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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

SANDRA V. MARQUEZ

ENTITLED CARBONATE CYCLES, ATOKAN(ZONE OF PROFUSULINELLA), OF THE ARROW CANYON, CLARK COUNTY, NEVADA

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE

R L Langenheim

Instructor in Charge

APPROVED: Patricia Lane for D. E. Anderson

HEAD OF DEPARTMENT OF GEOLOGY

O-1364

Carbonate Cycles, Atokan (Zone of Profusulinella), of the Arrow Canyon, Clark County, Nevada

By

Sandra V. Marquez

Thesis

for the
Degree of Bachelor of Science
in
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ABSTRACT

Rocks of the Zone of *Profusulinella* (Lower Atokan) of the Bird Spring Group at Arrow Canyon, Clark County, Nevada, occur in nine cycles, beginning at abrupt changes from shallow to deeper water deposition. These nine cycles are further organized within four, symmetrical cycles from deeper to shallow to deeper water sediments.

The model of Punctuated Aggradational Cycles (PAC), proposed by Goodwin and Anderson (1985), for cycles of shallowing upward rocks, correlate with the nine cycles of lithologic types described at Arrow Canyon. The four larger megacycles of upwardly fining rocks correspond to the Vail curves of eustatic sea level changes (Vail et al., 1977). Carozzi's (1986) attempt to relate the shallowing upward sequences, similar to the PAC's of Goodwin and Anderson, to the eustatic curves of Vail, according to his "New eustatic model for the origin of carbonate cyclic sedimentation", however, does not appear applicable to Arrow Canyon. The microfacies succession in the Zone of *Profusulinella* as described by Heath, Lumsden and Carozzi (1967), does not consistently match my perception of environmentally significant units. Chert of differing morphology, occurs cyclically in the Zone of *Profusulinella* and these chert cycles parallel the cyclicity of lithologic types. They aided in description and interpretation of environmental conditions and furnish an obvious "key" to quickly recognizing cycles in the field.

LIST OF FIGURES

CHAPTER I

INTRODUCTION

This study was conducted to describe, in detail, the Zone of *Profusulinella* (Atokan), of the Bird Spring Group at Arrow Canyon, Clark County, Nevada, as measured and generally described by V.A.M. Langenheim (1964) and C.P. Weibel (1982) in order to correlate these units with the microfacies succession of Heath (1965) and Lumsden (1965). Details of the succession are then compared with the deepening-shallowing cycles of Heath, Lumsden, and Carozzi (1967), middlewestern cyclothems, Vail curves (Vail et al., 1977), and Punctuated Aggradational Cycles (PAC) of Goodwin and Anderson (1985). The environmental and stratigraphic significance of chert in carbonate sedimentation also is discussed.

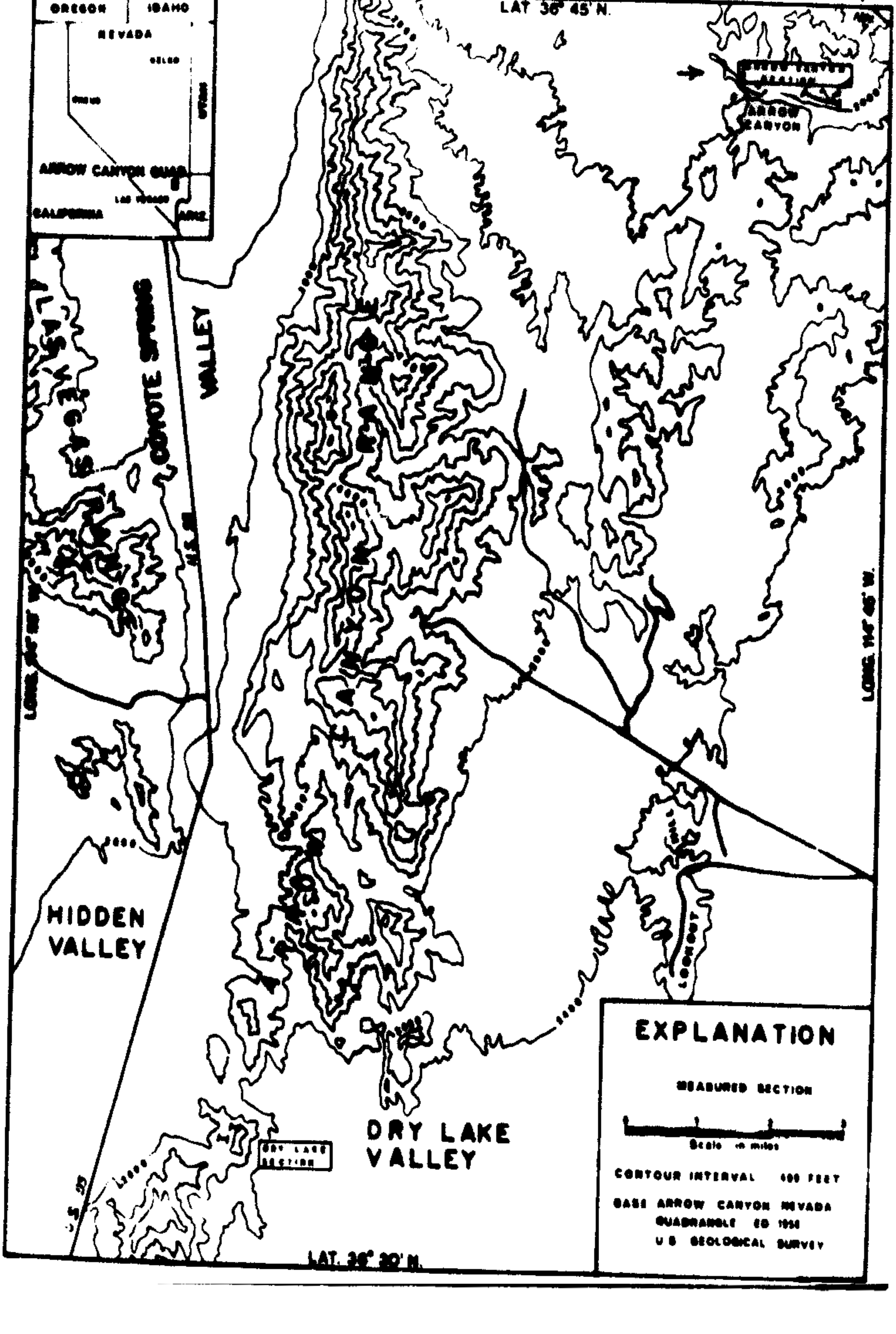
CHAPTER II

LOCATION

The sequence under study is exposed in Arrow Canyon, at the northeastern end of the Arrow Canyon Range. Most of the range is shown on the Arrow Canyon 15' Quadrangle, (1958 edition) of the United States Geological Survey. The quadrangle is bounded by latitudes 36° 30' N. and 36° 45' N. and longitudes 114° 45' W. and 114° 58' W. (figure 1). It's highest point reaches an elevation of 5,226 feet (1593 m) with 3,220 feet (981 m) of relief.

Arrow Canyon is superimposed across the northwest corner of the Arrow Canyon Range and is approximately 50 miles northeast of Las Vegas, (E1/2, sec. 11, S1/2, sec. 12, T14S, R64E and SW1/4, sec. 7, T14S, R65E)(figure 1). The section at the canyon can be reached from Las Vegas by taking Interstate 15 north to Glendale, Nevada. From Glendale, proceed 14 miles northwest on Nevada Route 7, then turn left onto a secondary paved road. Continue down this road for approximately 200 yards then turn right onto a jeep trail which runs through a refuse dump and past a water monitoring well. The section is located approximately 2 miles up the canyon along this jeep trail which can easily be travelled by vehicles with high road clearance.

