1990

Stratigraphy and depositional history of the Bird Spring Formation (Pennsylvanian to Permian), Spring Mountains, Southern Nevada

Brian D. Ho
San Jose State University

Follow this and additional works at: https://scholarworks.sjsu.edu/etd_theses

Recommended Citation

Ho, Brian D., "Stratigraphy and depositional history of the Bird Spring Formation (Pennsylvanian to Permian), Spring Mountains, Southern Nevada" (1990). *Master's Theses*. 3265.
DOI: <https://doi.org/10.31979/etd.ncrx-6acb>
https://scholarworks.sjsu.edu/etd_theses/3265

This Thesis is brought to you for free and open access by the Master's Theses and Graduate Research at SJSU ScholarWorks. It has been accepted for inclusion in Master's Theses by an authorized administrator of SJSU ScholarWorks. For more information, please contact scholarworks@sjsu.edu.

INFORMATION TO USERS

The most advanced technology has been used to photograph and reproduce this manuscript from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

U·M·I

University Microfilms International
A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor, MI 48106-1346 USA
313 761-4700 800 521-0600

Order Number 1340518

**Stratigraphy and depositional history of the Bird Spring
Formation (Pennsylvanian to Permian) Spring Mountains,
southern Nevada**

Ho, Brian D., M.S.

San Jose State University, 1990

U·M·I

**300 N. Zeeb Rd.
Ann Arbor, MI 48106**

STRATIGRAPHY AND DEPOSITIONAL HISTORY
OF THE BIRD SPRING FORMATION
(PENNSYLVANIAN TO PERMIAN)
SPRING MOUNTAINS, SOUTHERN NEVADA

A Thesis

Presented to

The Faculty of the Department of Geology
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

By

Brian D. Ho

May, 1990

APPROVED FOR THE DEPARTMENT OF GEOLOGY

Dr. Calvin Stevens

Dr. David Andersen

Dr. Scott Creely

APPROVED FOR THE UNIVERSITY

ACKNOWLEDGEMENTS

I am grateful to Calvin H. Stevens for guidance and kind advice concerning every aspect of this investigation. In addition to providing constant encouragement, Cal has greatly assisted this investigation by studying the faunal collections and providing valuable information on the biostratigraphy. I would also like to thank the members of my advisory committee at San Jose State University, David Andersen and Scott Creely, for critically reviewing the manuscript and providing helpful suggestions. This investigation was funded, in part, by grants from the American Association of Petroleum Geologists Research Fund and San Jose State University, for which I am grateful.

Gratitude is extended to Cheryl Treat for providing assistance in the field and to Bob Maggini for his helpful comments during analysis of faunal samples. Karen Skinner greatly assisted in this investigation. Karen's nimble fingers and computer talents have been indispensable. Special thanks are given to my parents, Ronald and Gladys Ho, and sister, Cindy, for their encouragement and loving assistance in time of need.

TABLE OF CONTENTS

	Page
ABSTRACT	xii
INTRODUCTION	1
Purpose of Study	1
Geographic Setting	4
Regional Geology	6
Previous Work	8
Methods	9
Field Work	9
Laboratory Work	10
STRATIGRAPHY	11
Introduction	11
Description of Stratigraphic Sections	12
Lee Canyon Composite Section	12
Member A	14
Member B	16
Member C	17
Member D	19
Wheeler Wash Composite Section	23
Southern Section	26
Northern Section	31

TABLE OF CONTENTS (CONTINUED)

	Page
Lovell Canyon - Mountain Springs Pass - Composite Section	36
Member 1: Mountain Springs Pass	39
Member 2: Mountain Springs Pass	44
Member 2: Lovell Canyon	49
Member 3: Lovell Canyon	51
Member 4: Lovell Canyon	55
ENVIRONMENTS OF DEPOSITION	60
Environmental Interpretation of the Lee Canyon Section	60
Member A	60
Member B	61
Member C	62
Member D	63
Environmental Interpretation of the Wheeler Wash Sections	64
Southern Section	64
Northern Section	66
Environmental Interpretation of the Lovell Canyon - Mountain Springs Pass Composite Section	67
Member 1	67
Member 2	68
Member 3	69
Member 4	71

TABLE OF CONTENTS (CONTINUED)

	Page
CORRELATION OF STRATIGRAPHIC SECTIONS	72
LATE PALEOZOIC DEPOSITIONAL HISTORY IN THE SPRING MOUNTAINS . .	76
Latest Mississippian	76
Morrowan to Early Wolfcampian	77
Early Wolfcampian to Late Wolfcampian	78
Late Wolfcampian	79
Early Leonardian	79
COMPARISON WITH PENNSYLVANIAN-PERMIAN ROCKS IN NORTHEASTERN NEVADA AND SOUTHEASTERN CALIFORNIA	81
CONCLUSIONS	88
REFERENCES CITED	94
APPENDIX 1: DESCRIPTION OF MEASURED SECTIONS	97
Lee Canyon Section	97
Wheeler Wash, Southern Section	100
Wheeler Wash, Northern Section	102
Mountain Springs Pass Section	104
Lovell Canyon Section	109
APPENDIX 2: FUSULINIDS OF THE BIRD SPRING FORMATION, SPRING MOUNTAINS	111
APPENDIX 3: PETROGRAPHIC ANALYSIS OF ROCK SAMPLES	121

LIST OF ILLUSTRATIONS

Figure	Page
1. Map Showing the Early Permian Shelf and Its Relationship to the Study Area	2
2. Location of Measured Sections in the Spring Mountains	5
3. Map Showing the Thrust Plate Relationships in the Spring Mountains	7
4. Location of Measured Sections in the Lee Canyon Area	13
5. Columnar Section from the Lee Canyon Area	15
6. Bird Spring Limestone of Member C at Lee Canyon	18
7. Chert Pebbles Aligned Along Bedding Planes of the Uppermost Dolomite Beds in Member D at Lee Canyon	21
8. Chert Pebbles of Member D at Lee Canyon	22
9. Pisoliths from the Chert-pebble-bearing Dolomite Bed of Member D	24
10. Location of Measured Sections in the Wheeler Wash Area	25
11. Composite Columnar Section from the Wheeler Wash Area	27
12. Bird Spring Limestone of the Southern Section at Wheeler Wash	28
13. Horn Corals in Limestone Bed in the Southern Section at Wheeler Wash	30
14. Bird Spring Limestone of the Northern Section at Wheeler Wash	32
15. Interbedded Limestone and Siltstone of the Northern Section at Wheeler Wash	33
16. Photomicrograph of Dasycladacean Algal Fragments from the Northern Section at Wheeler Wash	35

LIST OF ILLUSTRATIONS (CONTINUED)

Figure		Page
17.	Location of Stratigraphic Section at Lovell Canyon . .	37
18.	Location of Stratigraphic Section at Mountain Springs Pass	38
19.	Geologic Map of the Lovell Canyon - Mountain Springs Pass Area	40
20.	Columnar Section of Bird Spring Strata in the Mountain Springs Pass Area	41
21.	Columnar Section of Bird Spring Formation and Permian Red Beds in Lovell Canyon	42
22.	Bird Spring Siltstone, Dolomite, and Limestone at Mountain Springs Pass	45
23.	Outcrop View of White, Quartzine Nodules in Dolomite of Member 2 at Mountain Springs Pass	47
24.	Polished Surface of Dolomite of Member 2 at Mountain Springs Pass	48
25.	Assorted Peloids in Micrite from Member 3 at Lovell Canyon	52
26.	Photomicrograph of Spar-filled Ostracodes and Calcispheres, and Assorted Peloids in Micrite from Member 3 at Lovell Canyon	53
27.	The Contact Between Upper Bird Spring Siltstones and Dolomites and Permian Red Beds in Lovell Canyon	56
28.	Sedimentary Structures in Permian Red Beds at Lovell Canyon	57
29.	Wedge-planar Laminae Preserved in Quartzose Sandstone at Lovell Canyon	59
30.	Generalized Representation of the Relationship Between Outer Shelf and Inner Shelf Environments During the late Paleozoic	76

LIST OF ILLUSTRATIONS (CONTINUED)

Figure		Page
31.	Location of Sites in Southeastern California, Northeastern Nevada, and Southern Nevada	82
32.	Late Paleozoic Stratigraphic Units in Southern Nevada, Northeastern Nevada, and Southeastern California . . .	83

LIST OF PLATES

Plate		Page
1.	Fusulinids of the Wheeler Wash Southern Section and Member D of Lee Canyon Section	111
2.	Fusulinids of the Wheeler Wash Northern Section	113
3.	Fusulinids of the Wheeler Wash Northern Section	115
4.	Fusulinids of the Mountain Springs Pass Section	117
5.	Fusulinids of the Mountain Springs Pass Section	119

LIST OF TABLES

Table	Page
1. Rock Samples from the Wheeler Wash Area and Lee Canyon Area	122
2. Rock Samples from the Lovell Canyon Area	125
3. Rock Samples from the Mountain Springs Pass Area	126

ABSTRACT

The Bird Spring Formation in the Spring Mountains records part of the late Paleozoic depositional history of the Cordilleran miogeocline in southern Nevada. Throughout the Spring Mountains, Pennsylvanian to lower Wolfcampian (lowermost Permian) rocks consist of shallow-water, skeletal lime-wackestone interbedded with calcareous shale. At Lee Canyon, lower Wolfcampian rocks grade into deeper-water, black, thin-bedded, bioclastic limestone interbedded with siltstone, whereas at Mountain Springs Pass and Lovell Canyon to the southeast, coeval rocks consist of shallow-water to supratidal quartzine nodule-bearing dolomite, and siltstone, and limestone. Lower Wolfcampian to lower Leonardian rocks at Lee Canyon are characterized by shallow-water, limestone overlain by interbedded limestone and dolomite. At Lovell Canyon, coeval rocks consist of nearshore, silty, lime-wackestones that grade into reddish-brown, fine-grained sandstone of the overlying Permian red beds. The overall history demonstrates two major transgressions and a final progradational event.

INTRODUCTION

Very thick sequences of miogeoclinal Pennsylvanian to middle Permian rocks are well exposed in the Spring Mountains of southern Nevada (fig. 1). Because few detailed studies have been done on the stratigraphy of these rocks, their depositional history in southern Nevada is not well understood. In addition, this lack of detail has hindered the correlation of late Paleozoic rocks in southern Nevada with rocks of similar age to the north and west, which is necessary to better understand the Pennsylvanian-Permian paleogeography of this region.

Purpose of Study

The purpose of this study is to: 1) interpret the depositional history of the Late Paleozoic shelf rocks of the Cordilleran miogeocline in the Spring Mountains region, 2) interpret the lateral facies patterns and their origin, and 3) better define the regional extent of the facies present by comparison with the stratigraphic succession in northeastern Nevada and southeastern California.

Where Pennsylvanian-Permian rocks have been studied in detail in northeastern Nevada, Stevens (1979) has shown that a series of north-northeast-trending facies belts are represented across the miogeocline. These consist (from east to west) of inner shelf, outer shelf, shelf margin, and basinal facies belts (Stevens, 1977). The inner shelf facies belt is characterized by interlayered sandstone, dolomite, and red beds. These rocks represent laterally shifting

Figure 1. Map showing the extent of the Early Permian Shelf and its relationship to the study area (after Stevens, 1977).

shoreline environments (continental, supratidal, intertidal, and shallow subtidal settings). The outer shelf facies belt is characterized by fossiliferous limestones containing shallow-water, open-marine organisms, interbedded with very fine-grained sandstone. The shelf margin facies belt includes coarse-grained calcarenite (which indicates relatively high energy conditions), but otherwise, it is characterized by rock types that are similar to those of the outer shelf (Stevens, 1977). The most distinguishing feature of the early Permian shelf margin facies belt in northeastern Nevada is the presence of abundant colonial rugose corals (Stevens, 1977, 1979). A relatively shallow basinal facies belt is characterized by calcareous mudstone and siltstone, and very argillaceous fine-grained limestone. A deep basinal facies is not present east of the old Antler Orogenic Belt in the well known parts of northeastern Nevada. Farther west, near-shore sandstones and conglomerates contain abundant chert grains or pebbles derived from remnants of the Devonian-Carboniferous Antler Orogenic Belt (fig. 1). In southeastern California, in contrast, Pennsylvanian and Permian rocks consist of sequences of fine-grained limestone, siltstone, and shale interspersed with coarse-grained, submarine debris-flow deposits and turbidites (Stevens, 1977; Stone and others, 1987) representing basinal deposition.

