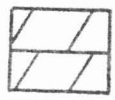
Measured Stratigraphic Sections

Explanation of Stratigraphic Sections

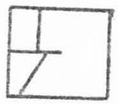
Rock Symbols



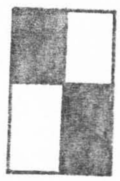
Limestone



Dolostone



Poorly exposed
or covered



N2-N5

N6-N8

Section 1

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

Ute Formation, mudrock

Contact: sharp, wavy

Langston Formation, dolostone

Unit		Thickness in meters
Mc-3:	Dolostone, medium to very light grey (N5.5-N8), weathers to sugary, very pale orange (10 YR 8/2) to moderate brown (5 YR 4/4), medium to thick bedded (10-60 cm), often massive, fine to medium crystalline, containing bioturbation in lower part (mottled with pale red (5 R 6/2) to yellowish grey (5 Y 7/2)), birdseye structures in middle, cryptalgalaminae, intraclasts, mudcracks, and stylolites at top, and peloids and small vugs throughout; exposed as resistant ledges and rugged cliffs..	65.5
Mc-2:	Limestone, medium dark grey (N4), weathers to medium light grey (N6), thin to thick bedded (2-30 cm), finely crystalline, containing vertical to horizontal burrows, wavy laminations, ?stromatolites, and birdseye structures; highly bioturbated in places; lower part contains a 30 cm bed of spar cemented limestone breccia; remarkably consistent lithology; bedding surfaces weather to smooth humps or knobs; exposed as resistant outcrops and rugged cliffs..........................	63.1

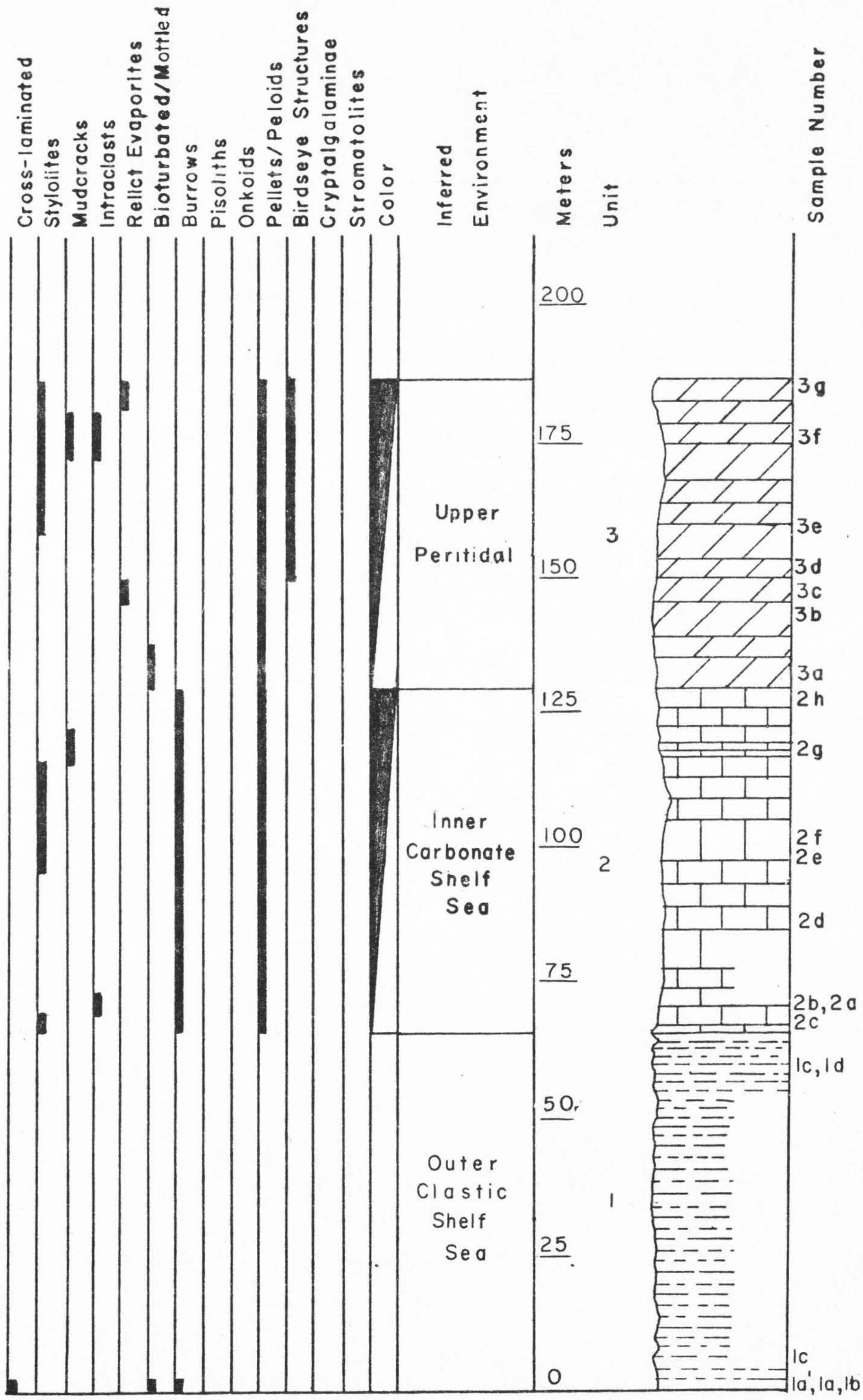
Mc-1: Siltstone and mudshale, pale olive grey (5 Y 6/2) to olive grey (5 Y 4/1), weathers to light grey (5 Y 5/2) to yellowish grey (5 Y 7/2), thin to thick bedded (3-45 cm), laminated, containing silt to medium sand (< 1/16-1/4 cm), cross-laminations, parallel-laminations, trails, burrows, and body-fossils; the siltstone and mudshale are interbedded; exposed as poor outcrops on moderate slope; approximately 3/4 covered, with shale float in covered section.................. 58.2

Total = 186.8

Contact: gradational, conformable

Prospect Mountain Quartzite, sandstone/orthoquartzite

SECTION I


Cross-laminated
Styolites
Mudcracks
Intraclasts
Relict Evaporites
Bioturbated/Mottled
Burrows
Pisoliths
Onkoids
Pellets/Peloids
Birdseye Structures
Cryptalgalaminae
Stromatolites
Color
Inferred Environment
Meters
Unit
Sample Number
200
175
150
125
100
75
50
25
0
Upper Peritidal
Inner Carbonate Shelf Sea
Outer Clastic Shelf Sea
3
2
1
3g
3f
3e
3d
3c
3b
3a
2h
2g
2f
2e
2d
2b,2a
2c
lc,ld
lc
la',la,lb

Section 2

Location: High Creek, Cache County, Utah, 7 miles northwest of Richmond, Utah on main ridge of High Creek in Section 11, T. 14 N., R. 2 E., line of section measured follows up ridge on south fork side. Very well exposed.