Figure 1 Location map Arrow indicates location of section at Arrow Canyon



LAT 36° 45' N.
OREGON
IDAHO
NEVADA
CALIFORNIA
ARIZ.
ARROW CANYON QUAD.
ARROW CANYON
LAS VEGAS
COYOTE SPRINGS
VALLEY
HIDDEN VALLEY
DRY LAKE VALLEY
DRY LAKE SECTION
LOOKOUT
LONG. 114° 45' W.
LAT. 36° 30' N.
EXPLANATION
MEASURED SECTION
Scale in miles
CONTOUR INTERVAL
U S GEOLOGICAL SURVEY

CHAPTER III
GENERAL STRATIGRAPHY

Mid- Mississippian through Permian strata are exposed on both walls of the narrow canyon In the canyon the beds strike about N30E and dip 30-35 degrees southeast

Pennsylvanian rocks in the area originally were placed in the Callville Formation, in the Muddy Mountains and at Arrow Canyon, by Longwell (1921,1928) The Bird Spring Formation, described in the Spring Mountains by Hewett (1931) is composed of Late Mississippian through Permian rocks in the Bird Spring Range west of Las Vegas The sequence at Arrow Canyon more closely resembles the Bird Spring Formation than the Callville Formation which is more arenaceous and possessing more unconformities (Rich, 1971) Therfore, thick, "geosynclinal" sequences, as at Arrow Canyon, are generally referred to as the Bird Spring Formation Langenheim <u>et al</u> (1962) further divided the Arrow Canyon section into five, informal, formational units, elevating the Bird Spring Formation to group status

The Bird Spring Group is dominated by limestone and ranges from 1000 to 7000 feet thick (305-2135 meters) The five formational units recognized within the Bird Spring Group at Arrow Canyon are the Battleship Wash Formation (Langenheim and Langenheim, 1965), Indian Springs Formation (Webster and Lane, 1967), and three unnamed units BSc, BSd, and BSe (Langenheim <u>et al</u>., 1962)

At Arrow Canyon, rocks of the Bird Spring Group lie conformably on Mississippian Monte Cristo Limestone and are overlapped by Tertiary Muddy Valley Formation to the east, and by Quaternary alluvium

The carbonate rocks of the Bird Spring Group at Arrow Canyon were deposited on the eastern edge of the Bird Spring Basin, in the southern part of the Cordilleran Miogeosyncline (Rich, 1971) The miogeosyncline bordered the Antler Orogenic Belt to the west and the Las Vegas Wasatch Line to the east At the time of deposition, the basin was characterized by changes in size and therefore sediment accumulation as sea level fluctuated Wilson (1975) has inferred transgressions during the Morrowan, Desmoinesian, and Virgilian and regressions during the Atokan and Missourian. Heath, Lumsden, and Carozzi (1967), however, have documented a complete cycle of transgression and regression, at Arrow Canyon, between Early Morrowan and Early Missourian.

CHAPTER IV
GEOLOGIC SETTING

The Arrow Canyon Range is within the Basin and Range province in which north-south trending mountain ranges are separated by broad valleys filled with alluvium. Some Precambrian rocks occur in the southern parts of the province, but folded and faulted Paleozoic sedimentary rocks, products of the Nevadan Orogeny (Late Jurassic to Early Cretaceous) are more characteristic.

The basins and ranges resulted from block faulting which began in the Miocene and continues today. Tertiary volcanism resulted in widespread volcanic rocks throughout the province. Arrow Canyon is the product of a superimposed stream which eroded Tertiary and Quaternary alluvial deposits which had filled the valleys by the end of the Pliocene.

The Arrow Canyon Range includes a main ridge in the west and low foothills in the east (figure 1). The western edge of the range drops off as a scarp face, the product of a normal fault separating the Las Vegas Range from the Arrow Canyon Range. The eastern flank of the main portion of the range lies parallel to the axis of a north-south trending syncline that lies within the main body of the range and plunges to the north (Longwell et al., 1965). Stratigraphic units of the eastern foothills, which include the Arrow Canyon section, dip east to southeast.

CHAPTER V

METHODS AND TECHNIQUES

Description and measurement of section as well as sample collecting were done over a 10-day period in January, 1988. Unit descriptions given in this paper refer to rock units originally defined by V.A. Langenheim (VAL) (Weibel, 1982). Boundaries of the VAL units later were referenced to measurement markers placed at 5 feet (1.5m) intervals by Amoco geologists. Detailed measurements within the VAL units were obtained at significant points using a 1 foot hand ruler. Also, photographs were taken of the section. Examination of rocks was done on the macroscopic level using a handlens. Attitudes were obtained using a Brunton compass. All data were obtained from the north wall of the canyon.

Figure 2 Upper Morrowan-Lower Atokan units exposed on north wall at Arrow Canyon, VAL 96 through 104; (arrow 4 is to be disregarded)

Unit	Boundaries
1	-VAL 96B/97
2	-VAL 97/98
3	-VAL 98/99
5	-NEL 1 (Nelson, 1980)
6	-VAL 99/100
7	-VAL 100/101A
8	-VAL 101A/101B
9	-VAL 101B/102
10	-VAL 102/103A
11	-VAL 103A/103B
12	-VAL 103B/103C
13	-VAL 103C/103D
14	-VAL 103D/103E
15	-VAL 103E/104


1
2
3
4
5
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11
12
13
14
15

Figure 3. Lower and Upper Atokan units exposed on north wall at Arrow Canyon; VAL units 103E through 115E

Unit	Boundaries
1	-VAL 103E/104
2	-NEL 11/12 (Nelson, 1980)
3	-VAL 104/105
4	-VAL 105/106
5	-VAL 106/107
6	-VAL 107/108
7	-VAL 108/109
8	-VAL 109/110
9	-VAL 110/111
10	-VAL 111/112
11	-VAL 112/113
12	-VAL 113/114
13	-VAL 114/115A
14	-VAL 115A/115B
15	-VAL 115B/115C
16	-VAL 115C/115D
17	-VAL 115D/115E

CHAPTER VI
DESCRIPTION

Rocks of the Zone of *Profusulinella* (Lower Atokan), as identified by Cassity and Langenheim (1966), in the Bird Spring Group at Arrow Canyon and a few feet of older rock, are described herein.

The section has a total thickness of 141' 8", of which the lower 20'10" lies within the Zone of *Millerella* (Upper Morrowan). The Morrowan rocks have been included in order to begin at the base of a prominent "sandstone" unit and thus aid correlation with the Heath, Lumsden, and Carozzi (1967) sequence of microfacies as well as to compare the cyclicity of the Arrow Canyon succession with the P.A.C. sequences of Goodwin and Anderson (1985).

Limestone dominates this section with lesser amounts of interbedded calcareous shale and sandstone. The limestone is abundantly fossiliferous and contains much chert and flint. Calcite filled veins and vugs also are present.

Four distinct lithologic types have been identified. These are distinguished primarily by overall grain size (very fine to medium), bedding (thin to massive or nodular), weathering characters, color, occurance of silt or sand within the limestone, and by the occurance of chert according to type, thickness, and abundance.

The first lithologic type, "type 1", is massive, calcareous sandstone that is free of chert. This quartz-rich cliff former, weathers yellow to rusty as result of the presence of iron oxides. It's basal contact is abrupt with fine-grained limestone.