The Spring Mountains are located in the general region where the northeastern Nevada facies belts should intersect the different facies

represented in southeastern California. If the Pennsylvanian-Permian shelf in the Spring Mountains is a continuation of the shelf to the northeast, then the facies belts that are present in northeastern Nevada should have similar counterparts in the Spring Mountains, but the proximity of the California facies might be reflected in some sedimentologic differences.

Geographic Setting

The Spring Mountains are located in southern Nevada, 16 km west of Las Vegas. Trending northwest for more than 72 km, the Spring Mountains are bounded to the northeast by Las Vegas Valley and to the southwest by Pahrump Valley. The present study involves four areas in the Spring Mountains (fig. 2). These are the Lee Canyon, Wheeler Wash, Lovell Canyon, and Mountain Springs Pass areas.

The section measured at Lee Canyon is located in Section 20, T. 17 S., R. 57 E., of the Charleston Peak 15-minute quadrangle in Clark County, Nevada. Two sections were measured in the Wheeler Wash area, located on the southwestern flank of the Spring Mountains, 12.9 km northeast of the town of Pahrump. The southern section was measured in Section 36, T. 19 S., R. 54 E. of the Mount Stirling 15-minute quadrangle in Clark County, Nevada. The northern section is located in Section 19, T. 19 S., R. 55 E. of the Mount Stirling 15-minute quadrangle.

Figure 2. Location of measured sections in the Spring Mountains.

Approximately 35 km to the west of Las Vegas is the Lovell Canyon area. The Lovell Canyon Section is located in Section 2, T. 21 S., R. 57 E. of the Mountain Springs 15-minute quadrangle in Clark County, Nevada. The nearby Mountain Springs Pass area is approximately 38 km southwest of Las Vegas. The stratigraphic section that was measured here is located in Section 24, T. 22 S., R. 57 E. of the Mountain Springs 15-minute quadrangle.

Regional Geology

Precambrian to Jurassic rocks, as well as Cenozoic sediments, are exposed in the Spring Mountains, with the Pennsylvanian-Permian Bird Spring Formation comprising the thickest unit of any age exposed in the mountains. The Bird Spring Formation is exposed in three allochthonous plates separated by northeast-trending thrust faults, the dominant structural features of the Spring Mountains (fig. 3). One of the easternmost thrust faults (Keystone Thrust) is interpreted to be a decollement by Burchfiel and others (1974) and Carr (1983). Studies by Burchfiel and others (1974) indicate that thrusting occurred between middle Permian and late Cenozoic time. They calculated a minimum shortening of 35 to 72 km due to thrust faulting, with movement distributed over all of the thrust faults. The northeast trend of the thrust faults subparallels the major facies trends in the Spring Mountains so that the overall effect of the thrust faulting is to

Figure 3. Map showing the thrust plate relationships in the Spring Mountains (after Burchfiel and others, 1974).

shorten the width of the facies belts. Therefore, the belts appear narrower than they were at the time of their formation.

Previous Work

The Bird Spring Formation was named by Hewitt (1931) for a sequence of fossiliferous limestone 762 m thick in the Bird Spring Range, 32 km south of Las Vegas. Longwell and Dunbar (1936), noted that the formation thickens northward from the type locality to 1600 m in the Spring Mountains. In 1961, Rich measured an incomplete stratigraphic section of Bird Spring Formation (over 2164 m) near Lee Canyon and subdivided the section into 5 major lithologic units. Rich (1963) subsequently published a detailed petrographic analysis of Bird Spring rocks from this same section. Many studies (Davis, 1963, 1973; Secor, 1963; Vincelette, 1964; Burchfiel, 1965; and Fleck, 1967) have focused on the structural geology of various parts of the Spring Mountains, the results of which were summarized in Burchfiel and others (1974).

Various fossils of the Bird Spring Formation have been studied by several authors. Christy (1956) studied some of the fusulinids from the lower part of the Bird Spring Formation at Lee Canyon, and Rich (1961) studied fusulinids from the Bird Spring Formation at Lee Canyon in detail. Welsh (1959) studied the biostratigraphy of the Pennsylvanian and Permian Systems in southern Nevada, and Lenhart (1975) and Gamache (1986) examined some upper Pennsylvanian and lower Permian

fusulinids near the town of Mountain Springs, in the southern Spring Mountains. Cassity and Langenheim (1966) have studied Pennsylvanian and Permian fusulinids from the Bird Spring Formation in the Arrow Canyon Range, 56 km northeast of Las Vegas.

Although Pennsylvanian-Permian stratigraphy and paleogeography of the Cordilleran miogeocline have been studied extensively in northeastern Nevada and southeastern California (Bissell, 1964, 1970; Rich, 1977; Stevens, 1965, 1977, and 1979), little work has been done on correlating the stratigraphic sequences there with the sequences in southern Nevada. Bissell (1970) showed the relationship between Permian lithofacies in eastern and southern Nevada, and Rich (1963) discussed the correlation of stratigraphic sequences between northeastern Nevada and southern Nevada. A general correlation of stratigraphic sequences was made by Barosh (1968), who compared the stratigraphic section in the Egan Range (near Ely, Nevada) with Rich's Lee Canyon section in the Spring Mountains.

Methods

Field Work

Field work was completed in seventeen days during July, 1984, May, 1985, and September, 1985. This work involved the measurement and study of stratigraphic sections, plus the collection of rock samples. The stratigraphic sections at Wheeler Wash were measured with a Jacob

Staff and compass. Stratigraphic sections at the remaining areas were measured by tape and compass. Fusulinid samples were collected for age correlation, and rock samples of major lithologies from each section were collected for petrographic analysis. Most of the section at Lee Canyon previously had been measured by Rich (1961, 1963), and his section is utilized here. The other sections were measured by the writer.

Laboratory Work

Approximately 110 thin sections of rock samples were prepared and studied by the writer. Thin section analysis helped to better define the nature (i.e., constituents, fabric, diagenesis, etc.) and classification (Dunham, 1962; Wilson, 1975;) of the various rock types. Forty thin sections of fusulinids were prepared by the writer. Well oriented fusulinids were photographed at X10 by placing the thin section in a photographic enlarger and obtaining a negative image on black and white, high-contrast paper.

STRATIGRAPHY

Introduction

This study is focused primarily on the rocks of the Pennsylvanian - Permian Bird Spring Formation, but by necessity also has involved the study of the relationships with the overlying and underlying units. The Indian Springs Formation (Mississippian), underlies the Bird Spring Formation at all localities and thus provides an excellent basal datum. Permian red beds and the Kaibab Limestone (Permian) overlie the Bird Spring Formation at the Mountain Springs Pass and Lovell Canyon areas. Because the Kaibab Limestone is the most widespread and reliable stratigraphic marker in the middle Permian in Nevada, this marker is used as the upper datum, where possible.

Studies by earlier workers (Longwell and Dunbar, 1936; Rich, 1961; Secor, 1962) defined the Bird Spring Formation as including all of the section from the top of the Monte Cristo Limestone to the base of the overlying red beds. Since then, a 30-m-thick sequence of quartzite with minor limestone at the base of the section has been separated as the Indian Springs Formation. Gordon and Poole (1968) used brachiopods and ammonoids to show that the sharp break in lithology coincides with a discontinuity that separates Mississippian and Pennsylvanian rocks, and that the Indian Springs Formation represents late Mississippian deposition. Thus, the base of the Bird Spring Formation is now placed immediately above the highest occurrence of quartzite or another

siliclastic bed, and below the cherty limestone beds of the Bird Spring Formation.

Description of Stratigraphic Sections

A detailed description of the stratigraphic sections that were measured at Lee Canyon, Wheeler Wash, Mountain Springs Pass, and Lovell Canyon is presented in Appendix 1. Photographs of some of the fusulinids in the Bird Spring Formation is shown in Appendix 2, and Appendix 3 lists the petrographic analysis of the rock samples collected from the Bird Spring Formation.

Lee Canyon Composite Section

A section of the Bird Spring Formation in which the uppermost part is missing is exposed in the vicinity of Lee Canyon. Rich (1961, 1963) examined and described more than 2164 m (7100 ft) of this sequence. During subsequent reconnaissance and examination of Rich's section, an additional 221 m (726 ft) of section was discovered by the writer (see Appendix 1). This additional section is several hundred meters west of Rich's line of traverse and is isolated in a down-dropped fault block (fig. 4). Its stratigraphic position relative to Rich's section is not known precisely; however, fusulinids from a limestone bed in the fault block indicate that these rocks are younger than any rocks previously described by Rich (1961, 1963). Exactly how much section is missing between the two stratigraphic sections is unknown. In addition,

Figure 4. Location of measured sections in the Lee Canyon area. Geologic map taken, in part, from Burchfiel and others (1974). The arrow points to the top of the sections.

the top of the Bird Spring Formation is not exposed. This partial section of more than 2385 m (7826 ft) of Bird Spring rocks at Lee Canyon is the thickest stratigraphic section of the Bird Spring Formation exposed anywhere in the Spring Mountains.

The section of Bird Spring near Lee Canyon (fig. 5) can be divided into 4 major lithologic units of which Rich (1961) described the lower 3. These units are here referred to as (from bottom to top) Members A, B, C, and D.

Member A. This unit, the lowest major lithologic unit of the Bird Spring Formation, consists of 965 m (3165 ft) of thick-bedded, fine-grained, fossiliferous limestone interbedded with silty limestone and calcareous shale (Rich, 1961). The fossiliferous limestone ranges from a bioturbated skeletal lime-wackestone to a skeletal lime-grainstone (Rich, 1963). Skeletal grains are the most abundant allochems, consisting of, in order of abundance, brachiopods, echinoderms, foraminifers, bryozoans, ostracodes, corals and sponges (Rich, 1963). Skeletal elements range from whole fossils to small, broken fragments. Detrital quartz silt and fine sand generally are present in small amounts. Rich (1963) indicated that some of the limestone occurs as boundstones or bafflestones in which Chaetetes, Komia, syringoporoid corals and rugose corals form the framework. The occurrence of fine-grained pockets of sediment between and on top of

Figure 5. Columnar section from the Lee Canyon area. Members A, B, and C represent the stratigraphic section measured by Rich (1961, 1963). Member D is a previously undiscovered section of Bird Spring Formation and is described in detail in Appendix 1. Petrographic analysis of rock sample LE-3 is provided in Table 1 in Appendix 3.

these organisms indicates that the latter acted as sediment traps. Based on the study of fusulinids, Rich (1961) showed that deposition of this unit began in the early Morrowan (earliest Pennsylvanian) and that deposition continued throughout Pennsylvanian time into early Wolfcampian (earliest Permian) time.

Member B. The type of sediment deposited changed abruptly in early Wolfcampian time with the development of the succeeding Member B (Rich, 1963) of the Bird Spring Formation. This unit consists of 747 m (2450 ft) of fine-grained skeletal limestone in which are interspersed thin zones of calcareous siltstone and bioclastic limestone.

The fine-grained limestone beds typically are black, platy, and thinly bedded. These features differentiate the limestone beds of Member B from those of Member A. In thin section, the limestone appears dark and carbonaceous, being composed of fine skeletal remains which are mostly unidentifiable. In some of the fine-grained beds, sponge spicules are the predominant recognizable fossil component. Rich (1963) suggested that the fine-grained limestone may be comparable to microcoquinas, with their constituents oriented parallel to bedding.

The bioclastic limestone in Member B contains gastropods, crinoid parts, foraminifers, algae, and bryozoans. In thin section, the bioclastic limestone appears very similar from one bed to another. Unlike the skeletal parts in the fine-grained limestone in Member A, the bioclasts in these beds appear jumbled and randomly oriented with

respect to bedding, and are much larger than their counterparts in the fine-grained limestone. Silt- to fine-sand-size quartz grains are present in the limestone beds, but the amount varies from one bed to the next. In some beds, quartz grains comprise only 2% of the total constituents, whereas in others, they comprise 20%.