Ute Formation, red shale

Contact: sharp, mostly planar

Langston Formation, limestone

Unit		Thickness in meters
Hc-9:	Limestone, medium dark grey (N4), weathers to very light grey (N8), thin to medium bedded (1/2-12 cm), finely crystalline, containing cryptalgalaminae, stromatolites (LLH-S), peloids, and birdseyes, interbedded with limestone, medium dark grey (N4), weathers to medium grey (N5), unlaminated, finely crystalline, containing rip-up clasts of cryptalgalaminated beds, peloids, birdseyes; stylolites well developed along contacts; partially dolomitized northwest of measured section; exposed as large steep ledge................	5.9
Hc-8:	Limestone, dark grey (N3) mottled with medium light grey (N6), weathers to medium dark grey (N4) mottled with light grey (N7), massive, fine to medium crystalline, bioturbated, containing vertical to horizontal burrows, onkoids in lower part (1mm-2cm), a 0.6 m bed of intraformational conglomerate (1mm-2cm) at top; partially dolomitized northwest of measured section; exposed as moderate slope..........	19.4
Hc-7:	Limestone, dark grey (N3), weathers to medium grey (N5), medium bedded (5-20cm), finely crystalline, containing silty partings along bedding planes (hematite and/or limonite stained), onkoids (1/2-2cm) more concentrated in lower third of unit and thinning out toward top; exposed as steep ledges and moderate slope..	28.5

Hc-6: Limestone, dark grey (N3), weathers to medium grey (N5) and medium light grey (N6) with small sharp knobs, thin to medium bedded (5-15cm), finely crystalline, containing some wavy, silty partings (limonite and/or hematite stained), vertical to horizontal recrystallized burrows which increase toward top of Hc-6, some fine cross-bedded laminations with planar bottoms: exposed as steep ledges and moderate slopes.................... 17.4

Hc-5: Limestone, dark grey (N3), weathers to medium dark grey (N4.5), medium bedded (10-15cm), finely crystalline, slightly bioturbated, containing fossils (trilobites), vertical to horizontal recrystallized burrows; oscillatory cross-ripple marks in float; breaks apart at silty (10 YR 7/4) partings; exposed as moderate to steep slope............................ 15.1

Hc-4: Covered, limestone float, contact of above limestone and lower shale is within this unit, and most likely at bottom as indicated by loss of shale float; moderate to steep slope............. 3.4

Hc-3: Mudrock, mudshale, color ranges from dark grey (N3) to light olive grey (5 Y 5/2), weathered color ranges from medium grey (N5) to greyish brown (5 YR 3/2) to light olive grey (5 Y 6/1) and weathers to small (1/2-1cm) chips, finely laminated to thin bedded (1 1/2cm), fissile, wavy and nodular, matrix is clay to very fine grained silt with macroscopic fossil and peloid grains, calcareous and non-calcareous, trilobite and brachiopod bearing; contains oscillation ripple marks in float; exposed as moderate slopes................................. 47.4

Hc-2: Covered, sample holes amd weathered gully southeast of measured section revealed limestone, medium dark grey (N4), weathers to medium grey (N5) through light grey (N7), thin bedded (1/2-10cm), nodular, finely crystalline, fossiliferous (trilobites and brachiopods), contains limonite pseudomorphs of pyrite pyritohedrons interbedded with silty claystone, pale red (5 R 6/2) and greyish red (5 R 4/2), weathers to same, thin bedded (1/2-1cm), pinching and swelling, contains same fossils, and peloids; forms moderate slopes...................................... 16.8

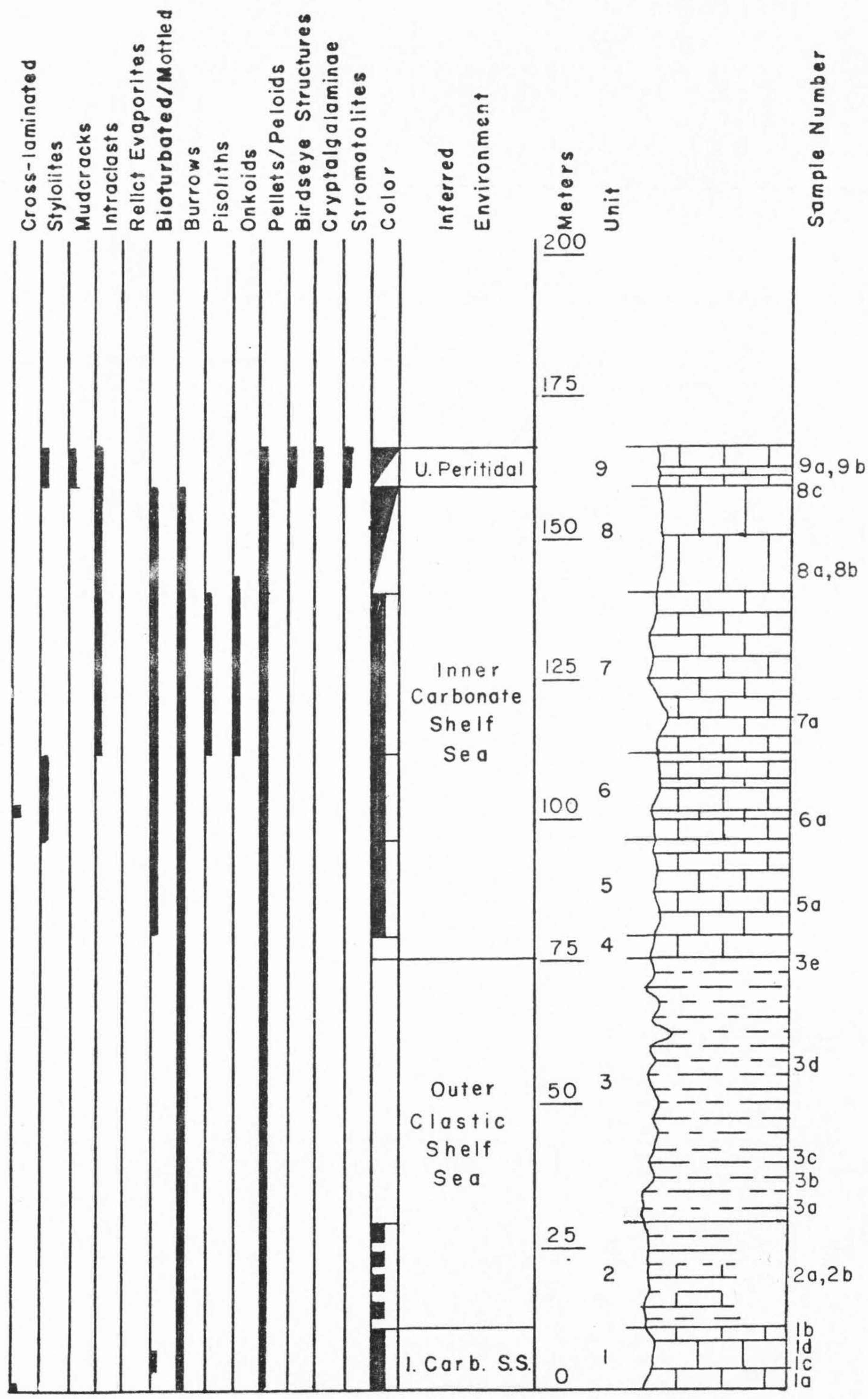
Hc-1: Limestone, greyish black (N2) to dark grey (N3), weathers to dark grey (N3) to medium dark grey (N4), thin bedded (2-8cm), finely crystalline, contains fossils, peloids, silty partings (5 Y 8/1), some recrystallized vertical to horizontal burrows; lower 0.9 m is a calcareous sandstone, very light grey (N8), moderate yellowish brown (10 YR 5/4), and moderate red (5 R 5/4), weathers same color, contains vugs (3mm-4cm high by 2.5-30cm wide) mostly parallel to bedding, cross-bedded, very fine sand to fine sand; middle of unit is highly bioturbated and massive; calcite leaches out 2-8 cm deep; interbedded with a 5-10 cm bed of slightly mottled limestone with same sandstone filling burrows within it; many greyish red shale chips in float, may indicate intercalated relationship with limestone; exposed as moderate slopes and small ledges.......... 11.6

Total = 165.4

Contact: gradational, conformable

Prospect Mountain Quartzite (?), non-calcareous sandstone

SECTION 2


Cross-laminated
Stylolites
Mudcracks
Intraclasts
Relict Evaporites
Bioturbated/Mottled
Burrows
Pisoliths
Onkoids
Pellets/Peloids
Birdseye Structures
Cryptalgalaminae
Stromatolites
Color
Inferred Environment
Meters
Unit
Sample Number
200
175
150
125
100
75
50
25
0
U. Peritidal
Inner Carbonate Shelf Sea
Outer Clastic Shelf Sea
I. Carb. S.S.
9
8
7
6
5
4
3
2
1
9a, 9b
8c
8a, 8b
7a
6a
5a
3e
3d
3c
3b
3a
2a, 2b
1b
1d
1c
1a

Section 3

Location: Smithfield Canyon, measured east to west along the ridge crest 1.2 miles north of U. S. Forest Service Smithfield Canyon road, Sec. 3, T. 13 N., R. 2 E., Cache County, Utah.