The second lithologic type, "type 2", is very fine-grained, argillaceous limestone characterized by thin, laminate to nodular bedding. These units weather light grey to yellow and are recessed and poorly exposed. Small to medium sized chert nodules, 3-4" in diameter, are scattered throughout these units.

A third lithologic type, "type 3", is fine-grained limestone in thin, parallel beds. These rocks weather grey and are characterized by discontinuous to continuous layers of nodular chert, 4-8" thick. Their basal contacts are gradational.

The final lithologic type, "type 4", is limestone with medium, parallel to massive bedding, 1-4' thick. This type weathers grey to dark grey and forms cliffs. Chert occurs as large nodules that are either scattered or in layers. Layers of very large "cannonball" chert nodules, 6-12" in diameter also occur.

Periodic breaks in sediment accumulation in which changes in lithologic facies occur, appear as abrupt contacts between units of differing sedimentary types at intervals within the section. These abrupt contacts mostly are at the base of units of lithologic type 2, the very fine-grained, argillaceous limestone. This silty limestone marks the shift to much finer-grained rock than that of the medium to massively bedded limestone on which it most generally rests. These abrupt contacts bound what appear to be a sequence of upwardly coarsening rocks, the individual units of which grade into one another.

There is no apparent evidence of disconformity at any of the unit bounderies within the studied sequence. The basal sandstone unit, however, which is at the bottom of the studied sequence, does appear to rest on an exposure zone.

Each of the above mentioned sequences of upwardly coarsening rocks consists of a cycle of stratigraphic units referable to the four lithologic types described previously. There are nine of these sequences in the stratigraphic column.

The basal unit, VAL 98-99A, is a calcareous sandstone and is the only occurance of a "type 1" lithology in this section (figure 6). It is bounded above and below by abrupt contacts and therefore is a cycle in itself, starting with an exposure zone.

The next cycle contains VAL 99B, "type 2" lithology, a fine-grained argillaceous limestone with nodular bedding, overlain by VAL 100, "type 3" lithology, fine-grained limestone with parallel bedding.

Cycle 3, which lies above these two units, contains VAL 101A at the base, also "type 2" lithology and is overlain by VAL 101B of "type 3" lithology.

The fourth cycle consists solely of VAL 102, a single unit composed of several lithologic types. At the base is a 4" silty layer of "type 2" lithology. This grades up into "type 3" lithology at the top of the unit. Therefore, this cycle which contains a sequence of lithologic types 2 to 3 to 4, then back to 3, indicating a reversal of the cycle which suggests a change from an apparent regressive phase to an apparent transgressive phase.

The fifth cycle begins with VAL 103A which consists of "type 2" lithology grading up to "type 3". This is overlain by VAL 103B, C, and D, which together are "type 4" lithology.

The sixth cycle is a small cycle of one unit, VAL 103E, all of which is "type 3" lithology.

The seventh cycle begins with VAL 104A of "type 2" lithology and is overlain by VAL 104B of "type 3" lithology.

Cycle eight begins with VAL 105 of "type 2" lithology. VAL 106-107 has a basal section of "type 3" lithology. A reversal in the cycle occurs in the center of the unit with an interbedded silty layer, ("type 2"), 2 feet thick. This is overlain by an upper "type 3" sequence.

The final cycle is very similar to cycle four in which the sequence is 2 to 3 to 4 to 3. The lower portion of VAL 108 is of "type 2" and grades into the upper portion which is "type 3". VAL 109 is of "type 4", however, it is less well developed than the "type 4" in the fourth cycle. Cannonball concretions are absent, although a layer of large, distinct chert nodules occurs at the top of the unit. VAL 110-111 signifies the unit at which the sequence reverts back to a "type 3" lithology indicating a change in base level.

The nine "cycles" are defined as having abrupt basal boundaries which indicate an instantaneous change from an apparent regressive sequence to an apparent transgressive sequence. Figure 4 shows these small scale cycles, bounded by abrupt lithologic contacts.

These small scale cycles represent episodic events which occur over relatively short periods of time and are generally of basin-wide extent. Larger megacycles of global extent, which represent events which occur over longer periods of time, can also be seen in the rocks of the Bird Spring Group at Arrow Canyon. In addition to the small scale cycles, there appear to be four megacycles in the rocks of the Lower Atokan. These are characterized by an overall fining upward of the sediments and are on a scale of 20-50 feet (65-163 meters).

The lowest of the megacycles consists of the 20'10" of Late Morrowan rocks and comprise a characteristic sandstone-shale-limestone, fining upward sequence.

The next megacycle consists of 48'6" of the basal Lower Atokan, units 99B to 102. At the base, a silty unit grades up through coarse, medium grained to fine grained limestone, also a fining upward sequence. The third megacycle is 37' thick, units 103A to 103D, and follows the same pattern as the previous cycle with a silty unit grading up to fine-grained limestone. The uppermost, fourth, megacycle follows the same pattern and is 32'4" thick.

These cycles are of fairly uniform thickness and follow nearly identical patterns indicating a repetitive nature to the depositional conditions under which each was laid down, broken only by an episodic event which resulted in the coarsening of the sediments being deposited.

CHAPTER VII
INTERPRETATION

Microfacies studies of the Bird Spring Group by Rich (1963) and Heath, Lumsden and Carozzi (1967) have provided a basis for inferring environmental conditions at the time of deposition, as well as revealing possible cyclic patterns of deposition.

Rich (1963), studied Chesterian to Leonardian rocks of the Bird Spring Group at Lee Canyon, 45 miles southwest of Arrow Canyon. He concluded that the Bird Spring Group was dominated by fine-grained sediments deposited in fairly deep seas with slight fluctuations between aerobic and anaerobic conditions. Shallowing during the Late Morrowan was suggested by the occurance of warm water corals and calcareous algae.

Also, during the Atokan, warm, shallow seas were indicated by abundant corals and calcareous algae interbedded with silty calcarenite. Rich further noted a cyclical pattern of deposition which he thought might have resulted from lateral shifts in facies.