The siltstone beds, which comprise as much as 25% of Member B, are yellow-brown and thinly bedded. Petrographic analysis of a calcareous siltstone reveals layers of recrystallized silty or sandy limestone which contain abundant sponge spicules (Rich, 1963). Analysis of other siltstones reveals coarser spiculiferous laminae containing medium-grained quartz silt alternating with darker, more argillaceous and carbonaceous laminae.

Local, small-scale slump structures and convolute laminae were observed by Rich (1963) within strata of Member B. Deposition of this unit, which began in early Wolfcampian time, ceased in late Wolfcampian time.

Member C. This member was deposited from late Wolfcampian to early Leonardian time based on the conformable relationship with the middle(?) Wolfcampian Member B and the occurrence of the early Leonardian fusulinid Schwagerina crassitectoria near the top of this member. Member C is approximately 457 m (1500 ft) thick and consists of thick-bedded (fig. 6), bioturbated, skeletal lime-wackestone and

Figure 6. Bird Spring limestone of Member C at Lee Canyon. Note the characteristic thick-bedded, ledge-forming manner in which the limestone is exposed. Ledges are from 3 to 12 m thick.

skeletal lime-grainstone. Calcareous siltstone and silty, bioclast-bearing limestone are abundant in this unit. The skeletal limestone of this sequence resembles the limestone of Member A in texture, composition, and fossil content. Pelletal limestone is common in the upper 76 m (250 ft) of this unit (Rich, 1963). Brown-weathering, black chert in nodules and thin seams also is abundant in Member C.

A fault truncates the top of Member C so that the top of the section is not exposed. The uppermost beds of Member C represent the youngest beds in Rich's (1961) measured section.

Member D. An additional 221 m (726 ft) of section not noted by Rich (1963) was discovered in a fault block several hundred meters to the west of Rich's line of measurement. The lower 53 m of Member D consists of medium-gray, fine-grained, skeletal limestone interbedded with light-gray, fine-grained, unfossiliferous dolomite. The limestone beds commonly contain small brachiopods, with whole fusulinids occurring in a few beds. The limestone and dolomite are very evenly bedded, occurring in beds 30 to 60 cm thick. Brown-weathering black chert commonly occurs as nodules and discontinuous seams, 1 to 10 cm thick.

The limestone and dolomite grade upwards into a 67-m-thick sequence of alternating beds of light-gray to pinkish-gray dolomite and brownish-gray siltstone. The dolomite is fine-grained, unfossiliferous, and occurs in beds 45 to 90 cm thick. Silt-size quartz grains are present in the dolomite, but the amount varies from one bed to another.

The siltstone beds, 45 to 90 cm in thickness, are unfossiliferous and commonly weather to light yellow.

The interbedded dolomite and siltstone sequence is capped by a 101-m-thick sequence of almost pure dolomite. The dolomite occurs in beds 30 to 60 cm thick and is brownish gray to light gray, fine grained, and devoid of fossils. The dolomite contains quartz silt, but the amount varies from one bed to another. Within this 101-m-thick dolomite sequence is a 7-m-thick calcareous siltstone unit and two 1-m-thick limestone beds containing small, whole gastropods. Near the top of the dolomite sequence is a 2-m-thick dolomite bed that contains small, whole brachiopods which have been silicified.

The uppermost 1 to 2 m of Member D consists of a sequence of horizontally stratified to cross-stratified dolomite that contains chert pebbles (fig. 7). The pebble-bearing dolomite is on top of a 3-m-thick sequence of thinly laminated (2- to 4-mm-thick), light-gray dolomite. The pebbles are well rounded, have smooth surfaces, range in size from 2 mm to 5 cm (fig. 8), and are aligned along bedding planes in the stratified dolomite. Most of the pebbles consist of microcrystalline chalcedony, although one large pebble was found to be composed of foraminiferal tests and other unidentifiable skeletal fragments that had been cemented together. Very little matrix was observed in this pebble,

Figure 7. Chert pebbles aligned along bedding planes of the uppermost dolomite beds in Member D at Lee Canyon. Knife is 8.5 cm long.

Figure 8. Chert pebbles of Member D at Lee Canyon. Well-rounded, smooth surfaces suggest chert was transported a long distance or reworked for some time. Knife is 8.5 cm long.

and the pebble is completely replaced by silica. The transition between the two sequences is abrupt as the thinly laminated dolomite is completely devoid of pebbles. Petrographic analysis of the pebble-bearing dolomite (see Appendix 3, LE-3) revealed numerous small pisoliths of uniform size in the matrix between the pebbles in one rock sample (fig. 9). The pebble-bearing dolomite is mostly unfossiliferous, although rare, silicified crinoid stems, one silicified cast of a crinoid stem, and one coral of probable late Paleozoic age (Stevens, 1986, personal commun.) were observed among the chert clasts.

A limestone bed containing the fusulinid Parafusulina apiculata? occurs near the middle of Member D. Parafusulina apiculata? is shown in Appendix 2. Parafusulina apiculata? is middle Leonardian and is younger than the youngest fusulinid in Rich's measured section. Therefore, the newly discovered section is younger than Rich's (1961) section. The contact between Members C and D is not exposed and how much section is missing between C and D is unknown.

Wheeler Wash Composite Section

The Wheeler Wash section is composed of a northern subsection and a southern subsection. The location of both subsections is shown in Figure 10. The two subsections are separated by an alluvium-covered wash. The southern section (fig. 10) consists of lower Bird Spring rocks that range in age from Virgilian (late Pennsylvanian) to earliest

Figure 9. Pisoliths from the chert-pebble-bearing dolomite bed of Member D at Lee Canyon. Pisoliths are photographed in plane light. Field of view is 1.25 mm wide.

Figure 10. Location of measured sections in the Wheeler Wash area. Geologic map taken in part, from Burchfiel and others (1974). The arrow points towards the top of the section.

Wolfcampian (fig. 11). The base of the Bird Spring section here is covered by Quaternary alluvium; younger strata also are covered by alluvium. The northern section contains upper Bird Spring strata that range in age from late Wolfcampian to early Leonardian. As is the case at the southern section, both the top and bottom of this section are covered by alluvium. The orientation of the rocks suggests that the two sections represent different parts of the same stratigraphic sequence with the middle of the Bird Spring Formation being buried beneath the alluvium. It is possible that the alluvium conceals a fault separating the two sections, but the ages and lithologies present do not necessarily imply that one is present.

Southern Section. This section consists of 305 m of massive, thick-bedded, ledge-forming, fossiliferous limestone with minor beds of silty limestone (fig. 12). Bird Spring strata of this section resemble the limestones of Member A at Lee Canyon in composition and fossil content. Petrographic analysis of 13 rock samples collected throughout the section revealed that skeletal grains represent the main allochems, consisting (in order of abundance) of echinoderms, bryozoans, foraminifera, brachiopods, corals, ostracodes, and pelecypods. The predominant rock type is a bioclastic wackestone (see Appendix 3, WW-1 through WW-13), with crinoids, bryozoans, and fusulinids comprising the major skeletal types. Fusulinid-bearing mudstone commonly is interbedded with echinoderm-bearing wackestone in this section. In some

Figure 11. Composite columnar section from the Wheeler Wash area. The southern section is Pennsylvanian and lowermost Permian. The northern section is Permian. Petrographic analyses of rock samples WW-1 through WW-28 are provided in Table 1 in Appendix 3.

Figure 12. Bird Spring Limestone of the southern section at Wheeler Wash. Note the cliff-forming manner in which the thick-bedded, limestone is exposed.

thin sections, the micritic matrix of the limestone has been altered to microspar. Individual burrows locally are discernible in thin sections of bioclastic mudstones, but for the most part, the lime mud is homogeneous with no laminae apparent. Near the top of the unit, coralline wackestones become increasingly common, with rugose corals occurring at the top of the sequence (fig. 13). A 9-m-thick sequence of light-gray dolomite containing numerous white sparry calcite stringers and veinlets occurs 177 m above the bottom of the section. Rugose and syringoporoid corals and brown-weathering, black chert are present throughout the section. The chert occurs in irregularly shaped nodules and thin seams. Detrital quartz silt is present throughout the section in small amounts (1 to 3%), and it locally comprises as much as 15% of the total components in a single bed.

Approximately 50 m above the base of the section is an echinoderm-bearing lithoclastic wackestone-packstone (WW-2 in Appendix 3). The lithoclastic wackestone-packstone is composed of almost equal amounts of micritic mud and allochems; 25% of the allochems are intraclasts (rip-up clasts); the remaining allochems consist of coated echinoderm fragments.

The southern section is late Pennsylvanian to early Permian in age based on the occurrence of the early Virgilian fusulinid Triticites muddiensis near the base of the section, and the early Wolfcampian fusulinid Thompsonella? sp. near the top of the section.

Figure 13. Horn corals in limestone bed in the southern section at Wheeler Wash.

Northern Section. This section is 401 m thick and consists of fossiliferous limestone, silty limestone, and siltstone. The limestone beds of the northern section differ from those of the southern section in that they are thinner and form a much more subdued topography (fig. 14) with fewer ledge-forming outcrops. Thin sections from 16 rock samples collected throughout the section were studied to determine the composition of the rock along with the fossil content.

The lower 76 m of the northern section consists of fine-grained, fusulinid-rich limestone and gastropod-bearing limestone. The fusulinid-rich limestone consists of peloidal wackestone which also contains fecal pellets and crinoid parts. The gastropod-bearing limestone occurs in beds 30 to 60 cm thick, and contains whole gastropods (up to 2.5 cm in diameter) along with gastropod and crinoid fragments. This sequence grades upward into 30 m of medium- to thin-bedded, dark-gray limestone interbedded with silty limestone and brown siltstone (fig. 15). The dark-gray limestone commonly contains whole fusulinids and broken echinoderm fragments in a micritic matrix. In thin section, the micrite appears to be thoroughly homogenized, probably due to reworking of the sediment by an infauna. In two thin sections, 3-mm-wide burrows filled with lime mud are discernible.

The next 159 m of section consists of thick-bedded, light-gray, fine-grained limestone and silty limestone. Analysis of thin sections indicates that these rocks range from fossil-bearing, silty mudstone to

Figure 14. Bird Spring Limestone of the northern section at Wheeler Wash.

Figure 15. Interbedded limestone and siltstone beds of the northern section at Wheeler Wash. The short, black markings on the Jacob Staff are one inch in length.

bioclastic wackestone. Among the various skeletal components preserved in the rocks are fragments of echinoderms, pelecypods, ostracodes, foraminifera, dasycladacean algae (fig. 16), and the alga, Girvanella. Girvanella occurs as discrete clumps in the matrix and as coatings on shell fragments. No single bed, however, contains all of the skeletal types; commonly, one or two of the fossil groups are absent. Small, dark peloids are abundant locally in the matrix. In some beds, the micritic matrix has been partially altered to microspar. The amount of detrital quartz silt, which varies from one bed to another, may comprise as much as 40% of the rock. The sediment is completely homogenized and laminae were not observed in any of the thin sections. This probably is due to the complete mixing of the sediment by a burrowing fauna.

The limestone grades upwards into interbedded limestone and siltstone with siltstone becoming predominant upward. The upper 47 m of the northern section consists of brown, calcareous siltstone. The siltstone weathers tan to light-yellowish orange and is composed of well sorted, detrital quartz silt and very fine quartz grains. The light-yellowish orange color of the siltstone stands out in stark contrast with the underlying gray limestone, such that the contact between the two rock types can be easily observed from a distance of more than 3 km.

The northern section is middle Wolfcampian to early Leonardian in age based on the occurrence of the middle Wolfcampian fusulinid Schwagerina eolata near the base of the section, and an early Leonardian Parafusulina? sp. near the top of the section.

Figure 16. Photomicrograph of dasycladacean algal fragments from the Northern Section at Wheeler Wash. Field of view is 1.25 mm wide.