Ute Formation, green mudshale

Contact: sharp, conformable

Langston Formation, dolostone

Unit		Thickness in meters
Sm-10:	Dolostone, medium grey (N5), weathers to sugary, pale greyish orange (10 YR 7/2), thin bedded (0.5-2 cm) to massive, fine to medium crystalline, containing birdseye structures, stylolites, and faint ? cryptalgalaminae; lower contact with Sm-9 is gradational; upper 1.7 meters are very light grey (N8) with more distinct algal laminations; exposed as steep rugged ledges and small cliffs......................	17.8
Sm-9:	Dolostone, dark grey (N3) mottled with medium light grey (N6.5), weathers to sugary, pale greyish orange (10 YR 7/2) mottled with medium dark grey (N4), massive, medium crystalline, highly bioturbated; exposed as rugged ledges and cliffs....................................	11.7
Sm-8:	Limestone, dark grey (N3), weathers to medium dark grey (N4), thin to medium bedded (5-13 cm), fine to medium crystalline, containing laminations, lenses, and pockets of pale red (5 R 6/2) to very light grey (N8) silt, which causes a mottled texture, also containing vertical to horizontal burrows, large fractures, and stylolites; upper 1.7 meters is dolomite, medium grey (N5), weathers to sugary, pale greyish orange (10 YR 7/2), dolomite contact is irregular and crosscuts 5 cm beds; mottling increases upward; exposed as rugged ledges.................................	21.9

SM-7: Limestone, dark grey (N3), weathers to medium grey (N5), massive, fine crystalline, slightly mottled, containing calcite filled fractures, burrows, and cross-laminations; lower contact is sharp and wavy; exposed as sheer cliff............ 3.4

Sm-6: Limestone, medium dark grey (N4), weathers to medium light grey (N6), thin to medium bedded (2-12 cm), fine to medium crystalline, containing vertical to horizontal burrows, fossils (brachiopods), peloids, and stylolites; throughout unit there are very light grey (N8) to greyish orange pink (5 YR 7/2) wavy, silty laminations up to 0.5 cm thick; upper contact has small erosional channel cut in it; exposed as sheer cliff.. 5.3

Sm-5: Covered, limestone float like Sm-6, forms talas slope; contact of Sm-6 and Sm-4 is within this unit................................... 2.4

Sm-4: Limestone, medium dark grey (N4), weathers to medium light grey (N6), massive, fine crystalline containing vertical to horizontal burrows; possibly out of place; exposed as small resistant ledge in middle of dense talus slope..................................... 1.4

Sm-3: Covered, limstone float like Sm-6, contact of limestone and mudshale is within this unit toward base; forms steep, covered talus slope.. 7.5

Sm-2: Mudrock, mudshale, light olive grey (5 Y 6/1), weathers to light olive brown (5 Y 6/2), calcareous, thin and nodular laminated (0.1-2 cm), very fine grained, containing trails, burrows, and fossils (trilobites and brachiopods); exposed as gentle slope in ridge saddle... 16.8

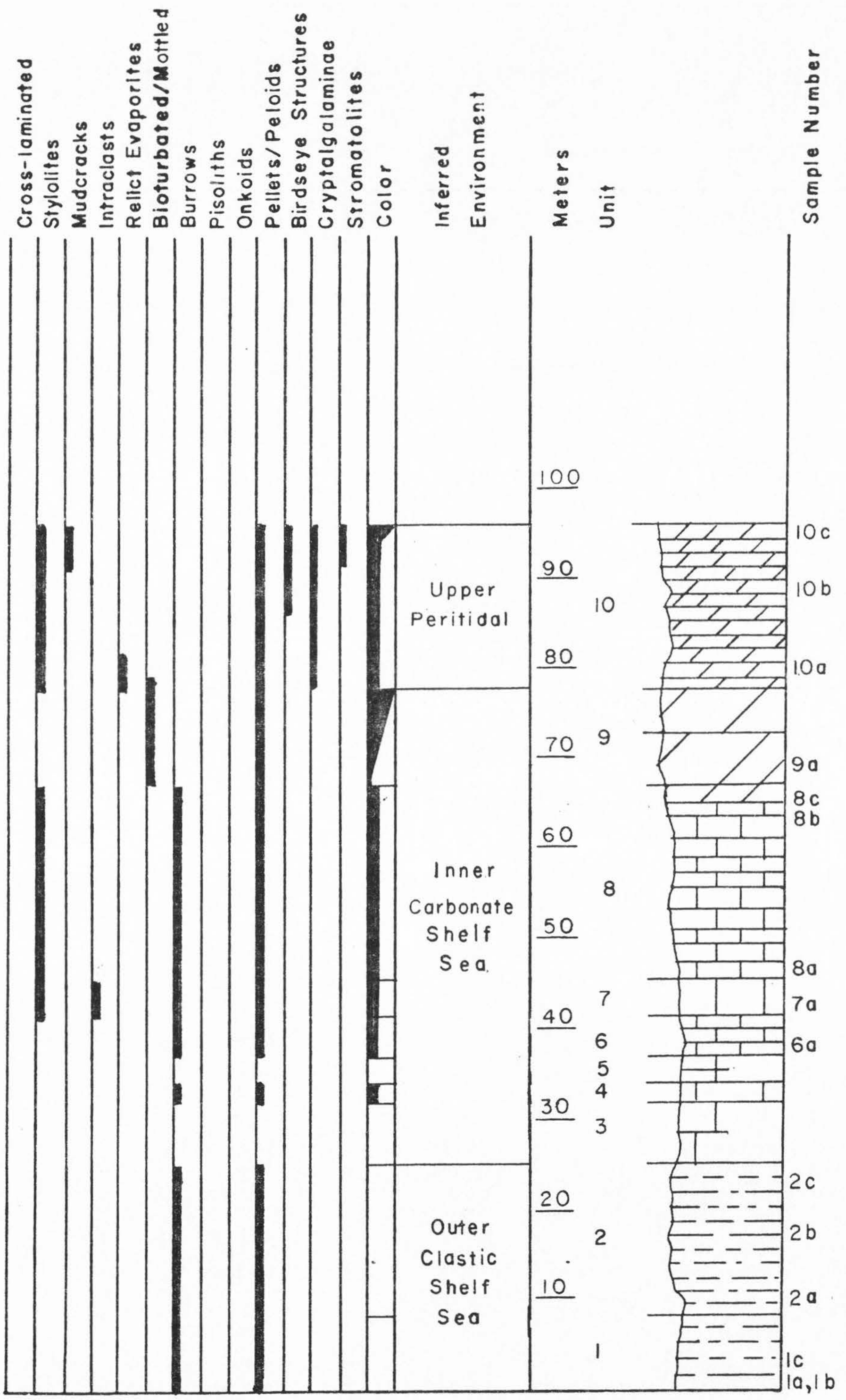
Sm-1: Mudrock, mudshale, moderate reddish brown (10 R 4/6) to olive grey (5 Y 4/1), weathers to same, noncalcareous, thin to thick laminated (0.05-1 cm), very fine grained, containing trails and fossils; unit covered and samples taken from holes 0.5 m deep.......................... 8.4