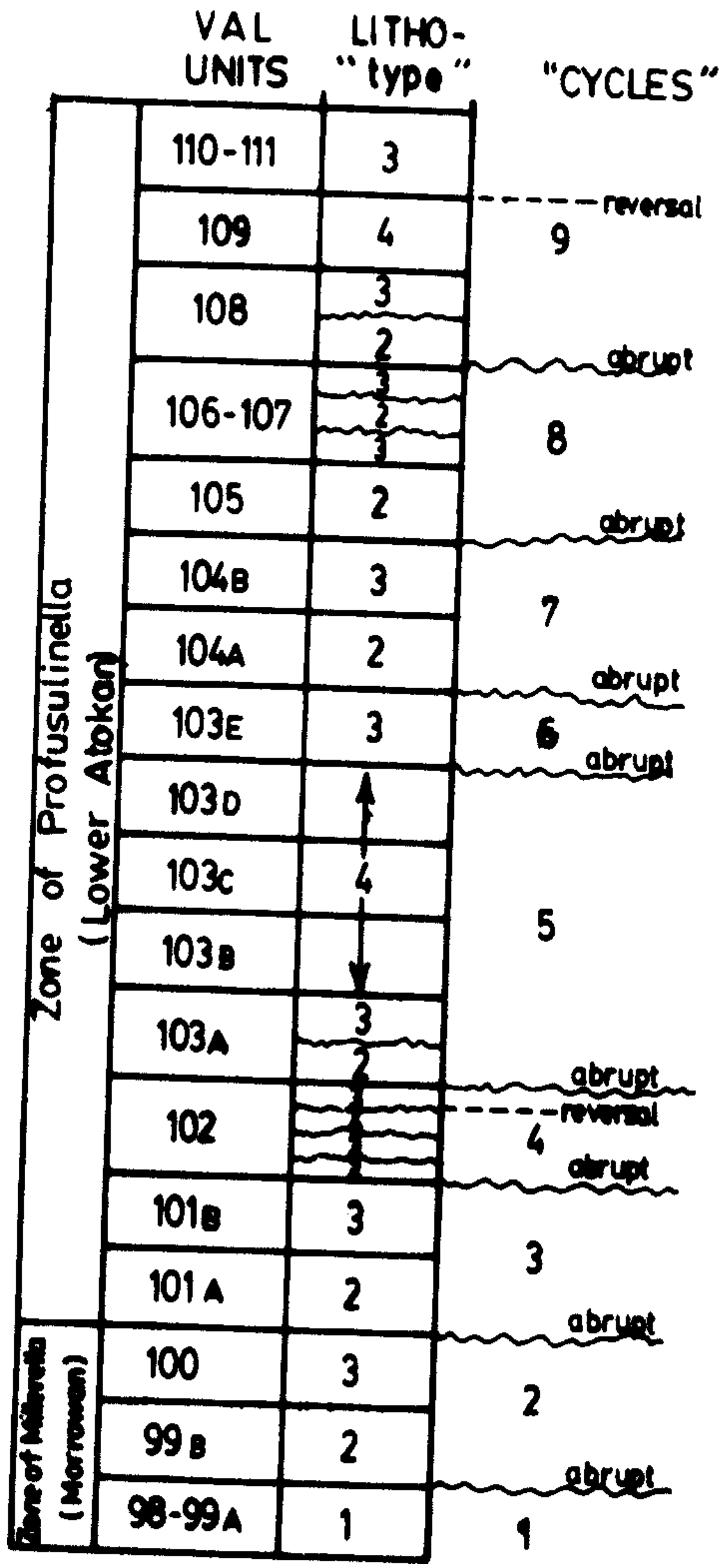
However, Heath, Lumsden and Carozzi (1967), first assigned a specific environment of deposition to each of the various lithologic types in the Bird Spring Group. They established eleven microfacies, based on examination of more than 2,000 samples from Arrow Canyon, and inferred a depositional environment for each. Energy level, (maximum grain size), and amount and type of debris were the parameters utilized.

Only six of their eleven microfacies, 0-5 , occur in the Zone of *Profusulinella*, the other five, 0a-4a, being quartz-rich equivalents of 0-4, are absent in this part of the sequence.

Microfacies cycles in which different environments of deposition occurring in repeated, stratigraphic order, were defined by Heath, Lumsden and Carozzi (1967). Their ideal cycle begins at 0, low energy, deep ocean environment, grades upwards to 5, a high-energy, shallow ocean environment and then returns to 0. Thirteen such cycles are reported by Heath, Lumsden and Carozzi (1967), as occurring in the Atokan at Arrow Canyon.

Figure 4 shows their bathymetric curve for the Zone of *Profusulinella* adjusted to fit the stratigraphic section as described for this study. The solid curve represents the observed microfacies in specific samples plotted against the stratigraphic column. The dashed-line curve, the envelope curve, is believed by Heath, Lumsden and Carozzi (1967) to represent longer-term fluctuations in water depth, a higher order depth curve. Microfacies 0 is not

Figure 4: Column of Stratigraphic units with respective lithologic types and associated cycles


VAL UNITS
LITHO- "type"
"CYCLES"
Zone of Profusulinella
(Lower Atokan)
Zone of Millerella
(Morrowan)
110-111
3
109
4
9
reversal
108
3
2
abrupt
106-107
3
2
3
8
105
2
abrupt
104B
3
7
104A
2
abrupt
103E
3
6
abrupt
103D
103C
4
103B
5
103A
3
2
abrupt
102
reversal
4
abrupt
101B
3
3
101A
2
abrupt
100
3
2
99B
2
abrupt
98-99A
1
1

represented in the Lower Atokan. Microfacies 0 signifies deep marine deposition and it's absence from these rocks indicates shallower seas as suggested by Rich (1963). Microfacies 0, however, does appear in the basal 11' of the section, which is Morrowan. This coincides with Rich's (1963), fairly deep Morrowan seas. Figure 4 shows that the microfacies curve agrees, for the most part, with the macroscopic succession. Some discrepancies, however, do exist. In some instances microfacies are described as continuous across an abrupt lithologic contact where in fact, an abrupt change in lithologic aspect would be expected to coincide with a change in microfacies. An example of this occurs at the abrupt contact at the base of VAL 108. Here is an abrupt change from medium-grained, massive limestone (VAL 106-107) to the fine-grained, silty unit at the base of VAL 108. According to Lumsden (1965), these units represent 1, (VAL 106-107), and microfacies 2, (basal VAL 108) (fig. 6), a definite abrupt change in lithology. However, the microfacies curve shows all of VAL 106-107 and VAL 108 as part of a smooth continuous shift to the deep water, low energy conditions of microfacies 1, giving no indication in the apparent break in the cycle.

Therefore, although there is some correlatibility between the microfacies curves of Heath, Lumsden, and Carozzi (1967), and the stratigraphic succession, they can not be related to all the rocks in the section.

That is not to say, however, that there are no cycles of apparent upward shallowing and increased energy conditions. There is a series of nine cycles, in the section, each of which begins with an abrupt lithologic contact. Each of these cycles comprises a sequence of rock representing upwardly shallowing conditions. Goodwin and Anderson(1985), described similar cycles within the Late Devonian rocks of the Helderberg Group of east-central New York, recognizing several small-scale coarsening upward cycles, 1-5 meters thick, separated by surfaces at which there is an abrupt change to a deeper facies. These punctuated or episodic events have been given the name, Punctuated Aggradational Cycles (PAC's), the punctuating event being an instantaneous rise in base level which Goodwin and Anderson believe is caused by glacial eustacy driven by orbital perturbations.

The nine cycles in the Lower Atokan rocks of Arrow Canyon, can be referred to as PAC's. However, breaks in the apparent shallowing upward sequence, as indicated by the reversals in lithologic types, indicate periods of apparent transgressions within the apparent regressive PAC.

In the model proposed by Wilkinson (1982) and James (1984), the shallowing upward sequence is explained as a result of a constant rate of carbonate sedimentation with periodic changes in the absolute position of sea level (eustatic). In contrast, Ginsburg (1971), suggests that while there is a slow rise in sea level or a gradual subsidence, the rate of carbonate sedimentation is also changing, as controlled by the subtidal source area (autocyclic).

Schlager (1981), states that in order for a flat, sediment-covered platform to build up and prograde basinward (shallow upward), the amount of sediment coming in must exceed the relative rise in sea level. In fact, based on his study of pre-Holocene prograding platforms, he has determined that sediment accumulation rates range from 30 to 500µm/yr (Schlager, 1981). He has also determined that the average rate of basin subsidence (sea level rise), is 10-100µm/yr, indicating that a carbonate platform does indeed have the ability to build up at a faster rate than sea level rise (Schlager, 1981). Therefore, it is possible that a sequence of shallowing upward rocks (apparent regression), can form during periods of stable sea level as well as periods of sea level rise (apparent transgressions), if the sediment produced exceeds the rate of sea level rise, any changes in the amount of incoming sediment would result in leveling off or reversal of the depositional rock sequence as evidenced in the lithologic type reversals described in the Lower Atokan rocks of Arrow Canyon.