Lovell Canyon-Mountain Springs Pass Composite Section

The composite Lovell Canyon-Mountain Springs Pass section is made up of 2 partial stratigraphic sections of Bird Spring rocks. At both localities, the Bird Spring Formation disconformably overlies the Indian Springs Formation. At Lovell Canyon, Bird Spring rocks are conformably overlain by Permian red beds, which in turn are overlain by the Kaibab Limestone. A complete stratigraphic section of Bird Spring Formation occurs in Lovell Canyon, 17.7 km north of Mountain Springs Pass, but dense foliage and a thick soil layer covering the hillsides make it impossible to examine (much less measure) pre-middle Wolfcampian Bird Spring rocks in this area. Consequently, only a partial section containing post-middle Wolfcampian rocks was measured here (fig. 17). At Mountain Springs Pass (fig. 18), Pennsylvanian and lower to middle Wolfcampian Bird Spring rocks are well exposed, but middle Wolfcampian and some of the younger rocks are covered by Quaternary alluvium. Two kilometers west of the Mountain Springs section, however, bluffs of red beds rise above the alluvium with strike and dip similar to that of the Bird Spring rocks, suggesting that the two formations form a continuous and conformable stratigraphic section beneath the alluvium. I consider the composite Lovell Canyon - Mountain Springs Pass sections to

Figure 17. Location of stratigraphic section at Lovell Canyon. The arrow points toward the top of the section.

Figure 18. Location of stratigraphic section at Mountain Springs Pass. IS = Indian Springs Formation and Monte Cristo Limestone, BS = Bird Spring Formation, QAL = Quaternary Alluvium. The map is taken, in part, from Burchfiel and others (1974).

represent an almost complete stratigraphic sequence of the Bird Spring Formation, with the Lovell Canyon section occupying a stratigraphic position above the Mountain Springs Pass section. My reasoning for this is twofold: (1) the composition and stratigraphic sequence of very distinctive rocks in the lower parts of the Lovell Canyon section bear a very close resemblance to that of the uppermost part of the Mountain Springs Pass section and, (2) the Bird Spring rocks at Lovell Canyon and Mountain Springs Pass occur in the same linear belt of late Paleozoic rocks (fig. 19). There probably is a small amount of section missing between the two partial sections, but exactly how much is unknown.

Pennsylvanian to middle Permian rocks of the Lovell Canyon - Mountain Springs Pass composite section can be divided into 4 major lithologic units (figs. 20, 21). These units are here referred to as (from bottom to top) Members 1, 2, 3, and 4. Members 1, 2, and 3 are composed of the Bird Spring Formation whereas Member 4 is the lower part of the Permian red beds.

Member 1: Mountain Springs Pass. The partial section of Bird Spring rocks exposed at Mountain Springs Pass is approximately 737 m thick. Member 1 is the lowest major lithologic unit, comprising the lower 633 m of the section (fig. 20).

Member 1 consists of predominantly medium- to thick-bedded fossiliferous limestone with minor beds of silty limestone and

Figure 19. Geologic map of the Lovell Canyon - Mountain Springs Pass area (from Burchfiel and others, 1974) showing spatial relationship of the measured sections in this area.

Figure 20. Columnar section of Bird Spring strata in the Mountain Springs Pass area. Petrographic analysis of rock samples MS-1 through MS-16 is provided in Table 3 in Appendix 3.

Figure 21. Columnar section of Bird Spring Formation and Permian red beds in Lovell Canyon. Petrographic analysis of rock samples LO-1 through LO-9 are provided in Table 2 in Appendix 3.

calcareous siltstone. This sequence overlies brown quartzite beds of the Indian Springs Formation. Limestone beds of Member 1 are evenly bedded, exhibiting a consistent thickness of 1 to 2 m. The limestone ranges from bioclastic wackestone, to crinoidal wackestone, to whole-fusulinid wackestone. Some of the bioclastic wackestones are characterized by abundant brachiopod spines and echinoid spines. Micrite is the major component in these rocks. In many cases, the lime mud has been partially altered to microspar. Sparite is a relatively minor constituent in these rocks, occurring as a void-filling material in the skeletal grains. The sediment is completely homogenized and laminae were not observed in any of the thin sections. This probably is the result of complete reworking of the sediment by a burrowing fauna.

Skeletal grains are the most abundant allochems, consisting (in order of abundance) of echinoderms, bryozoans, fusulinids and other foraminifera, brachiopods, and ostracodes. The quantity of skeletal grains in the limestones is highly variable, ranging from a low of 10% to a high of 40%. No single bed, however, contains all of the skeletal types, with one or two of the fossil groups being absent. Preservation of the skeletal elements ranges from whole fossils to small broken fragments. In addition to skeletal grains, small peloids or micritic intraclasts are common in some limestone beds.

Detrital quartz silt and very fine sand are present in the limestone, but the amount is small (approximately 1-2%). Silty

limestone and calcareous siltstone beds occur infrequently and generally are fossil-poor. The siltstone occurs in beds 30 to 60 cm thick. Dark-brown chert commonly occurs as irregularly shaped nodules and as discontinuous stringers and seams.

The lime mudstone and bioclastic wackestone in this sequence resemble those of Member A (at Lee Canyon) in composition, texture, and fossil content. Member 1 strata differ from those of Member A at Lee Canyon in that Member 1 limestones are more evenly-bedded and do not crop out in a ledge-forming manner as do the Member A Bird Spring limestones. Studies of fusulinids by Lenhart (1975) and the writer indicate that this member was deposited from early Morrowan (earliest Pennsylvanian) to Wolfcampian (early Permian) time.

Member 2: Mountain Springs Pass. Member 2 is shown on two stratigraphic columns-the Mountain Springs Pass and the Lovell Canyon columns (figs. 20, 21). The type of sediment deposited changed gradually during Wolfcampian time; thus, Member 2 of the Bird Spring Formation consists of interbedded siltstone and dolomite, with minor limestone. This sequence at Mountain Springs Pass is 104 m thick and overlain by alluvium (fig. 20).

Member 2 consists of interbedded limestone and siltstone, with fewer beds of dolomite. Figure 22 is a photograph of Member 2 at Mountain Springs Pass. Some limestone beds are fossiliferous whereas

Figure 22. Bird Spring siltstone, dolomite, and limestone at Mountain Springs Pass. View is to the north, towards Lovell Canyon.

other beds are devoid of fossils. Analysis of one limestone bed showed the limestone to be a fusulinid wackestone-packstone, and another bed was found to be a fusulinid-bearing brachiopodal wackestone. Micrite is the major constituent in these limestones (60 - 65%), but it occurs in lesser quantities than in the wackestones of Member 1. The spar cement occurs as a void-filling material between the skeletal grains. No laminae or bedding is observed in thin section, indicating complete reworking of the sediment, presumably by a burrowing fauna.

Member 2 is distinguished from the underlying Member 1 by the occurrence of dolomite beds in Member 2. In thin section, the dolomite appears as microspar. Three dolomite sequences in Member 2 contain common, distinctive, white, irregularly-shaped nodules up to 2.5 cm long (fig. 23, 24). Petrographic analysis reveals that these nodules are composed of a combination of zebraic chalcedony; randomly fibrous, microcrystalline quartz; and mosaics of megaquartz crystals. Many of the megaquartz crystals are optically length-slow. All of these features have been interpreted by Folk and Pittman (1971) and Milliken (1979) to represent former evaporite nodules (e.g., gypsum, anhydrite) that formed in situ and were subsequently replaced by silica. Evaporite nodules replaced by silica were referred to as quartzine nodules by Folk and Pittman (1971) and Milliken (1979). The siltstone and dolomite beds generally are unfossiliferous, although in a few quartzine-free dolomite beds, large echinoid spines (up to 5 cm long) were observed, and one

Figure 23. Outcrop view of white, quartzine nodules in light-gray dolomite of Member 2 at Mountain Springs Pass.

Figure 24. Polished surface of dolomite specimen. White nodules are composed of length-slow chalcedony, zebraic chalcedony, and other features indicating replacement of authigenic gypsum nodules by silica. The dolomite is from Member 2 at Mountain Springs Pass.

siltstone bed was observed in which trails (ichnofossils) are common. Dense, irregularly-shaped, black chert nodules occur in many of the beds of dolomite.

Quartz silt is present in the dolomite beds in varying quantities. Most of the dolomite beds contain small amounts of silt (less than 1%), although in one bed, as much as 10% of the total rock was composed of quartz-silt grains.

Near the top of the sequence, two thin beds of very fossiliferous limestone occur. These beds consist of a bioclastic wackestone and a crinoid packstone-grainstone. The wackestone is composed predominantly of micrite, with echinoderms, fusulinids, and lesser amounts of bryozoans. This bed contains the fusulinid Paraschwagerina. The crinoid packstone-grainstone contains large quantities (35 - 40%) of skeletal grains (crinoid and other echinoderm fragments, and fusulinids and other benthic foraminifera), with sparry calcite filling the void space between the skeletal grains. This bed contains the fusulinids Schwagerina aculeata? and Paraschwagerina (see Appendix 2), indicating a middle Wolfcampian age (Stevens, 1985, personal commun.). The age of the base of Member 2 is not known.

Member 2: Lovell Canyon. The partial stratigraphic section that was studied and measured at Lovell Canyon is approximately 453 m thick (fig. 21). Member 2 constitutes the lower 183 m of the section. Older Bird Spring rocks occur in the area, but they are covered by a

thick layer of soil, such that outcrops are rare or are inadequately exposed. The rocks assigned to Member 2 at Lovell Canyon, which consist of interbedded dolomite and siltstone, are similar in lithology to the upper 104 m of Member 2 at Mountain Springs Pass. The dolomite beds here also contain white, quartzine nodules. Some of the dolomite beds near the top of Member 2 also contain large echinoid spines along with dense, black, chert nodules. The echinoid-bearing dolomite beds are devoid of quartzine nodules.

The interbedded dolomite and siltstone grade upward into calcareous siltstone interbedded with silty limestone beds of Member 3. The silty limestone generally is fossil-poor, although fragments of gastropods become increasingly common in the uppermost limestone beds.

Member 2 at Mountain Springs Pass and Lovell Canyon is characterized by interbedded siltstone, dolomite, and limestone. Distinctive sequences of quartzine-bearing dolomite along with echinoid-bearing dolomite occur at both localities. Because of the similarities between Member 2 at Mountain Springs Pass and Lovell Canyon, the Lovell Canyon and Mountain Springs Pass sections are considered to form a composite stratigraphic section that probably represents an almost complete section of Bird Spring Formation, despite the fact that the two localities are 16.6 km apart. Because of the absence of marker beds or fusulinids that might be common to both sections, it is unknown whether or not part of the section is missing, or if there is a repetition of beds in the combined section.

Member 3: Lovell Canyon. This unit consists of silty limestone interbedded with minor beds of siltstone that grades upwards into thick beds of fossil-poor, silty limestone. The upper part of Member 3 is characterized by an 18-m-thick sequence of reddish brown, very fine-grained sandstone, which is in turn overlain by 29 m of thick-bedded, fossil-poor limestone. Petrographic analysis of rock samples collected from this section reveals that these limestone beds consist of silty lime-mudstone and wackestone, silty pelletal-wackestone, and pelletal-packstone. Coated peloids are a major component of the rocks of Member 3 (fig. 25). Several meters above the base of Member 3 is a pelleted ostracode-rich mudstone/wackestone bed. This bed is predominantly micrite (75%) with ostracodes and fecal pellets making up the remainder of the rock (fig. 26). Spar-filled desiccation cracks occur in some non-pelletal mudstone beds. Higher in the sequence, peloids become more abundant, and the rocks are silty pelletal wackestones and packstones. The peloids occur in such quantities as to form a grain-supported rock with calcareous mud filling the void space. Quartz silt is present in the pelletal packstones, but the amount varies from bed to bed. Several beds contain 1 to 3% quartz silt, whereas other beds are composed of as much as 12% silt.

Faunal diversity of the limestone apparently increases up-section. A pelleted lime-mudstone bed near the base of Member 3 contains common ostracodes, calcispheres, and foraminifera (Tuberitina

Figure 25. Assorted peloids of varying size and composition in micrite that has been altered to microspar. The limestone is from Member 3 at Lovell Canyon. Field of view is 3.12 mm wide.