Total = 96.5

Contact: covered, probably gradational

Brigham Group, quartzite

SECTION 3


Cross-laminated
Stylolites
Mudcracks
Intraclasts
Relict Evaporites
Bioturbated/Mottled
Burrows
Pisoliths
Onkoids
Pellets/Peloids
Birdseye Structures
Cryptalgalaminae
Stromatolites
Color
Inferred Environment
Meters
Unit
Sample Number
Upper Peritidal
Inner Carbonate Shelf Sea.
Outer Clastic Shelf Sea
100
90
80
70
60
50
40
30
20
10
10
9
8
7
6
5
4
3
2
1
10c
10b
10a
9a
8c
8b
8a
7a
6a
2c
2b
2a
1c
1a, 1b

Section 4

Location: Left Fork Canyon, measured south to north on north side of Forest Service access road, approximately 3.2 miles east of Herd Hollow, S.E. 1/4, N.W. 1/4, Sec. 23, T. 11 N., R. 3 E., Cache County, Utah.

Ute Formation, mudrock

Contact: sharp, wavy

Langston Formation, dolostone

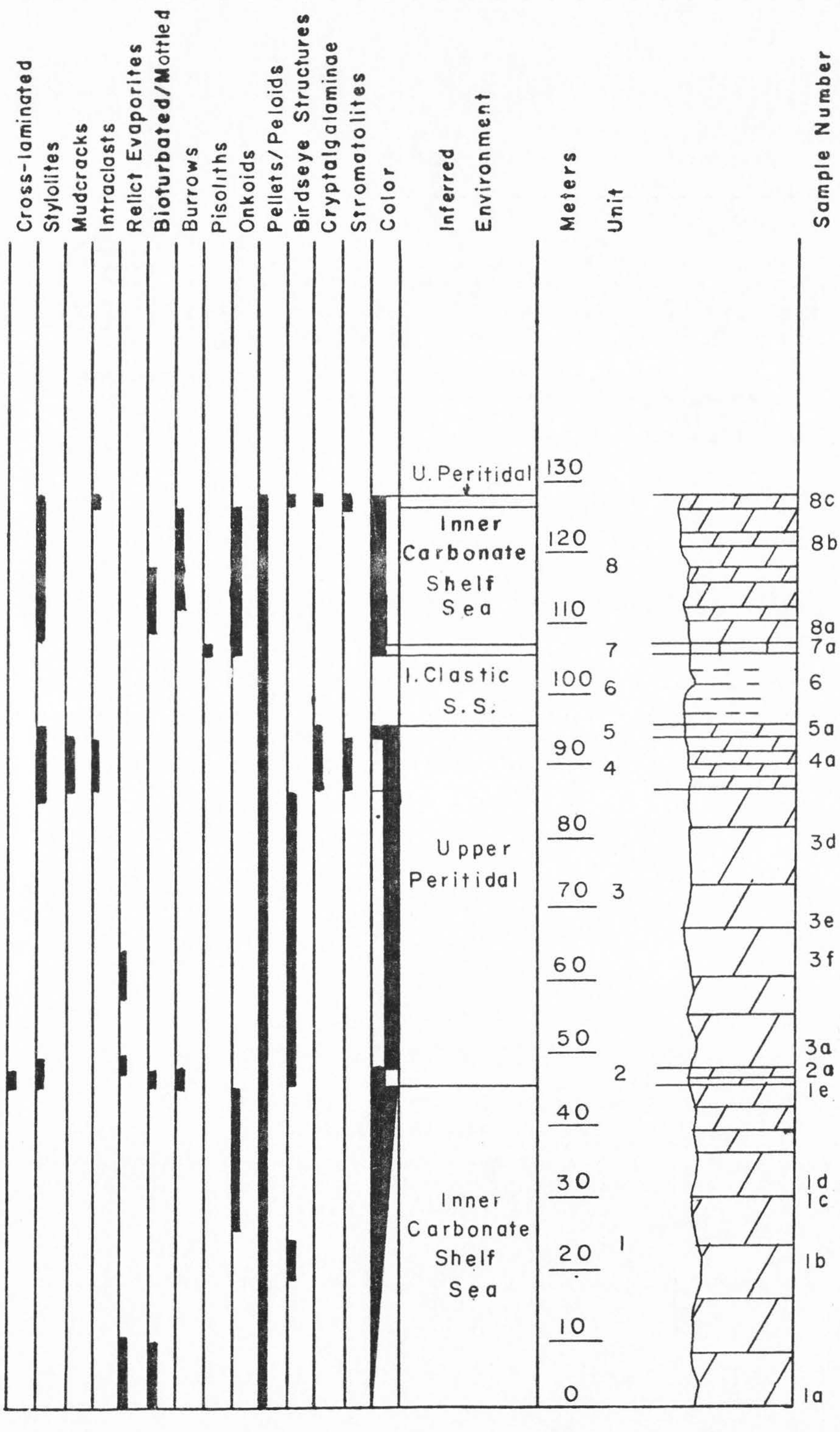
Unit		Thickness in meters
Lf-8:	Dolostone, medium dark grey (N4), weathers to sugary light brown (5 YR 5/6), fine to medium bedded (5-20 cm), fine to medium crystalline, containing onkoids and pellets in lower half, vertical and horizontal burrows and slight bioturbation in middle, and cryptalgalaminations and stromatolites (LLH) at top; lower half is highly fractured in places; exposed as large ledges and tall sheer cliffs..	21.0
Lf-7:	Limestone, dark grey (N3), weathers to medium grey (N5), thin to medium bedded (5-15 cm), medium crystalline, containing poorly sorted onkoids (0.1-2 cm, elongate to oval), ? pisoliths, and fossil fragments (brachiopods); beds thin toward top; limestone grades into dolostone upward; exposed as small cliff............	1.5
Lf-6:	Covered, limestone float, dark grey (N3), weathers to medium grey (N5) and some shale float at bottom, light olive grey (5 Y 5/2)...........	10.3
Lf-5:	Dolostone, medium dark grey (N4), weathers to sugary light brown (5 YR 5/4), fine to medium bedded (8-20 cm), fine crystalline, containing some faint laminations; exposed as a steep slope..	1.5

Lf-4:	Dolostone, medium light grey (N6), weathers to pale yellowish orange (10 YR 8/6), thin bedded, containing cryptalgalaminae, stromatolites, and stylolites; exposed as a small cliff....................................	7.3
Lf-3:	Dolostone, very light grey (N5), weathers to sugary, pale greyish orange (10 YR 8/4), massive to thick bedded (0.3-1.0 m), fine to coarse crystalline, containing stylolites, faint laminations (?algal?), and birdseye structures; lower contact contains a large (1.0 x 6.0 m) channel with cross-beds above channel; exposed as steep high cliff.................	39.0
Lf-2:	Dolostone, medium dark grey (N4), weathers to sugary, medium grey (N5) to pale greyish orange (10 YR 7/2), thin bedded (1.0-3.0 cm), fine crystalline, containing peloids, wavy laminations (?algal?), burrows, slight mottling, and cross-bedding; exposed as steep high cliff.................................	1.9
Lf-1:	Dolostone, medium dark grey (N4) to light grey (N7), weathers to sugary, moderate yellowish brown (5 YR 5/2) to dark greyish orange (10 YR 6/4), mostly massive bedded with some medium beds toward top, fine to coarse crystalline, containing birdseye structures at bottom and peloids, onkoids, and slight bioturbation at top; exposed as steep slope and cliff.............	46.0
	Total =	128.6