A new eustatic model for the origin of carbonate cyclic sedimentation has been proposed by Carozzi (1986). He attempts to eliminate the apparent discrepancies encountered when trying to compare the autocyclic model of carbonate sedimentation, that of a slow, shallowing upward event (apparent regression), followed by a fairly rapid deepening event (apparent transgression), to the eustatic model proposed by Vail et al. (1977), in which there is a slow rise in sea level followed by a rapid fall in sea level. He suggests two possible ways of comparing the two cycles. If a constant rate of subsidence is assumed, a slow rise in sea level can be outpaced by an increase in sediment productivity and will result in a shallowing upward sequence topped by an exposure zone and a short break in deposition as sea levels fall (Carozzi, 1986). The second possibility also assumes a constant rate of subsidence, but a variable increase in sediment productivity which may fall behind the rate of sea level rise. This would result in a shallowing upward sequence that does not result in an exposure zone, but acquires a thin sequence of disconformable, carbonate sediments or a complex lag deposit (Carozzi, 1986).

However, although Carozzi gives possible account for some of the discrepancies in comparing the two end-member models of repetitious shallowing upward sequences, his concept does not appear to be applicable to the problems faced in interpreting the carbonate cyclicity at Arrow Canyon.

The global cycles of relative change of sea level (eustatic) (Vail et al., 1977), appear to coincide with the four megacycles described for the rocks at Arrow Canyon. The fining upward sequence bounded by an abrupt change to shallower water deposition fit the pattern of Vail's cycles which represent relatively slow periods of sea level rise followed by fairly rapid sea level drops. As indicated by Vail et al. (1977), these cycles occur as hierarchial pattern of paracycles, cycles, and super or megacycles in which each successively larger cycle represents a longer period of time. Several smaller order cycles form a higher order cycle with patterns of successive rises and falls between each major fall. Therefore, the four megacycles described in the section at Arrow Canyon can be said to fit the patterns assigned to Vail's cycles of eustatic sea level changes.

Cyclothemic coal measure deposits recognized by Udden in 1906 and described by Weller (1930), Wanless (1931), and Moore (1931), characterize much of midcontinental and eastern interior Pennsylvanian sedimentation in North America. This series of beds representing a single sedimentaty cycle, ranges from non-marine sand and silt to brackish swamps and marshes where peat deposits occur, to marine carbonate deposits. The section at Arrow Canyon consists entirely of carbonate rocks deposited in a miogeosyncline and do not obviously conform to the cyclothemic pattern of deposition.

Extensive occurance of chert is an aspect of the carbonate rocks of Arrow Canyon. Several different types of chert occur in this section, each related to a particular lithologic type. Small, individual nodules of chert, 1-3" in size, generally occur in the fine-grained, silty limestone. Larger, individual nodules of chert occur in medium-grained, medium to thickly, parallel bedded limestone. The discontinuous to continuous bands of nodular chert tend to occur in the fine-grained, thin to medium-bedded limestone. Finally, the large, individual nodules or "cannonball" style chert occur in the medium-grained, massive, cliff forming limestones

It has been suggested by several authors (Mortimore, 1986, Clayton, 1986; Williams, 1986, Bromley and Ekdale, 1986, Felder, 1986, and several others), that chert occurance in Cretaceous chalk is related to the depositional history and to the depositional interface of carbonate sediments. Based on the repeated occurance of chert of a particular morphological type within a specific lithotype and the cyclic pattern of lithotype deposition at Arrow Canyon, this control of chert accumulation by original depositional environments, also appears to be the case for these Pennsylvanian rocks.

Chert formation is a diagenetic event in which biogenic silica (opal-A), produced by dissolution of sponges or other siliceous organisms, is converted to intermediate Opal-CT by a process of solution-redeposition (Kastner and Gieskes, 1983). Conversion of opal-CT to quartz (chert) also is a solution-precipitation process (Carr and Fyfe, 1958).

Based on their study of Cretaceous chalk sedimentation in southern England, Kennedy and Garrison (1975), suggest that if repetitive occurance of chert bands at regular intervals parallels rhythmicity of chalk sedimentation, then it seems reasonable to assume that chert deposition is an integral part of that rhythmicity.

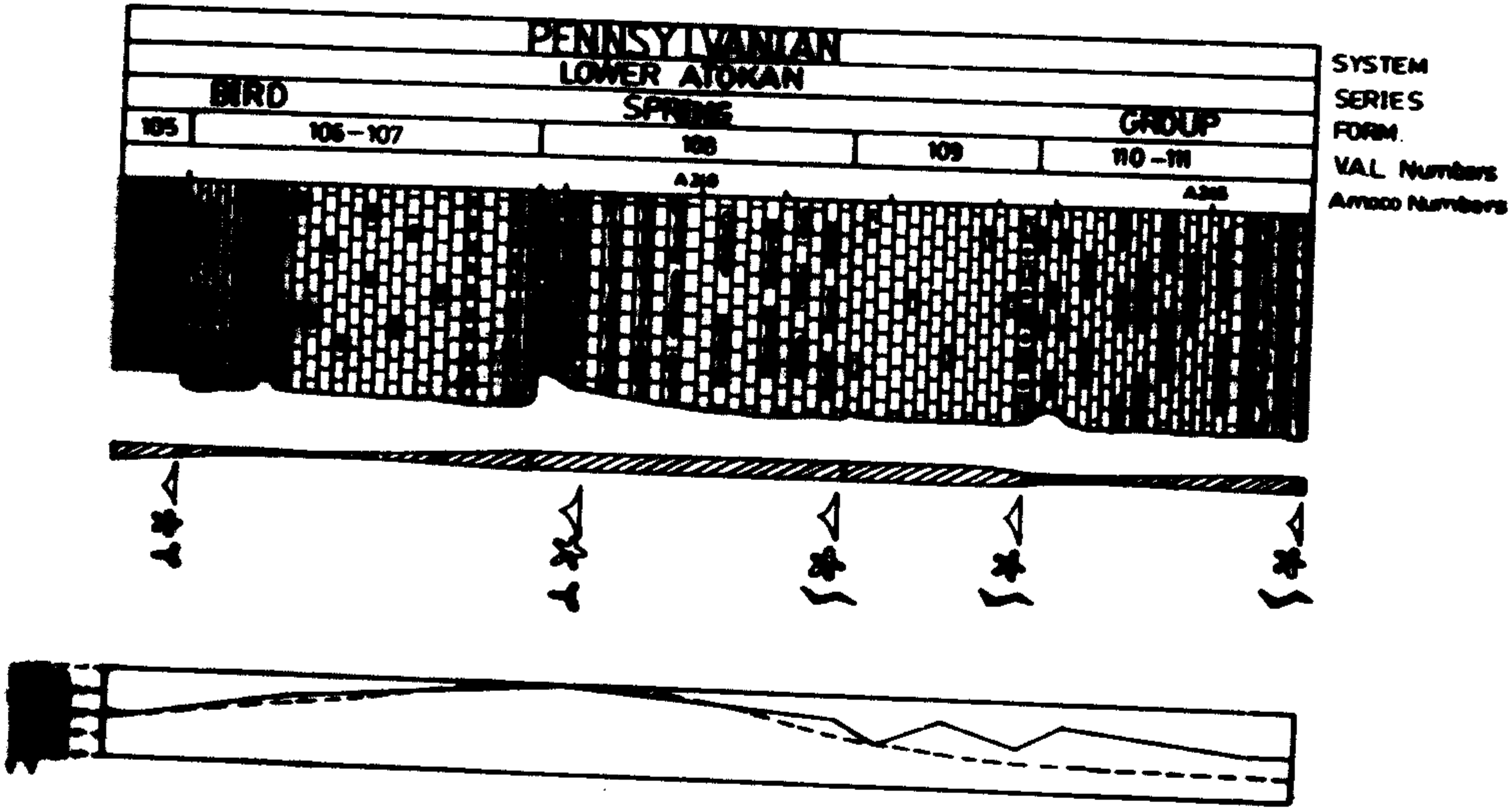
Distinct bands of chert occur as a result of a break in sedimentation during which reduced sulphates are re-oxidized (Clayton, 1986). The boundary between sulphate reducing and oxidizing conditions localizes formation of banded chert, 5-10 meters below the surface (Clayton, 1986).