Figure 26. Photomicrograph of spar-filled ostracodes and calcispheres, and assorted peloids in micrite from Member 3 at Lovell Canyon. Field of view is 3.12 mm wide.

sp.). Farther up-section, crinoids become more abundant, and bryozoans and pelecypods occur more frequently. In a crinoid-bearing pelletal packstone bed near the top of Member 3, abundant peloids and echinoderm fragments with lesser amounts of bryozoans, pelecypods, and foraminifera, are the major constituents of this particular bed.

A silty wackestone interbedded with calcareous siltstone from the middle of the sequence was analyzed petrographically. The wackestone consisted primarily of lime mud (80%), quartz silt (15%), and sparry calcite (5%). No fossils were observed in the matrix, but faint laminae were observed in thin section. In contrast, the siltstone consists of quartz silt and sand grains (55%), micrite (25%), and micrite altered to microspar (20%). The siltstone is completely homogeneous; no laminae are present.

Approximately 47 m from the top of Member 3 is a sequence of very fine-grained sandstone beds. The sandstone is light orange to reddish brown, unfossiliferous, and consists of well-sorted quartz grains. The color of the sandstone is due, in part, to hematite-stained grains and/or hematitic cement.

Fusulinids are conspicuously absent from the strata of Member 3. Therefore, the exact age of this sequence is not known, but because Member 3 is underlain by Member 2 (middle Wolfcampian, at Mountain Springs Pass), and overlain by a very thick sequence of red beds and the Kaibab Limestone (Leonardian in age), Member 3 probably is middle to

late Wolfcampian in age. Member 3 is approximately 213 m thick, and represents the uppermost units of the Bird Spring Formation in the stratigraphic section (fig. 27).

Member 4: Lovell Canyon. Thin-bedded, platy, light-orange to reddish-brown sandstone characterizes this sequence. Petrographic analysis shows that the sandstone is very fine to fine grained, very well sorted, and unfossiliferous, consisting of hematite-stained detrital quartz sand grains that have been cemented together by silica and/or hematite. Siltstone laminae and some very fine-grained sandstone laminae commonly are stained yellow by goethite.

In Lovell Canyon, outcrops of red beds occur infrequently because much of the landscape is covered by red-brown sandstone talus and soil. The hematite staining is so pervasive that, as the sandstone weathers, it imparts a reddish color to the soil. It should be noted, however, that on those hillsides that are covered by talus and soil and where outcrops are nonexistent, the only rock type observed was reddish brown quartzose sandstone in rust-colored sandy-silty soil. No limestone or dolomite float was observed in the talus. Sedimentary structures such as cross-bedding and horizontal laminae (fig. 28),

Figure 27. A view of the contact between upper Bird Spring siltstones and dolomites (gray), and the overlying reddish sandstones of the Permian red beds in Lovell Canyon. Light-gray ridge in the background is composed of Kaibab Limestone (Leonardian). The view is toward the north.

Figure 28. Sedimentary structures in Permian red beds at Lovell Canyon. Horizontal laminae and cross-bedding are preserved in hematite-stained quartzose sandstone. Scale is in inches and centimeters.

small-scale wedge-planar cross-laminae (fig. 29), and small-scale trough-cross-bedding along with bimodally-dipping ripple sets commonly occur in the sandstone. Flaser and lenticular bedding, and two beds with silt-filled desiccation cracks also occur in rocks of Member 4.

The rocks of Member 4 belong to the Permian red bed unit rather than to the Bird Spring Formation; the contact between the two formations is placed at the top of the highest limestone bed in the stratigraphic section.

Figure 29. Wedge-planar cross-laminae preserved in quartzose sandstone of Member 4 at Lovell Canyon. Scale is in inches and centimeters.

ENVIRONMENTS OF DEPOSITION

The rocks in the area of this study record environments ranging from basinal through open shelf and marginal marine to supratidal. Most of the units studied were deposited on the shelf. Wilson (1975) and Wilson and Jordan (1983) discussed in detail the factors that influence deposition on carbonate shelves and listed various sedimentological patterns that are characteristic of carbonate shelves. Wilson defined 9 different depositional settings (numbered 1 through 9) which may occur across a shelf which he referred to as "Standard Facies Belts." Wilson further defined 24 different "Standard Microfacies" (referred to as SMF-1 through SMF-24), each of which is characterized by a specific set of sedimentary textures, components, and fossil assemblages. In interpreting the environmental conditions in which the Bird Spring sediments were deposited, analogies are made, whenever possible, to Wilson's Standard Microfacies and Standard Facies Belts.

Environmental Interpretation of the Lee Canyon Section

Member A

The bioclastic wackestones, packstones, and grainstones that comprise Member A are interpreted to have formed in shallow-water environments such as open shelves, lagoons, and bays. At times, warm, shallow, open waters prevailed in which Chaetetes, Komia, and syringoporoid and large horn corals proliferated (Rich, 1963). Rich (1963) concluded that the water was shallow because the rocks of this sequence contain "abundant calcareous algae that probably flourished at

water depths less than 25 meters." Faunal assemblage of brachiopods, echinoderms, fusulinids and other foraminifera, and bryozoans, dominate the sediment of this sequence and point to well-oxygenated, marine waters of normal salinity. This is in accord with Stevens (1969) who showed that fusulinids required minimum water depths of approximately 13 m in order to thrive.

Times when agitated waters with persistent currents or waves were prevalent alternated with times of reduced current or wave activity. Spar-cemented, bioclastic grainstones point to times of scour by waves and currents. The coralline boundstones of Rich (1963) may be patch reefs that populated the outer fringes of the carbonate platform, and the grainstones may represent winnowed skeletal sands (Standard Facies Belts 5 and 6, respectively). At other times, reduced current activity allowed impure carbonate mud to accumulate, resulting in the formation of bioclastic wackestone. Episodic influxes of terrigenous silt and clay resulted in the formation of calcareous siltstone and shale.

Member B

An abrupt change to fine-grained, thin-bedded, dark limestone and siltstone signifies a change in environmental conditions. Rocks of this interval are interpreted to have formed in a basinal setting where the waters were relatively deep and quiet. Restricted water circulation resulted in anaerobic conditions, such that fine-grained beds containing

carbonaceous matter and sulphides accumulated (Rich, 1963). The local slump structures and convolute laminae observed by Rich (1963) probably were caused by downslope movement of unstable, water-saturated sediment. Although no graded bedding was observed, the fossil-rich limestone is believed to have been transported downslope via sediment-gravity flows (e.g., turbidity currents, debris flows) on the foreslope of the shelf margin because all fossils occur in very thin, continuous beds, and the beds are composed almost exclusively of fossils.

Member C

A gradual return to warm, shallow-water, open-shelf environments is recorded in the rocks of this member. Limestone that formed in these environments consists of bioturbated, bioclastic wackestones, packstones, and grainstones. Fusulinids, gastropods, echinoderms, corals, and algae become increasingly abundant. The varying amounts of calcareous mud in the limestones suggest variable current or wave action, perhaps close to wave base. The faunal communities were occasionally overwhelmed by an influx of calcareous mud (Rich, 1963), and at other times, waves and currents winnowed away fine material, leaving the coarse, skeletal grains behind.

Fecal pellets and other peloids become increasingly abundant at the top of the member, suggesting shoaling of marine waters. The peloids were derived from organic pelleting of the mud and generally are preserved in quiet, low-energy marine environments where water movement

is very slight. According to Wilson (1975), peloids are a common feature of deposits that form on tidal flats and natural levees, and in very restricted lagoons, bays and ponds. The peloidal limestones of Member C are interpreted to have formed in similar environmental settings.

Member D

This unit is interpreted to have formed in subtidal to hypersaline tidal-flat settings that evolved into a supratidal environment with hypersaline ponds. This interpretation is based on the characteristics of the individual beds of the stratigraphic sequence, which consist of interbedded limestone and dolomite that grade upwards into interbedded dolomite and siltstone.

The lower interbedded skeletal limestone and unfossiliferous dolomite sequence reflects periods when water depths fluctuated, resulting in deposition of sediment in shallow-water, open-marine environments to hypersaline tidal-flat and supratidal environments. The occurrence of fusulinids in at least two limestone beds points to times when open circulation prevailed and the water probably was a few tens of meters deep. During periods of low water, poor circulation coupled with intensive evaporation of intertidal waters in the arid climate resulted in high salinities that were conducive to dolomitization of the calcareous sediments.

The interbedded nature of the dolomite and siltstone that forms the upper half of this member indicates that the physicochemical conditions that favored the formation of dolomite were enhanced through progradation of coastal sediments. Quartz silt occasionally blanketed the intertidal areas.

The dolomite that forms the uppermost bed in Member D contains chert pebbles (fig. 7) along with pisoliths between the chert clasts (fig. 9). The chert pebbles are well-rounded, have smooth surfaces, and are arranged along bedding planes in the cross-bedded dolomite. The chert pebbles probably were transported by fluvial processes and deposited in environments where current action was strong.

Environmental Interpretation of the Wheeler Wash Sections

Southern Section

The bioclastic mudstone, wackestone, and packstone that comprise the Bird Spring Formation in the southern section at Wheeler Wash are interpreted to have formed in a shallow-water environment where open circulation prevailed, such as the middle to inner shelf. Faunal assemblages of echinoderms, bryozoans, fusulinids, brachiopods, horn corals and syringoporoid corals are important components in the rocks of this sequence, indicating the presence of well-oxygenated, marine waters of normal salinity.

The prominent occurrence of calcareous mud in the limestones indicates that deposition occurred primarily below wave base, where lack of agitation allowed the fine-grained material to accumulate. The fusulinid-bearing mudstones (Wilson, 1975) indicate that at times, water was a few tens of meters deep. Bioclasts in the mudstones and wackestones range from whole fossils (e.g., fusulinids) to small fragments of many organisms. The bioclastic wackestone in this section is similar to Wilson's SMF-9 in texture and composition.

At times, the waters were agitated and perhaps shallower as indicated by the occurrence of an echinoderm-bearing lithoclastic wackestone-packstone and a thin bed of dolomite. The rip-up clasts and coated echinoderm fragments suggest that deposition occurred above wave base where agitated waters resulted in fragmentation, abrasion, and formation of a micritic coating on the skeletal grains. A thin (0.6 m) bed of dolomite occurs approximately 80 m above the base of the section. The dolomite bed is distinctive because it contains continuous, wavy laminae of white, sparry calcite. The laminae may represent algal laminations; with the exception of the wavy laminae, however, dolomitization has destroyed all original features in this bed.

Localized areas of coralline wackestone become increasingly common towards the top of the section. The coralline limestone contains horn corals and syringoporoid corals that are filled with sparry calcite and cemented with a mixture of lime mud and sparry calcite.

Northern Section

The lower half of the Bird Spring Formation at this location is composed of unfossiliferous limestone, bioclastic wackestone and peloidal wackestone-packstone that are interpreted to have formed in shallow-water environments on an open shelf. Faunal assemblages of fusulinids, crinoids, bryozoans, pelecypods, and brachiopods flourished, pointing to well-oxygenated marine waters of normal salinity. The micritic mud is completely homogenized, thoroughly reworked by burrowing organisms. Fusulinid and pelecypodal wackestone-packstones commonly contain peloids suggesting that these sediments formed in places of very slight water movement, probably at water depths of a few tens of meters. At times, the faunal communities were overwhelmed by an influx of calcareous mud.

Quartz silt becomes increasingly common in the lime-mudstones and bioclastic wackestones up-section. Petrographic analysis of a bioclastic wackestone (from a sequence of interbedded silty limestone and bioclastic wackestone) reveals the presence of peloids, dasycladacean algae (fig. 16), and the alga Girvanella, pointing towards decreasing water depths.

Gradual shoaling of marine waters continued because the section is capped by sequences of interbedded calcareous siltstone and silty limestone. The interbedded relationship between the siltstones and limestones indicates that the area was occasionally blanketed by

terrigenous quartz silt, probably as water depths decreased. The siltstone is unfossiliferous, and the silty limestone is devoid of fossils. The unfossiliferous nature of the siltstone reflects the inhospitable nature of the shifting silt.