Contact: gradational, conformable

Brigham Group, sandstone

SECTION 4


Cross-laminated
Stylolites
Mudcracks
Intraclasts
Relict Evaporites
Bioturbated/Mottled
Burrows
Pisoliths
Onkoids
Pellets/Peloids
Birdseye Structures
Cryptalgalaminae
Stromatolites
Color
Inferred Environment
Meters
Unit
Sample Number
U. Peritidal
Inner Carbonate Shelf Sea
I. Clastic S.S.
Upper Peritidal
Inner Carbonate Shelf Sea
130
120
110
100
90
80
70
60
50
40
30
20
10
0
8
7
6
5
4
3
2
1
8c
8b
8a
7a
6
5a
4a
3d
3e
3f
3a
2a
1e
1d
1c
1b
1a

Section 5

Location: Blacksmith Fork Canyon, measured east to west, approximately one mile south of Blacksmith Fork Canyon on east-facing slope in South Cottonwood Canyon, N.E. 1/4, N.E. 1/4, and S.E. 1/4, N.E. 1/4, Sec. 18, T. 10 N., R. 3 E. Cache County, Utah.

Ute Formation, green mudshale

Contact: sharp, wavy, conformable

Langston Formation, dolostone

Unit		Thickness in meters
Bf-11:	Dolostone, medium grey (N5), weathers medium grey (5.5), medium bedded (10-20 cm), fine crystalline, upper part mottled with pale red purple (5 RP 6/2) and medium light grey (N6), containing onkoids (1.5 cm, eliptical), vertical to horizontal burrows, ? birdseye structures, stylolites and calcite-filled fractures; exposed as part of steep rugged cliff...	15.4
Bf-10:	Limestone, medium dark grey (N4), weathers to medium grey (N5.5), thin to medium bedded (5-20 cm), medium crystalline, containing onkoids (0.15-1.2 cm), stylolites, pockets of limonite-stained silt/clay, and intraclasts; onkoids often replaced by limonite; exposed as part of steep rugged cliff..........................	6.7
Bf-9:	Limestone, medium dark grey (N4), weathers medium grey (N3), thin bedded (1-3 cm), fine crystalline, containing onkoids, fossil fragments (brachoipods, and trilobites), many recrystallized oval allochems which are probably onkoids, stylolites, calcite filled fractures and intraclasts; grain sizes range from 0.05 to 1.5 cm; exposed as a talus slope with few outcrops..................................	8.1

Bf-8: Dolostone, medium grey (N5), weathers sugary, light brown (5 YR 5/6) to greyish orange (10 YR 7/4) to medium grey (N5), massive bedded, very coarse crystalline, containing faint cryptalgalaminae and stromatolites (LLH); erosional contact at base; exposed as upper part of cliff.................................... 3.7

Bf-7: Dolostone, medium grey (N5), weathers light brown (5 YR 7/4) to greyish orange (10 YR 7/4) to medium grey (N5), thin bedded, containing cryptalgalaminae, stromatolites (LLH), and stylolites; exposed as lower part of cliff........... 1.8

Bf-6: Covered, float contains rocks from above cliff; forms talus slope............................ 4.7

Bf-5: Dolostone, very light grey (N8.5), weathers to same and moderate yellowish brown (10 YR 5/4), massive bedded with some thin beds, medium to very coarse crystalline, containing some small vugs, onkoids, faint cryptalgalaminae, and stromatolites; 12 meters above base there is a 4.5 m bed of mottled dolostone, dark grey (N4) to dark yellowish brown (10 YR 4/2), massive bedded, coarse to very coarse crystalline, containing pellets, birdseye structures, and calcite-filled fractures; upper 7 meters are also darker than most of unit; exposed as small resistant outcrops and cliffs................. 43.9

Bf-4: Dolostone, medium dark grey (N4), weathers dark greyish orange pink (5 YR 6/2), mostly massive with some thin to medium beds (2-20 cm), medium to coarse crystalline, slightly mottled in spots (medium yellowish grey (5 Y 7/1), containing peloids, fractures, and recrystallized onkoids or pisoliths; some calcite-filled fractures are stained with hematite and/or limonite; exposed as resistant outcrops................................ 26.4

Bf-3: Covered, float contains rocks like Bf-6; forms slope.................................... 5.6

Bf-2: Dolostone: medium dark grey (N4), weathers to dark orange pink (5 Y 6/2), massive bedded with some thin beds, medium to coarse crystalline, highly fractured, containing onkoids (1.5-2.0 cm) and peloids; approximately 4.5 m up from base is a large fracture (3 cm wide) which is filled with Fe-stained calcite, quartz, and malachite; exposed as small cliff.............................. 6.9

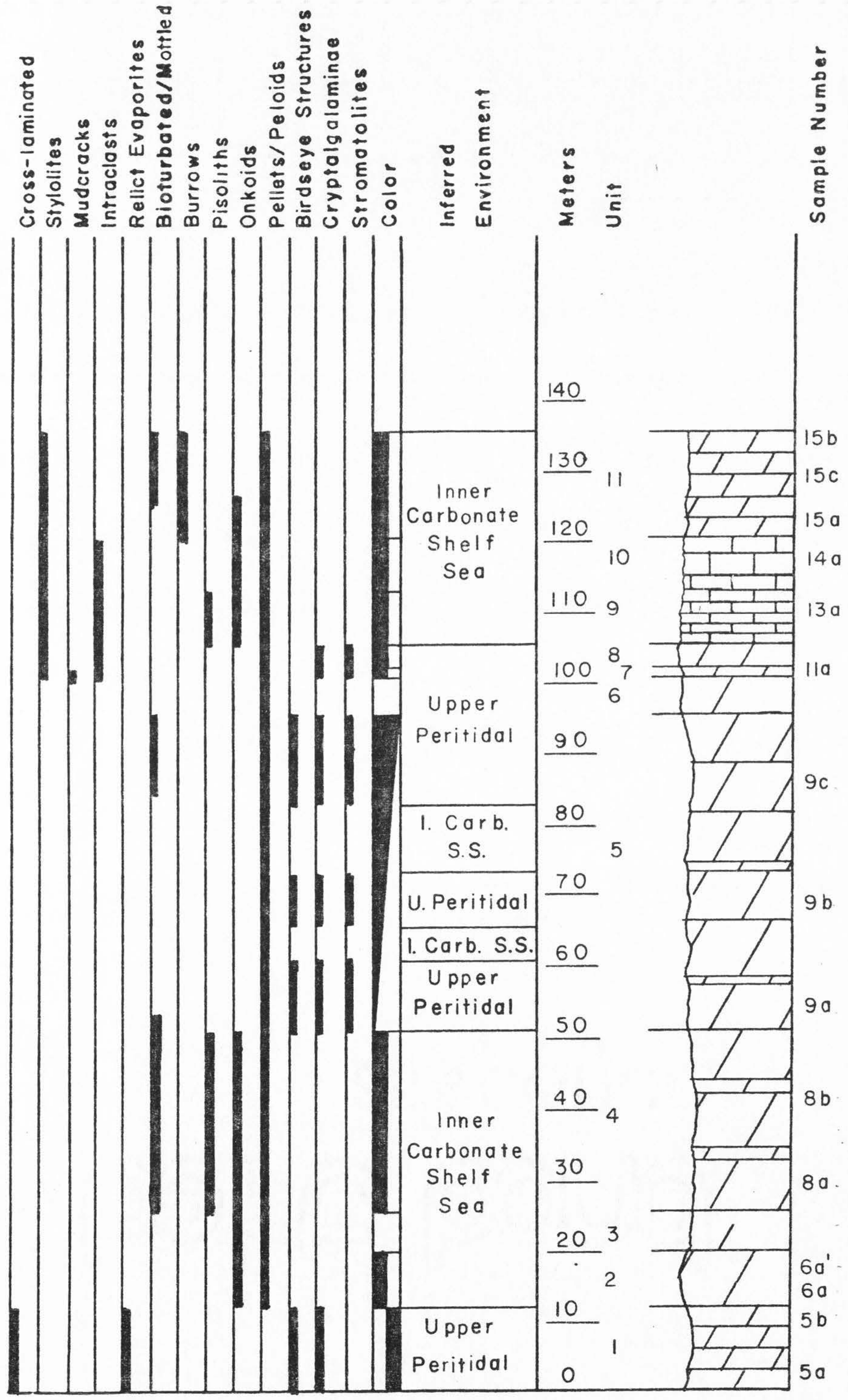
Bf-1: Dolostone, medium light grey (N6.5) and pale reddish brown (10 R 5/4), weathers to sugary, brownish grey (5 YR 4/1), medium bedded (10-15 cm) with 2 mm laminations, fine to coarse crystalline, containing cryptalgalaminae, birdseye structures, highly disturbed internal structures (solution breccia of evaporites) and some cross-laminations; exposed as resistant ledges.................................... 12.6