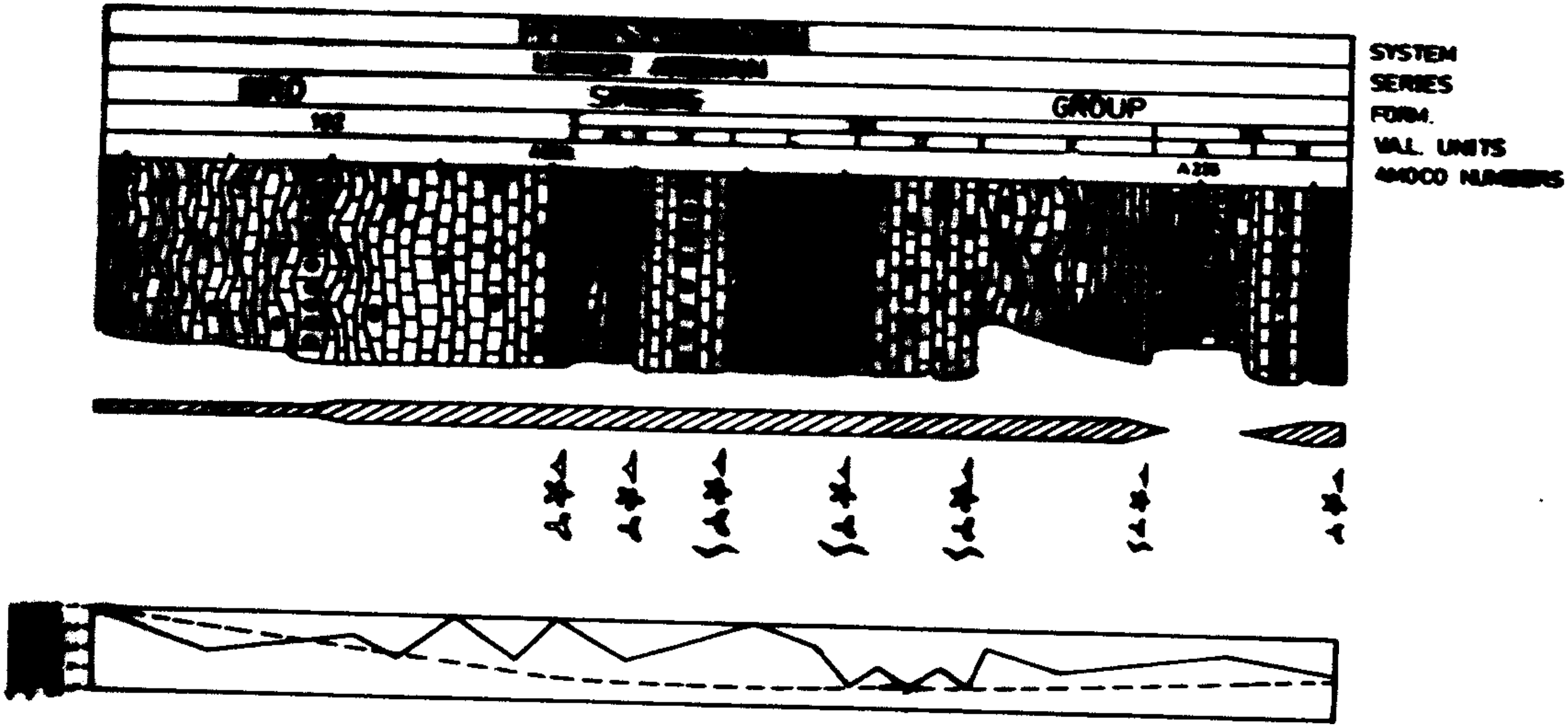
A distinct band of chert, approximately 6-8" in thickness, occurs within the section at Arrow Canyon. It lies at the top of VAL 102 and suggests a break in sedimentation between VAL 102 and VAL 103A, during which a "redox" surface formed. This is supported by the existance of an abrupt contact at that point.

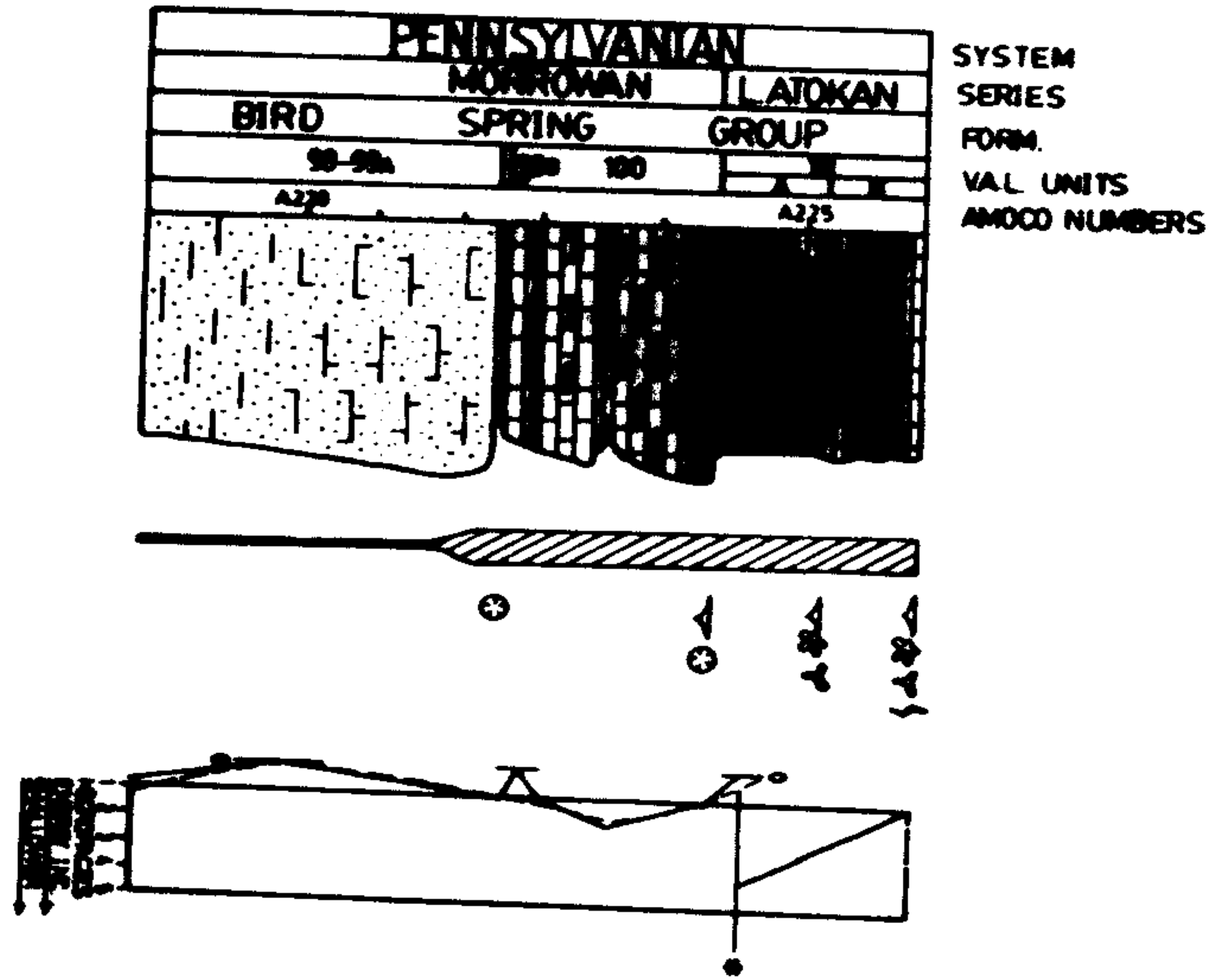
The formation of certain cherts can by related to lithology. The large chert nodules of the "cannonball" type in units VAL 102, VAL 103B, VAL 103D, and VAL 109 are an example. The "cannonballs" occur along distinct layers and are evenly spaced. They occur in fairly homogeneous limestone beds that are evenly bedded. They are somewhat isolated in that they occur in single layers as opposed to successive layers. Clayton's (1986) interpretation of these characteristics is that the homogeneity of the rock unit results in uniform porosity and permeability throughout. The sulphide reduction and oxidation zone (zone of mixing), is uniform. Therefore, when chert crystallization begins it proceeds uniformly on all sides and the circular pattern of "cannonball" develops as each concretion continues growing until it interferes with another or until renewed carbonate sedimentation halts the diagenetic process.