Environmental Interpretation of the Lovell Canyon-Mountain Springs Pass Composite Section

Based on the occurrence of distinctive lithological sequences of Bird Spring Formation at Lovell Canyon and Mountain Springs Pass, this composite section is divided into 4 members. Member 1 (the oldest) and the lower part of Member 2 are located at Mountain Springs Pass. The upper part of Member 2 along with Members 3 and 4 are located in Lovell Canyon.

Member 1

The bioclastic wackestone, silty limestone and calcareous siltstone that comprise this member of the Bird Spring Formation are interpreted to have formed in shallow-water environments such as on an open shelf, in shallow lagoons or bays, or in areas adjacent to tidal deltas. The lower part of the section consists of interbedded unfossiliferous limestone and siltstone. The interbedded nature of the limestone and siltstone suggests that water was fairly shallow and that the area was occasionally blanketed by terrigenous quartz silt. These sediments probably formed at or just below wave base where the

environment was not hospitable to marine life because of the shifting sediment.

The interbedded limestone and siltstone grades up-section into beds of fossiliferous limestone (bioclastic wackestone) with minor beds of calcareous siltstone. Thorough homogenization of the lime mud by burrowing organisms, along with the occurrence of echinoderms, brachiopods, bryozoans, fusulinids and other foraminifera point to times of well-oxygenated waters of normal salinity on an open shelf. The abundance of calcareous mud in the limestone beds indicates that deposition occurred in quiet waters below wave base, or in protected areas of slight water movement, where the fine-grained material could accumulate.

The bioclastic wackestone of this member is similar in texture and composition to Wilson's (1975) Whole fossil wackestone (SMF-8) and Bioclastic wackestone (SMF-9). Wilson considers these microfacies to be characteristic of shelf facies or open marine platform facies where water was a few tens of meters deep, or deep enough to be below wave base. They were, however, shallow enough so that the bottom sediment was affected by intermittent storms.

Member 2

The siltstone, dolomite, and limestone beds that characterize this member of the Bird Spring Formation are interpreted to have formed in environments ranging from shallow-water, open-shelf to restricted,

hypersaline intertidal-supratidal settings. The contact between Member 1 and Member 2 is marked by a change from fossiliferous limestone (bioclastic wackestone) of Member 1 to siltstone and dolomite of Member 2, indicating decreasing water depths. Although the siltstone is unfossiliferous, possible ichnofossils (worm trails) were observed in one siltstone bed.

Unfossiliferous dolomite beds at Mountain Springs Pass and Lovell Canyon contain white quartzine nodules similar to those that have been shown by Folk and Pittman (1971) and Milliken (1979) to represent former gypsum nodules that formed in situ and subsequently were replaced by chalcedony. Widespread occurrences of unfossiliferous dolomite containing silicified gypsum nodules indicate that deposition occurred in hypersaline waters where salinity levels exceeded (1) the tolerance levels of even the most euryhaline organisms, (2) levels necessary for gypsum precipitation, and (3) levels at which the geochemistry of the waters favored dolomitization of the underlying sediment. The quartzine-bearing dolomite beds probably represent sediment that formed in a supratidal-flat environment.

Member 3

A trend towards increasing water depths is recorded in the rocks of Member 3. These rocks are interpreted to have formed on intertidal flats that gradually deepened to shallow lagoons and bays. The base of this member is composed of numerous beds of thinly-laminated, pelleted

mudstone. Abundant fecal pellets in calcareous mudstone indicate that deposition occurred in a shallow-water environment where water movement was slight. Spar-filled desiccation cracks are common, indicating that the sediment occasionally was subjected to subaerial exposure. Low faunal diversity is a common feature, although ostracodes, calcispheres, and foraminifers (e.g., Tuberitina sp.) are locally abundant (fig. 26). The occurrence of a locally abundant euryhaline fauna (e.g., ostracodes) and the general paucity of stenohaline fossils indicate that the waters were of highly variable salinity. Salinity levels ranged from hypersaline to normal marine to possibly brackish. All of these features combined suggest deposition on intertidal flats, shallow cut-off ponds, and very shallow lagoons with restricted circulation.

A trend towards increasing water depths and moderate circulation is indicated by the occurrence of increasingly common pelletal wackestones and packstones that grade upward into bioclastic pelletal limestones. The increase in pellets suggests increasing biological activity, perhaps the result of the introduction of oxygenated, normal-marine waters associated with increased water circulation. Limestone beds near the top of the member are rich in an open-marine fauna such as echinoderms, bryozoans, and pelecypods. Ostracodes also are present, but occur in quantities that are insignificant when compared with the other faunal groups. The occurrence of stenohaline fossils along with abundant pellets and calcareous mud indicates that deposition probably

occurred in shallow-water lagoons and bays where moderate water circulation prevailed. Fusulinids are missing from this sequence suggesting a very shallow-water environment (Stevens, 1969).

Member 4

The rocks of this member are interpreted to have formed in very shallow-marine waters, fluctuating between tidal-flat environments and subaqueous environments dominated by persistent currents. Rocks of this sequence consist of hematite-stained, argillaceous siltstones and very-fine-grained, argillaceous sandstones. The well-sorted, relatively pure quartzose sandstones and siltstones may represent tidal flat deposits. The high degree to which the red beds are stained by hematite suggests that post-depositional conditions were oxidizing. Sedimentary structures such as cross-bedding, horizontal laminae, small-scale wedge-planar cross-laminae, and small-scale trough-cross-bedding indicate that currents persistently swept across the sandy bottom. Flaser and lenticular bedding, and silt-filled shrinkage cracks point to times when deposition occurred in tidal flat environments.

CORRELATION OF STRATIGRAPHIC SECTIONS

Fusulinids were utilized to establish the relative ages of the rocks in each stratigraphic section for the purpose of correlating the sections. The writer collected and examined fusulinids from: Member D at Lee Canyon, both Wheeler Wash sections, and the Permian and uppermost Pennsylvanian rocks at Mountain Springs Pass. Appendix 2 contains photographs of some of the fusulinids collected during the course of this study. Rich (1961) studied fusulinids from Members A, B, and C of the Lee Canyon section; Lenhart (1975) and Gamache (1986) studied the fusulinids at Mountain Springs Pass. Correlations involving the Lee Canyon and Mountain Springs Pass stratigraphic sections were aided by their data.

Rich (1961) showed that the stratigraphic section of the Bird Spring Formation at Lee Canyon was deposited throughout the Pennsylvanian and into early middle Permian (Leonardian) time. The time boundaries shown in Figure 5, from early Pennsylvanian through early Leonardian time, are based on his work. The uppermost beds of the Bird Spring Formation that Rich (1961) encountered were early Leonardian, based on the occurrence of the fusulinid Schwagerina crassitectoria in Member C. Limestone beds in the newly discovered section of Member D contain the fusulinid Parafusulina apiculata? which is younger than S. crassitectoria (Stevens, 1985, personal communication).

At Wheeler Wash, the southern section is early Virgilian to early Wolfcampian in age (fig. 11). A limestone bed 88 m above the base of the section contains the fusulinid Triticites muddiensis, which was

shown by Cassity and Langenheim (1966) to be early Virgilian. A limestone bed 247 m above the base of the section contains Triticites sp., and 20 m above this bed are species of Triticites conforming to T. coronadoensis or T. whetstonensis of Virgilian age. The fusulinid Thompsonella? sp., which is early Wolfcampian (Stevens, 1989, personal commun.), occurs at the top of the section.

The northern section at Wheeler Wash consists of Permian (Wolfcampian and Leonardian) rocks (fig. 11). The Wolfcampian fusulinid Schwagerina eolata occurs 17 m above the base of the section. Schwagerina elkoensis occurs in beds 72 m and 114 m above the base of the section. Schwagerina elkoensis was shown by Rich (1961) to be Wolfcampian in age. The long-ranging fusulinid Staffella? sp. occurs 157 m above the base of the section. Rocks containing the fusulinid Parafusulina?, a Leonardian form, occur 285 m above the base of the section. Younger rocks consist predominantly of silty limestone and calcareous siltstone, with no fusulinid-bearing rocks present. These rocks are interpreted to be Leonardian also.

The Bird Spring Formation at Mountain Springs Pass consists of Pennsylvanian through middle (?) Wolfcampian rocks (fig. 20). The Pennsylvanian (Virgilian) fusulinid (Triticites muddiensis) occurs 308 m above the base of the section. The Permian fusulinid Triticites californicus occurs 392 m above the base of the section. Triticites confertus, also considered to be a Wolfcampian species, occurs 15 m

above the beds in which I. californicus occurs. Schwagerina aculeata var. plena, along with Pseudofusulinella sp., occur 509 m above the base of the section. Stewartina uber and Schwagerina modica?, considered to be middle Wolfcampian in age (Stevens, 1986, personal commun.), occur in limestone beds 539 m and 583 m above the base of the section, respectively. The fusulinids occurring highest in the section are Schwagerina aculeata and Paraschwagerina sp., which occur 718 m above the base of the section. These also are middle Wolfcampian in age.

No fusulinids were observed in the Lovell Canyon area, possibly because environmental conditions were inimical to fusulinids. Consequently, the location of the Wolfcampian-Leonardian boundary there is not known. At Lovell Canyon, red beds conformably overlie Wolfcampian rocks of the Bird Spring Formation and are, in turn, overlain by the Leonardian Kaibab Limestone (Burchfiel and others, 1974). Because Bird Spring rocks at Lee Canyon contain fusulinids of Leonardian age, part or all of the red beds at Lovell Canyon probably are equivalent to the marginal marine dolomite and siltstone units (Member D) at Lee Canyon. The Kaibab Limestone is not present in the Lee Canyon area the section is truncated by faulting and erosion.

Figures 5, 11, 20, and 21 illustrate the sections from each locality and show the stratigraphic distribution of fusulinids collected by the writer. Fusulinid identifications were made by Calvin Stevens, San Jose State University.

LATE PALEOZOIC DEPOSITIONAL HISTORY IN THE SPRING MOUNTAINS

The Pennsylvanian to middle Permian Bird Spring Formation in the Spring Mountains records a shelf-to-basin transition along a north-trending transect from Mountain Springs Pass to Lee Canyon. This shelf-to-basin transition is characterized by gradual changes from shelf sequences with lagoonal to intertidal depositional features or with rich, benthic faunas, to basinal sequences containing a few sediment-gravity-flow deposits.

Two major depositional sequences, each beginning with a marine transgression, can be recognized in the Bird Spring Formation (fig. 30). The sequences encompass Morrowan (earliest Pennsylvanian) to early Wolfcampian (earliest Permian) time, and early Wolfcampian to early Leonardian time. Early Leonardian time is marked by the onset of a progradational episode which saw decreased water depths across the shelf.

The Wheeler Wash stratigraphic sections are not shown in Figure 30 because the sections are incomplete, and the lithofacies exposed there are similar to those of similar age at Lee Canyon. In the nearshore areas to the south, a minor progradational event occurred, probably during early Wolfcampian time.

Latest Mississippian

During latest Mississippian time, the area of study, from Mountain Springs Pass to Lee Canyon, was dominated by marginal marine

Figure 30. Generalized representation of the relationship between outer shelf and inner shelf environments during the late Paleozoic.

environments as indicated by lithologic sequences in the Indian Springs Formation. Cross-bedded quartzites interbedded with marine limestones occur in the Lee Canyon, Lovell Canyon, and Mountain Springs Pass areas, suggesting that deposition occurred in subtidal to perhaps supratidal environments.

Morrowan to Early Wolfcampian

During Morrowan (early Pennsylvanian) time, a marine transgressive event occurred (fig. 30). The Lee Canyon-Mountain Springs Pass area was covered by a shallow-water, open-shelf sea. At Lee Canyon and Mountain Springs Pass, shelf limestones of the Bird Spring Formation overlie marginal marine sediments of the Indian Springs Formation. At Lee Canyon, skeletal wackestones and packstones, and coralline boundstones attest to the presence of outer-shelf skeletal sands and patch reefs. The water probably was fairly shallow, and the shelf edge was located farther north-northwest. At times, local buildups occurred on the outer platform. At the same time, in areas now 58 km to the south, lagoonal muds were accumulating in the vicinity of Mountain Springs Pass. Intertidal and supratidal environments shifted progressively farther to the south-southeast as a result of the transgressing sea.