Total = 135.7

Contact: sharp, conformable

Brigham Group, sandstone

SECTION 5


Cross-laminated
Stylolites
Mudcracks
Intraclasts
Relict Evaporites
Bioturbated/Mottled
Burrows
Pisoliths
Onkoids
Pellets/Peloids
Birdseye Structures
Cryptalgalaminae
Stromatolites
Color
Inferred Environment
Meters
Unit
Sample Number
Inner Carbonate Shelf Sea
Upper Peritidal
I. Carb. S.S.
U. Peritidal
I. Carb. S.S.
Upper Peritidal
Inner Carbonate Shelf Sea
Upper Peritidal
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
11
10
9
8
7
6
5
4
3
2
1
15b
15c
15a
14a
13a
11a
9c
9b
9a
8b
8a
6a'
6a
5b
5a

Section 6

Location: East Fork Canyon, measured east to west, approximately 8.5 miles west of Avon in East Fork Canyon on SE facing slope, Sec. 7, T. 9 N., R. 3 E., Cache County, Utah.

Ute Formation, mudrock

Contact: covered, probably sharp

Langston Formation, dolostone

Unit		Thickness in meters
Ef-6:	Covered, dolostone, limestone, and mudrock; measured by Rigo (1967).............................	51.9
Ef-5:	Dolostone, light grey (N7), weathers to sugary, light yellowish brown (10 YR 6/4) in bottom half and pale orange (10 YR 7/2) in top half, thin bedded (5 cm), fine crystalline, containing cryptalgalaminae, stromatolites (LLH), and a few onkoids in the upper half; cryptalgalaminae are very faint in upper 2 m; exposed as resistant outcrops and small cliffs on moderate slope............................	4.3
Ef-4:	Dolostone, medium grey (N5.5), weathers to sugary, very pale greyish orange (10 YR 8/4) to pinkish grey (5 YR 8/1), medium bedded (10-25 cm), fine to coarse crystalline, containing peloids, birdseye structures, cross-bedding, onkoids (1/2 cm), and stylolites; slightly mottled in upper 1/3 of unit; exposed as steep high cliffs..................	29.4
Ef-3:	Covered, float like Ef-4; unit forms well vegetated gentle slope at base of cliff..............	18.9
Ef-2:	Limestone, medium dark grey (N4), weathers to medium grey (N5), thin to medium bedded (5-7 cm) to massive, fine crystalline, containing burrows, onkoids (1/2 cm), and wavy silty laminations; onkoids are concentrated in upper part of unit and are overlain by a thin bed of wavy silty laminated limestone with few	

onkoids; exposed as resistant outcrops on moderate slope.................................... 12.2

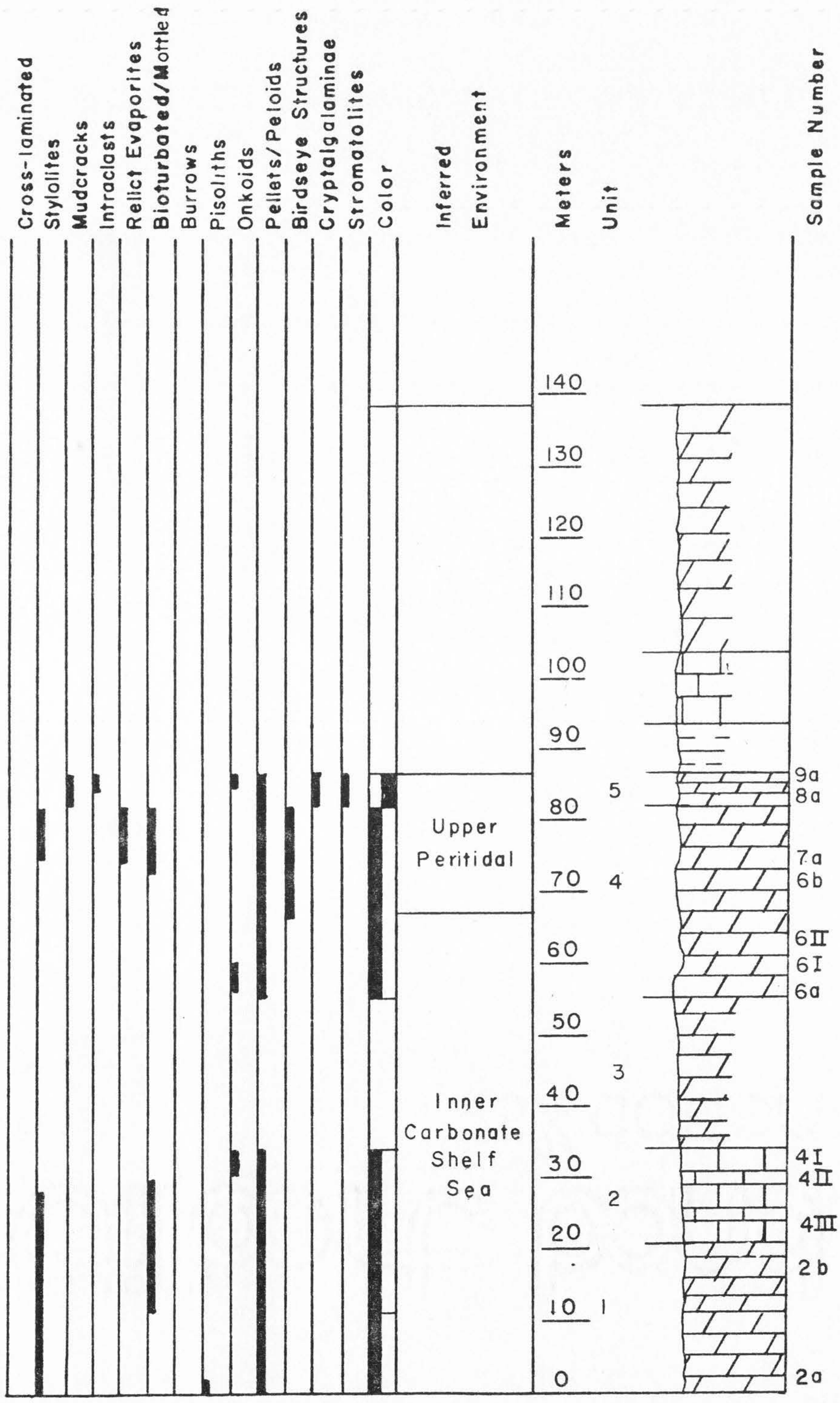
Ef-1: Dolostone, dark to medium grey (N3-N5), weathers to moderate yellowish brown (10 YR 5/2), medium bedded (8-20 cm), medium to coarse crystalline, containing wavy silty laminations, onkoids (1 cm), cross-bedding (planar bottoms), and a few birdseye structures; exposed as resistant outcrops on moderate slope.................................... 21.8