There appears to be a repetitive nature of chert occurance in the rocks at Arrow Canyon. That is, they occur in cyclic patterns within the lithologic cycles. PAC cycle four, described previously, exhibits a symmetrical pattern of chert occurances from "cannonball" type to discontinuous nodular bands to continuous nodular bands, then back through discontinuous nodular bands to "cannonballs".

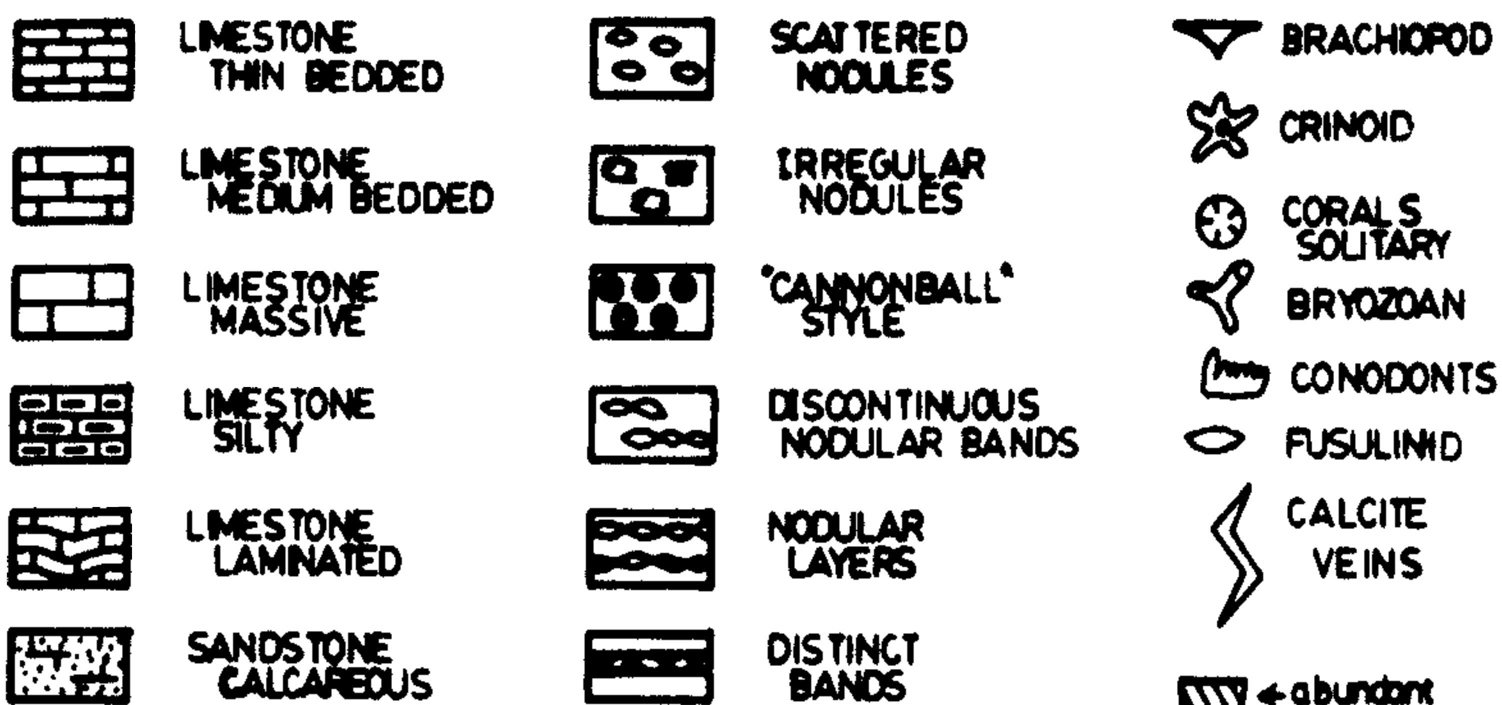
Figure 5. Columnar section of Arrow Canyon section with vertical representation of microfacies as recognized by Heath, Lumsden, and Carozzi (1967).

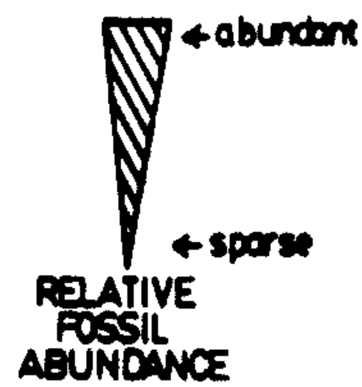

PENNSYLVANIAN
LOWER ATOKAN
BIRD
SPRING
GROUP
105
106-107
108
109
110-111
SYSTEM
SERIES
FORM.
VAL Numbers
Amoco Numbers


GROUP
SYSTEM
SERIES
FORM.
VAL. UNITS
AMOCO NUMBERS


PENNSYLVANIAN
MORROWAN
LATOKAN
BIRD SPRING GROUP
100
A225
SYSTEM
SERIES
FORM.
VAL. UNITS
AMOCO NUMBERS

EXPLANATION





MICROFACIES
(Lumsden, 1965 and Heath, 1965)

0 -Limestone, thin to massive beds; fine grained; extensive chert as nodules or discontinuous layers, nonresistant; few fossils.

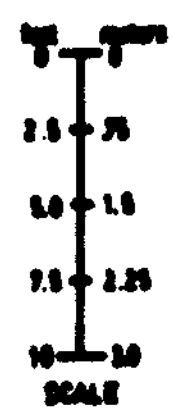
1 -Limestone, thin to massive beds, fine grained; extensive chert as nodules or layers; resistant, fossiliferous weathers nodular.