Shallow-water shelf environments persisted throughout Pennsylvanian time and into early Wolfcampian time. The carbonate

platform during this time probably conformed to the homoclinal ramp model of Read (1985).

Early Wolfcampian to Late Wolfcampian

Environmental conditions changed in the nearshore areas to the south during early Wolfcampian time. Deposition occurred at such a rate that coastal sediments prograded seaward. At Mountain Springs Pass and Lovell Canyon, marine limestone sequences give way to depositional sequences consisting of hypersaline intertidal-flat to supratidal-flat dolomites and siltstones (Member 2). Shallow-water, open-shelf environmental conditions prevailed offshore during this time. At Lee Canyon, early Wolfcampian marine limestone sequences remained relatively unchanged from the Pennsylvanian sequences as the shelf edge remained further north-northwest of the Lee Canyon area.

At the end of early Wolfcampian time, water depths increased across the shelf. At Lee Canyon, the thick-bedded skeletal wackestones and packstones of Member A give way to thin-bedded limestones with a few sediment-gravity-flow deposits that characterize Member B. This deeper-water facies accumulated on the drowned shelf.

In the nearshore areas, progradation ceased and the nearshore areas were inundated by the shallow sea. As the sea advanced landward, the marginal marine environments at Lovell Canyon were drowned and shallow-water marine environments, where calcareous peloidal muds

accumulated (Member 3), took their place. During this time, the shelf margin is inferred to have been in the central Spring Mountains area, between Lee Canyon and Lovell Canyon.

Late Wolfcampian

During late Wolfcampian time, water depths gradually decreased as more and more sediment accumulated. With the return to shallow-water conditions, prograding depositional sequences caused the shelf margin to shift seaward. At Lee Canyon, the deep-water limestones were blanketed by the shallow-water marine limestones of Member 3. In the nearshore areas, such as Lovell Canyon, shallow-water lagoonal muds were covered by silty and sandy, tidal-flat deposits.

Early Leonardian

During early Leonardian time, thick sequences of quartz silt and sand (Member 4) accumulated in the Lovell Canyon-Mountain Springs Pass area and prograded northward as the sea regressed (fig. 30). In the outer shelf areas, such as Lee Canyon, water depth was sufficient to allow the accumulation of shallow-water limestones, but the water became increasingly shallow.

By middle (?) Leonardian time, water depths were so shallow that the shallow-water shelf deposits at Lee Canyon gave way to intertidal and supratidal deposits of Member D. While marginal-marine siltstone

and sandstone were accumulating at Lee Canyon, sediment at Lovell Canyon and Mountain Springs Pass was being deposited in environments probably ranging from marginal marine to continental.

COMPARISON WITH PENNSYLVANIAN-PERMIAN ROCKS IN NORTHEASTERN NEVADA AND SOUTHEASTERN CALIFORNIA

The stratigraphic succession of Pennsylvanian to middle Permian units in the Spring Mountains is very similar to that in northeastern Nevada in the vicinity of Ely (fig. 31), where the shelf-margin history has been studied in greater detail. In northeastern Nevada, Pennsylvanian rocks of the Ely Limestone and the Hogan Formation (fig. 32) consist of gray, medium- to thick-bedded skeletal limestone with interbedded silty limestones and siltstones (Bissell, 1964). These rocks are very similar to Pennsylvanian rocks of Member A at Lee Canyon and Member 1 at Mountain Springs Pass. The occurrence of similar lithologies along with the presence of Chaetetes and syringoporoid corals in the Ely Limestone in the Egan Range (northeastern Nevada) led Barosh (1968) to suggest that a favorable comparison exists with Pennsylvanian rocks at Lee Canyon.

In northeastern Nevada, the base of the Permian succession is represented by the Riepe Spring Formation, a thin sequence of massive, gray to brown coralline limestone (Stevens, 1965). The corals in this unit compose part of the Thysanophyllum coral belt of Stevens (1982). Corals of this belt occur in the Egan Range (Barosh, 1968) and in the lower middle Wolfcampian Bird Spring rocks at Lee Canyon (Rich, 1963).

The Rib Hill Sandstone conformably overlies Riepe Spring rocks in northeastern Nevada, and consists mainly of light-yellow, calcareous siltstone, silty limestone, and limestone (Stevens, 1965; Barosh, 1968). West of Ely, Rib Hill rocks commonly contain beds of brown mudstone

Figure 31. Location of sites in southeastern California, northeastern Nevada, and southern Nevada.

Figure 32. Late Paleozoic stratigraphic units in southern Nevada, northeastern Nevada, and southeastern California. Stratigraphic units in southern California, and northeastern Nevada taken, in part, from Rich (1977) and Stevens (1977).

and gray, crinoidal limestone, representing a shallow basinal environment, whereas gray, micritic limestone and finely crystalline dolomite deposited in marginal marine environments occur in sections to the east (Stevens, 1965). In the Spring Mountains, Bird Spring rocks that are approximate time equivalents to the Rib Hill Sandstone exhibit similar characteristics. Offshore, at Lee Canyon, middle Wolfcampian rocks consist of interbedded siltstone and dark-gray, skeletal limestones deposited in shallow basinal environments, whereas in the Mountain Springs Pass-Lovell Canyon area, rocks of similar age are composed mainly of light-yellow siltstone, calcareous siltstone, and finely crystalline dolomite with quartzine nodules, all of which were deposited in near-shore environments.

In the western part of northeastern Nevada, west of Ely, the overlying Pequop Formation consists of biogenic, micritic limestone and crinoidal limestone, which grades upward into yellowish siltstone and fine-grained sandstone (Stevens, 1965). The Arcturus Formation to the east consists of a sequence of siltstone, fine-grained sandstone, limestone, and dolomite. Terrigenous detrital material increases in quantity towards the top of the formation, and a brackish to hypersaline fauna occurs throughout the upper part of the formation (Stevens, 1965). The time-equivalent rocks in the Spring Mountains are Member C at Lee Canyon and Member 3 at Lovell Canyon. Member 3 at Lee Canyon bears a

close resemblance to the Pequop Formation, whereas Member 3 at Lovell Canyon closely resembles the Arcturus Formation in northeastern Nevada.

The Loray Formation, which overlies the Pequop and Arcturus Formations in northeastern Nevada, consists of red and yellow siltstone and very fine-grained sandstone, argillaceous siltstone, limestone, mudstone, and gypsum (Stevens, 1965). The occurrence of euryhaline faunas and the great quantity of terrigenous detrital material in these rocks indicates that the Loray Formation was deposited in very shallow water, probably in highly saline and brackish-water bays and ponds. Time-equivalent units in the Spring Mountains are Member D at Lee Canyon and Member 4 at Lovell Canyon. These lithofacies are very similar to the coeval Loray Formation, consisting of yellow siltstone interbedded with dolomite, and limestone (Member D), and red and yellow, argillaceous siltstone and very fine-grained sandstone (Member 4). In both areas, these rocks are overlain by the Kaibab Limestone.

The vertical facies pattern of the Bird Spring Formation at Lee Canyon, Wheeler Wash, Mountain Springs Pass, and Lovell Canyon and the lateral facies changes between the Lee Canyon area and Mountain Springs Pass-Lovell Canyon area show that a series of north- to northeast-trending facies belts represented in the Cordilleran miogeocline in northeastern Nevada (Stevens, 1977, 1979) extend into the Spring Mountains.

In contrast to the similarities shared by units in northeastern Nevada and southern Nevada, Pennsylvanian and Permian units in southeastern California in the vicinity of the Inyo Mountains and Argus Range (fig. 31) exhibit facies that are completely different from those in Nevada. In the Inyo Mountains, these units are represented by the Keeler Canyon Formation and the Owens Valley Group (fig. 32). Limestone ranging from micrite to rudite is the predominant rock type in the first of these two units (Stevens, 1977), and prominent in the second (Stone and others, 1987). However, whereas the Pennsylvanian-Permian units in northeastern and southern Nevada consist of predominantly shallow-water shelf sediment, the units in southeastern California consist of deep-water basinal turbidites and coarse-grained sediment-gravity-flow deposits. In addition, Stone and Stevens (1984) have indicated that, in southeastern California, the facies belts indicate a southeasterly-trending continental margin whereas in Nevada, the belts trend southwesterly. Approximately 120 km of Cenozoic right-lateral displacement has occurred in between the Spring Mountains in southern Nevada and the Inyo-Argus Range area in eastern California (Stevens, pers commun., 1990); this shows that the two areas were relatively close to one another during the late Paleozoic.

Thus, the Pennsylvanian to middle Permian strata in the Spring Mountains can be correlated with units in northeastern Nevada on the basis of similarities in lithology, sequence, and age. This suggests

that Pennsylvanian-Permian environmental conditions on the shelf margin in southern Nevada were similar to those in northeastern Nevada, and that sedimentation was fairly uniform all along the north- to northeastward-striking shelf. This shelf, however, does not continue into southeastern California, where the rocks, vertical sequences, facies belts, and trends of facies belts differ greatly. This suggests that the typical miogeoclinal facies belts abruptly terminated against different facies belts somewhere between the Spring Mountains and the Permo-Pennsylvanian rocks exposed in the Inyo Mountains-Argus Range area west of Death Valley.

CONCLUSIONS

The Bird Spring Formation records the late Paleozoic depositional history of the Cordilleran miogeocline in southern Nevada. At Lee Canyon and Wheeler Wash, Pennsylvanian to lower Wolfcampian rocks consist of thick-bedded, skeletal lime-wackestone interbedded with silty limestone and calcareous siltstone. These rocks are represented by Member A at Lee Canyon. The skeletal fragments include brachiopods, echinoderms, bryozoans, corals, and foraminifers. Member A is interpreted to have formed in shallow-water environments, such as an open shelf, shallow lagoons or bays, or in areas adjacent to tidal deltas. The abundance of calcareous algae in the rocks of Member A led Rich (1963) to conclude that the water depth was probably less than 25 m. The early Wolfcampian rocks grade upward into black, thin-bedded, skeletal limestone and siltstone of Member B. In contrast to the skeletal components of Member A, the bioclasts in Member B are randomly oriented with respect to bedding, and small-scale slump structures and convolute laminae occur in this member. Rocks of Member B are interpreted to have formed in a basinal setting where the waters were mostly deep, quiet, and well below wave base, where local downslope movement of unstable, water-saturated sediment occurred. Member B is overlain by bioturbated, skeletal lime-wackestone and calcareous siltstone of Member C. The skeletal limestone of this member resembles the limestone of Member A in texture, composition, and fossil content. Member C is interpreted to have formed in open-marine, shallow-shelf

environments. The rocks of Member D at Lee Canyon consist of interbedded skeletal limestone, unfossiliferous dolomite and siltstone, which is capped by a thick sequence of dolomite. The uppermost bed of this member consists of horizontally stratified to cross-stratified dolomite with chert pebbles aligned along bedding planes. Member D probably formed in intertidal to hypersaline tidal-flat settings that evolved into a supratidal-flat environment.

At Mountain Springs Pass and Lovell Canyon, the Pennsylvanian to early Wolfcampian Bird Spring Formation consists of thick-bedded, bioclastic wackestone interbedded with lesser amounts of silty limestone and calcareous siltstone (Member 1). Skeletal grains consist of echinoderms, bryozoans, fusulinids, brachiopods, and ostracodes. The bioclastic wackestone represents deposits that formed on an open-marine shelf where water was a few tens of meters deep, but shallow enough so that bottom sediments were affected by intermittent storms. The interbedded nature of the limestone and siltstone also suggests that the water was fairly shallow and that the area was occasionally blanketed with terrigenous quartz silt.