Total = 138.5

Contact: gradational, conformable

Brigham Group, sandstone

SECTION 6


Cross-laminated
Stylolites
Mudcracks
Intraclasts
Relict Evaporites
Bioturbated/Mottled
Burrows
Pisoliths
Onkoids
Pellets/Peloids
Birdseye Structures
Cryptalgalaminae
Stromatolites
Color
Inferred Environment
Meters
Unit
Sample Number
Upper Peritidal
Inner Carbonate Shelf Sea
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
5
4
3
2
1
9a
8a
7a
6b
6II
6I
6a
4I
4II
4III
2b
2a

Section 7

Location: Hardware Ranch: measured west to east, approximately one mile east of Anderson Ranch, on south facing slope of Blacksmith Fork, S.E. 1/4, Sec. 25, T. 10 N., R. 3 E., Cache County, Utah.

Ute Formation, flaggy mudrock

Contact: sharp, wavy, conformable

Langston Formation, dolostone

Unit		Thickness in meters
Hr-2:	Limestone, medium grey (N5), weathers to medium light grey (N6), thin to-medium bedded (5-20 cm), fine crystalline, containing onkoids (1 cm), trails, burrows, silty laminations and pockets, and calcite-filled fractures; uppermost bed weathers moderate brown (5 YR 4/4), and contains cryptalgalaminae, stromatolites (LLH-S), intraclasts, and mudcracks; 8 m down from top of formation is a 2 m bed of mudshale, dark yellowish grey (5 Y 6/2), weathers to pale yellowish brown (10 YR 6/2), very fissile, containing trilobite fragments; lower dolomitization contact with Hc-1 is very irregular and cuts upward as much as 45 cm; exposed as resistant outcrops on moderate slope; approximately 1/4 of unit covered............	29.0

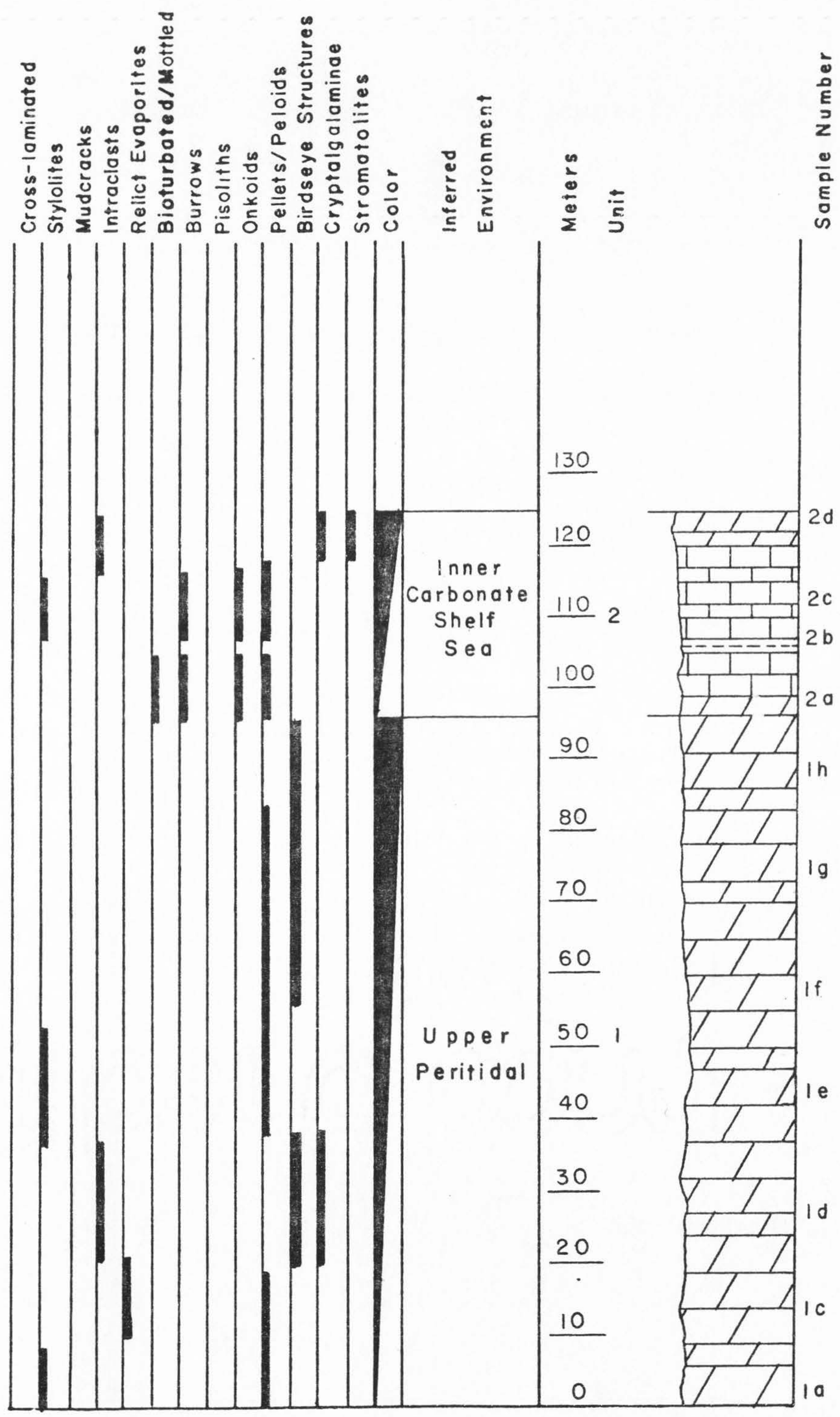
Hr-1: Dolostone, medium dark to medium light grey (N4-6), weathers to medium grey (N5) to dark yellowish brown (10 YR 4/2), mostly massive with some medium bedding (10-20 cm), medium to very coarse crystalline, containing peloids, faint cryptalgalaminae, birdseye structures, and slight mottling (5 YR 4/4); lower 15 m are very poorly exposed; exposed as resistant outcrops on gentle to moderate slope and steep rugged cliffs.................................... 96.0

Total = 125.0

Contact: gradational, conformable

Brigham Group, sandstone

SECTION 7



Cross-laminated
Stylolites
Mudcracks
Intraclasts
Relict Evaporites
Bioturbated/Mottled
Burrows
Pisoliths
Onkoids
Pellets/Peloids
Birdseye Structures
Cryptalgalaminae
Stromatolites
Color
Inferred Environment
Meters
Unit
Sample Number
Inner Carbonate Shelf Sea
Upper Peritidal
130
120
110
100
90
80
70
60
50
40
30
20
10
0
2
1
2d
2c
2b
2a
1h
1g
1f
1e
1d
1c
1a

Section 8

Location: Miners Hollow, measured west to east on west facing slope, on north side of Miners Hollow, approximately 1 mile east of Utah Highway 69, C, Sec. 14, T. 10 N., R. 2 W., Box Elder County, Utah.