2 -Limestone, mud supported; med. to massive beds; extensive chert as nodules; fossiliferous; nonresistant.

3 -Limestone, med. to coarse grained; med. to massive beds; some chert; laminated; resistant; fossiliferous.

4 -Limestone, massive; med. to coarse grained; little chert; fossiliferous; resistant.

5 -Limestone, thin to medium beds; medium grained; oolitic; no chert; resistant.



● -Gap in microfacies curves of Heath and Lumsden at their Morrowan/Atokan boundary reflect their unreconciled differences in interpretation.

APPENDICES

APPENDIX A

ARROW CANYON SECTION DESCRIPTION

Descriptions of the stratigraphic section of Middle Pennsylvanian strata (Zone of *Profusulinella*) at Arrow Canyon (E1/2, sec. 11 and S1/2, sec. 12, T14S, R64E and SW1/4, sec. 7, T14S, R65E). Unit number are those of V.A. Langenheim (1964) and have been referred to as "VAL" units in the text. Total thickness of units is based on surveyed markers placed by Amoco field geologists. These bench marks are referred to as "Amoco" numbers. Bedding thickness is defined as laminate or convolute (less than 1"), thin (1" to 1'), medium (1' to 3'), or massive (greater than 3'). Chert nodules range in diameter from very small (less than 1"), small (1" to 3"), medium (3" to 6"), or large (greater than 6"). All chert is dark brown to black with black fresh surface.

Unit(s)	Thickness	Description
110-111	11'1"	Limestone, grey to medium grey, weathers dark grey; fine to medium grained, thin to medium bedded, scattered to layered medium round dark brown chert nodules, few at base grading upward to 4-5 distinct chert bands 3-5" thick near top of unit highly fossiliferous including brachiopods and crinoid fragments, calcite veins throughout, lower 1'5" a silty limestone, buff to grey, weathers nodular, to dark grey; fine grained, thin bedded, little chert, few fossil fragments; basal contact gradational.
109	7'11"	Limestone, grey to medium grey, weathers dark grey, fine grained, thin bedded to massive, little chert present except for distinct layer of dark nodules 6-10" thick at top of unit, fossil hash throughout but concentrated in bands 1-2" thick; calcite veins throughout; basal contact gradational
108	13'4"	Limestone, light grey to buff, weathers buff to rust, fine grained, thin-medium bedded, bands of dark nodular to layered chert throughout 4-8" thick, calcite veins and vugs present, bioclastic with some productids, grades up from 2'2" of silty limestone; grey weathers buff; fine-grained; nodular to massive small dark chert nodules; fossiliferous throughout poorly exposed and lower portion recessed, basal contact abrupt
106-107	15'	Limestone, dark grey weathers buff to grey; fine to medium grained; massive; highly fractured; two zones of limestone separated by interbedded silty units; scattered chert nodules

		lower portion of upper limestone but two distinct layers near top, lower layer consists of small, dark brown nodules 3-6" in diameter, upper layer consists of larger dark brown nodules 8-12" in diameter approximately 1' from top of unit.
105	2'10"	Silty limestone, light grey weathers grey very fine grained; laminated to thin bedded; some very small chert nodules; highly fossiliferous, well preserved brachiopods, nacreous layer still preserved on some, crinoid stems and bryozoan abundant. unit grades upward into calcareous shale, unit recessed and poorly exposed, basal contact abrupt.
104B	4'6"	Limestone; grey weathers grey to buff fine to medium grained, thin to medium bedded, distinct layer of dark chert nodules 6-8" thick in lower half of unit, two layers in upper half of unit, absent from the rest of unit, section of interbedded silty limestone near center of unit, fossil fragments throughout with distinct, concentrated fossil layer 1" thick in central silty section, bench former, basal contact abrupt
104A	4'6"	Silty limestone; light grey weathers buff fine grained; laminated and highly convoluted; single layer of chert nodules 6" thick, also convoluted, near center of unit; some calcite veins; slickensides;no apparent fossils, unit recessed and poorly exposed; basal contact gradational.
103E	8'2"	Limestone. grey weathers grey to buff; medium grained; thin bedded to massive; very few dark medium chert nodules; limestone noduler at base grading up into laminate limestone;

		distinct band of concentrated fossil hash 1" thick near top of unit, calcite veins throughout, bench former, basal contact abrupt.
103D	5'8"	Limestone, dark grey to grey weathers grey, medium grained, medium bedded to massive; unit very homogeneous throughout; scattered dark chert nodules with a distinct layer of large dark brown balls of chert 8-10" in diameter at base of unit, "cannonball" style, bedding plane 2/3 up from base, few calcite veins, brachiopod and crinoid fragments throughout, basal contact gradational.
103C	5'10"	Limestone, dark grey to grey weather grey, fine to medium grained, medium bedded to massive, very similar to 103D except for 9 distinct bands of darkbrown layered chert 4-6" thick uniformly spaced 4-8" apart, some calcite veins, fossil fragments throughout, basal contact gradational
103B	4'2"	Limestone, dark grey weathers grey, medium grained, massive, distinct zone of , medium round balls near center of unit along bedding plane, unit of homogeneous lithology with few calcite veins, similar to 103C & D; brachiopod and crinoid fragments throughout; basal contact gradational
103A	3'4"	Limestone, dark grey weathers grey to buff, medium grained; thin bedded in upper portion, laminated and convoluted near base, small dark brown chert nodules scattered throughout; few fossils, brachiopod and crinoid fragment basal contact fairly abrupt
102	21'9"	Limestone with interbedded silty units, prominent silty unit

4" thick at base, dark grey to grey weathers grey; fine to medium grained; massive with some laminations near base; very little chert in lower portion of unit, distinct layer of dark brown chert balls 8-10" in diameter located near center of unit, also 3" band of dark chert at top of unit; fossils rare near base of unit grading up into fossil hash with brachiopod and crinoid fragments; basal contact fairly abrupt

101B	3'10"	Limestone, with interbedded silty units, grey to buff weathers nodularly to grey; fine to medium grained, medium bedded, small dark chert nodules throughout, but absent from silty units, some calcite veins, bioclastic in upper portion, brachiopod, crinoid, and bryozoan fragments; basal contact gradational
101A	3'11"	Limestone with silty limestone, grey weathers grey to buff; medium grained, medium bedded to massive; abundant dark chert nodules scattered throughout with distinctive bands of lenticular chert nodules 2-10" thick, fossiliferous with large brachiopods, bryozoan and crinoid fragments, basal contact abrupt.

ATOKAN / MORROWAN Boundary (Cassity and Langenheim, 1966; Webster, 1969)

100	7'6"	Limestone, grey weathers light grey; fine to medium grained; thin to medium bedded; abundant dark brown chert occuring as scattered nodules as well as banded layers of lenticular chert 4-8" thick; some interbedded silty units forming small recesses; fossiliferous with brachiopods and abundant solitary rug..a corals; basal contact abrupt.

99B	6"	Silty limestone, light grey, nodulerly weathering buff to rust; thin bedded, dark chert nodules throughout; solitary rugosa corals; basal contact abrupt.
98-99A	11'3"	Calcareous sandstone, buff weathers rust (iron oxide; fine to medium grained thin bedded to massive; distinctive absence of chert; calcite veins in upper portion; little or no fossils apparent at base, grading up to sparse fossil hash in upper portion; upper portion forms sandstone cliff, lower portion recessd and poorly exposed; basal contact abrupt

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