Ute Formation, green shale

Contact: sharp, wavy

Langston Formation, dolostone

Unit		Thickness in meters
Mh-6:	Dolostone, medium light grey (N6), weathers to sugary light grey (N7), thin to thick bedded (1/2-25cm), finely crystalline, unlaminated, containing rip-up clasts of cryptalgalaminated beds, and birdseyes, interbedded with dolostone, pale yellowish brown (10 YR 6/2), weathers to sugary very pale orange (10 YR 8/2), thin to thick bedded (1/2-25cm), finely crystalline, containing cryptalgalaminae, stromatolites (LLH-S), stylolites, and birdseyes; stylolites occur within beds and especially at bedding contacts of laminated and unlaminated beds; minor calcite fracture filling; exposed as steep ledges.....................	6.7
Mh-5:	Dolostone, medium grey (N5), weathers to sugary very pale yellowish brown (10 YR 7/2), thin to medium bedded, mostly massive, fine to coarse crystalline, containing lighter colored silty pockets and wavy layers in lower half, onkoids (1/2-3cm) in middle, birdseyes in upper half, slightly bioturbated throughout; upper 5 meters change color to light grey (N7), weathering to sugary moderate yellowish brown (10 YR 5/4); stylolites occur through Cf-5; at 8.5 meters from base of Cf-6 a 15 cm bed of interlayered dolostone and siltstone crops out, the beds above and below are highly mottled; exposed as steep ledges and cliffs..........	62.5

Mh-4: Siltstone, medium grey (N5), weathers to moderate brown (5 YR 4/4), thin bedded, very fine grained, calcareous, fissile, containing fossils (abundant trilobites), vertical to horizontal burrows, interbedded and interlensed with limestone, medium grey (N5), weathers to medium light grey (N6), thin bedded (1-5cm), finely crystalline, contains fossils, vertical burrows, trails, and slightly bioturbated; some beds have a "brick and mortar" appearance; upper meter consists of silty dolostone; exposed as steep resistant ledges.................................. 18.8

Mh-3: Mudrock, mudshale, greyish black (N2), weathers to dark reddish brown (10 YR 3/4), olive grey (5 Y 3/2) and medium grey (N5), thin bedded (2-5 cm), nodular, fissile, very fine grained, containing vertical burrows, trails, and fossils (trilobites and brachiopods); mostly calcareous; exposed as steep ledges....................................... 17.0

Mh-2: Limestone, brownish black (5 YR 2/1), weathers to medium light grey (N6) and pale yellowish brown (10 YR 6/2), thin bedded (1-3 cm), fine crystalline, fissile, silty, containing fossils, intraclasts, and ?ripples; occurs as alternating laminated and unlaminated beds; contains 2 calcareous shale beds at bottom, dark grey (N3), weather to brownish black (5 YR 2/1), finely laminated and fissile, very fine grained, containing fossils (trilobites and brachiopods); shale and limestone contacts are gradational; exposed on moderate slope........... 12.7

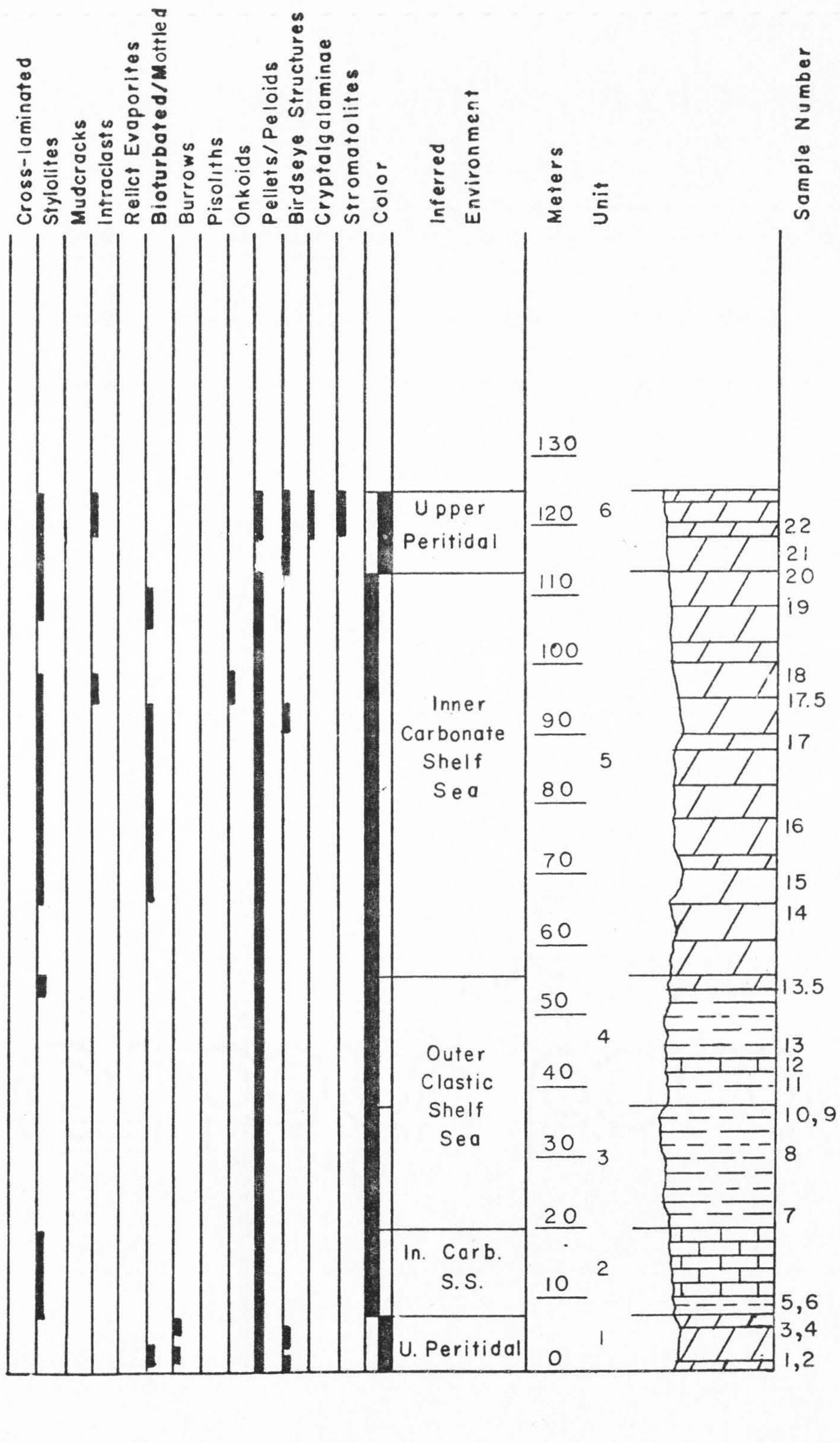
Mh-1: Dolostone, medium light grey (N6), weathers to sugary, moderate brown (5 YR 4/4), thin to medium bedded to massive (5-10 cm), medium to coarse crystalline, containing peloids, birdseye structures, solution vugs, intraclasts, stylolites (3 cm amplitude), burrows, silty partings, fossil hash and ? onkoids; dolomitization is extremely irregular; large lenses of limestone (1m x 5m) occur within the dolostone, and laterally lenses of dolostone occur within limestone; exposed as steep rugged ledges and cliffs............ 7.3

Total = 125.0

Contact: gradational, conformable

Brigham Group, sandstone

SECTION 8



Cross-laminated
Stylolites
Mudcracks
Intraclasts
Relict Evaporites
Bioturbated/Mottled
Burrows
Pisoliths
Onkoids
Pellets/Peloids
Birdseye Structures
Cryptalgalaminae
Stromatolites
Color
Inferred Environment
Meters
Unit
Sample Number
Upper Peritidal
Inner Carbonate Shelf Sea
Outer Clastic Shelf Sea
In. Carb. S.S.
U. Peritidal
130
120
110
100
90
80
70
60
50
40
30
20
10
0
6
5
4
3
2
1
22
21
20
19
18
17.5
17
16
15
14
13.5
13
12
11
10, 9
8
7
5, 6
3, 4
1, 2