At Mountain Springs Pass, the rocks of Member 1 are overlain by interbedded siltstone, dolomite, and limestone of Member 2. The rocks of Member 2 at Mountain Springs Pass and Lovell Canyon are distinctive in that certain dolomite beds contain white, cauliflower-shaped, quartzine nodules. Petrographic analysis of the nodules indicate that

they consist of length-slow chalcedony and zebraic chalcedony. These features are characteristic of authigenic evaporite nodules that have been replaced by silica. The transition from the bioclastic wackestone of Member 1 to the interbedded dolomite, siltstone, and limestone of Member 2 indicates decreasing water depths. Member 2 is interpreted to have formed in environments ranging from shallow-water, open-shelf to restricted, hypersaline intertidal-supratidal settings. The quartzine-bearing dolomite beds probably represent sediment that formed in a supratidal-flat environment. The rocks of Member 2 at Lovell Canyon grade upwards into fossil-poor, silty lime-wackestone and pelletal-wackestone of Member 3. Micrite, ostracodes, and coated peloids are major components in these rocks. Abundant fecal pellets in calcareous muds indicate that deposition of Member 3 occurred in a shallow-water environment where water movement was slight. Fecal pellets become increasingly abundant up-section, perhaps the result of increased biological activity associated with increased water circulation. Limestone beds near the top of Member 3 are rich in an open-marine fauna including bryozoans, echinoderms, and pelecypods. The rocks of Member 3 are interpreted to have formed on intertidal flats that gradually deepened to shallow lagoons and bays.

At Lovell Canyon, the transition from the rocks of Member 3 to those of Member 4 is rather abrupt, as Member 4 consists of hematite-stained, argillaceous siltstone and very-fine-grained sandstone.

Sedimentary structures such as cross-bedding, horizontal laminae, small-scale, wedge-planar cross-laminae are common features in the rocks of this member. Well-sorted, relatively pure quartzose sandstone and silt-filled shrinkage cracks along with flaser and lenticular bedding indicate deposition occurred in tidal-flat environments. The pervasive hematite staining suggests that post-depositional conditions were oxidizing. The rocks of Member 4 probably formed in very shallow-marine waters, fluctuating between tidal-flat environments and subaqueous environments dominated by persistent currents.

This study of the Bird Spring Formation has led to the identification of two major depositional sequences during Pennsylvanian to middle Permian time in the Cordilleran miogeocline in southern Nevada. Each sequence began with a marine transgression. The depositional sequences encompass Morrowan to early Wolfcampian time and early Wolfcampian to early Leonardian time. A progradational episode began in early Leonardian time resulting in decreased water depths across the shelf.

Subsidence of the shelf occurred during early Pennsylvanian time as intertidal to perhaps supratidal sediments of the Mississippian Indian Springs Formation are overlain by marine limestone of the Bird Spring Formation at Lovell Canyon-Mountain Springs Pass and Lee Canyon. The shelf edge probably was located north-northwest of Lee Canyon. Normal-marine, open-shelf environments dominated the shelf and

intertidal and supratidal coastal environments were shifted farther south-southeast as a result of the transgressing sea.

During early to middle Wolfcampian time, a minor progradation of intertidal-supratidal sediment occurred in the Lovell Canyon-Mountain Springs Pass area as marine limestone and calcareous siltstone give way to interbedded siltstone and quartzine-bearing dolomite. By the end of middle Wolfcampian time, water depths increased across the shelf. At Lee Canyon, deep-water facies accumulated on the drowned shelf as the shallow-water facies shifted farther south. Progradation ceased on the inner shelf and the nearshore areas were inundated by the sea. The marginal-marine environment, which was conducive to the formation of quartzine-bearing dolomite, was drowned and replaced by normal-marine, shallow-water environments.

A major progradation of fine-grained, clastic sediment occurred across the shelf during late Wolfcampian and early Leonardian time. As the coastal environments shifted seaward, siltstone and dolomite formed in the Lee Canyon area while very fine-grained sandstone of the Permian red beds formed at Lovell Canyon.

The Pennsylvanian to middle Permian strata in the Spring Mountains can be correlated readily with units in northeastern Nevada on the basis of similarities in lithology, sequence, and age. In contrast to the similarities shared by units in northeastern and southern Nevada, however, Pennsylvanian and Permian units in southeastern California in

the vicinity of the Inyo Mountains and Argus Range exhibit facies that are completely different from those in Nevada. Whereas the Pennsylvanian-Permian units in northeastern and southern Nevada consist of predominantly shallow-water shelf sediment, the units in southeastern California consist of deep-water basinal turbidites and coarse-grained sediment-gravity-flow deposits. This suggests that in Nevada, sedimentation was fairly uniform all along the northeastward-striking continental shelf. However, this shelf does not continue into southeastern California, where it terminates abruptly against facies belts of a different character.

REFERENCES CITED

- Barosh, P.J., 1968, Correlation of Permian and Pennsylvanian sections between Egan Range and Spring Mountains, Nevada: U.S. Geological Survey Bulletin 1254-I, p. 11-18.
- Bissell, H.J., 1964, Ely, Arcturus, and Park City Groups (Pennsylvanian-Permian) in eastern Nevada and western Utah: American Association of Petroleum Geologists Bulletin, vol. 48, p. 565-636.
- Burchfiel, B.C., Fleck, R.J., Secor, D.T., Vincelette, R.R., and Davis, G.A., 1974, Geology of the Spring Mountains, Nevada: Geological Society of America Bulletin, vol. 85, p. 1013-1022.
- Carr, M.D., 1983, Geometry and structural history of the Mesozoic thrust belt in the Goodsprings District, southern Spring Mountains, Nevada: Geological Society of America Bulletin, vol. 94, p. 1185-1198.
- Cassity, P.E., and Langenheim, R.L., Jr., 1966, Pennsylvanian and Permian fusulinids of the Bird Spring Group from Arrow Canyon, Clark County, Nevada: Journal of Paleontology, vol. 40, p. 931-968.
- Christy, R.B., 1956, Some Permian fusulinid faunas near Lee Canyon, Clark County, Nevada (Masters Thesis): Urbana, Illinois, University of Illinois, 76 p.
- Dunham, R.J., 1962, Classification of carbonate rocks according to depositional texture: American Association of Petroleum Geologists Memoir 1, p. 108-121.
- Folk, R.L., 1971, Length-slow chalcedony: a new testament for vanished evaporites: Journal of Sedimentary Petrology, vol. 41, p. 1045-1058.
- Gamache, M.T., 1986, Fusulinid biostratigraphy of the Bird Spring Formation in the Spring Mountains near Mountain Springs Pass, Clark County, Nevada (Masters Thesis): Pulman, Washington, Washington State University, 214 p.
- Gordon, M., Jr., and Poole, F.G., 1968, Mississippian- Pennsylvanian boundary in southwestern Nevada and southeastern California: Geological Society of America Memoir 110, p. 157-168.
- Hewitt, D.F., 1931, Geology and ore deposits of the Goodsprings quadrangle, Nevada: U.S. Geological Survey Professional Paper 162, 172 p.

- Lenhart, S.W., 1975, Some upper Pennsylvanian and lower Permian fusulinids from the Bird Spring Group near Mountain Springs, Clark County, Nevada (Masters Thesis): Lexington, Kentucky, University of Kentucky, 70 p.
- Milliken, K.L., 1979, The silicified evaporite syndrome - two aspects of silicification history of former evaporite nodules from southern Kentucky and northern Tennessee: *Journal of Sedimentary Petrology*, vol. 49, p. 245-256.
- Read, J.F., 1985, Carbonate platform facies models: *American Association of Petroleum Geologists Bulletin*, vol. 69, p. 1-21.
- Rich, M., 1961, Stratigraphic section and fusulinids of the Bird Spring Formation near Lee Canyon, Clark County, Nevada: *Journal of Paleontology*, vol. 35, p. 1159-1180.
- 1963, Petrographic analysis of the Bird Spring Group (Carboniferous-Permian) near Lee Canyon, Clark County, Nevada: *American Association of Petroleum Geologists Bulletin*, vol. 47, p. 1657-1681.
- 1977, Pennsylvanian paleogeographic patterns in the western United States, *in* Stewart, J.H., and others, eds., *Paleozoic Paleogeography of the Western United States*: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 1, p. 87-111.
- Secor, D.T., Jr., 1962, Geology of the central Spring Mountains, Nevada (Ph.D. Thesis): Stanford, California, Stanford University, 152 p.
- Stevens, C.H., 1965, Pre-Kaibab Permian Stratigraphy and history of Butte Basin, Nevada and Utah: *American Association of Petroleum Geologists Bulletin*, vol. 49, p. 139-156.
- 1969, Water Depth Control of fusulinid distribution: *Lethaia*, v. 2, p. 121-132.
- 1977, Permian depositional provinces and tectonics, western United States, *in* Stewart, J.H., and others, eds., *Paleozoic Paleogeography of the Western United States*: Society of Economic Paleontologist and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 1, p. 113-135.

----- 1979, Lower Permian of the central Cordilleran Miogeosyncline:
Summary: Geological Society of America Bulletin, part I,
vol. 90, p. 140-142.

----- 1982, The Early Permian Thysanophyllum coral belt: Another
clue to Permian plate-tectonic reconstructions: Geological
Society of America Bulletin, v. 93, p. 279-803.

Stone, Paul, Stevens, C.H., and Magginetti, R.T., 1987, Pennsylvanian
and Permian stratigraphy of the northern Argus Range and Darwin
Canyon areas, California: U.S. Geological Survey Bulletin 1691,
30 p.

Vincelette, R.R., 1964, Structural Geology of the Mt. Stirling
Quadrangle, Nevada, and related scale model experiments
(Ph.D. Thesis): Stanford, California, Stanford University,
141 p.

Wilson, J.L., 1975, Carbonate facies in geologic history:
New York, Springer-Verlag Publisher, 471 p.

----- and Jordan, C., 1983, Middle shelf, in Scholle, P.A., and
others, eds., Carbonate Depositional Environments: American
Association of Petroleum Geologists Memoir 33, p. 298-343.

APPENDIX 1: DESCRIPTION OF MEASURED SECTIONS

The following are detailed descriptions of the stratigraphic sections at Lee Canyon, Wheeler Wash, Lovell Canyon and Mountain Springs Pass. The lower 2164 meters of section at Lee Canyon, described by Rich (1961), is not repeated here. The description of stratigraphy at Lee Canyon listed here is that of the newly discovered section (Member D).

Lee Canyon Section

Lee Canyon section measured from SE 1/4 NW 1/4 of section 20, T. 17 S., R. 57 E., Charleston Peak 15-minute quadrangle, Clark County, Nevada.

Top of section: upper part of Bird Spring Formation has been eroded.

	Thickness (m)
26. Dolomite, light-gray, thinly-laminated to thin-bedded, horizontally-laminated to cross-bedded; well-rounded chert pebbles aligned along bedding planes, chert pebbles up to 5 cm diameter; unfossiliferous except for rare crinoid stems and corals in silicified clasts	1
25. Dolomite, light-gray, thinly-laminated (2-4 mm), fine-grained, unfossiliferous	3
24. Dolomite, medium- to dark-gray, fine-grained, unfossiliferous	9
23. Siltstone, light-yellow-brown to tan, fine-grained, unfossiliferous; may be slightly calcareous	7
22. Dolomite, dark-gray to brown, weathers light-gray, fine-grained, unfossiliferous	4
21. Limestone, medium-gray, weathers light-gray, fine-grained; commonly contains small, whole gastropods	1

	Thickness (m)
20. Dolomite, dark-gray, weathers light-gray, fine-grained, unfossiliferous; locally contains discontinuous seams or lenses (4-10 cm thick) of gray chert	25
19. Limestone, medium-gray, weathers light-gray, fine-grained; contains small patches or zones of small, whole gastropods	1
18. Dolomite, silty, medium-gray, fine-grained, in beds 30-60 cm thick; contains chert in thin, discontinuous seams	22
17. Dolomite, silty, medium-gray, fine-grained, in beds 60 cm thick; interbedded with siltstone, dark-brown, weathers light-brown, in beds 30 cm thick, calcareous	18
16. Dolomite, dark-brown, weathers medium-gray, fine-grained; more calcareous than previous dolomites; contains gray chert in nodules and seams	9
15. Dolomite, brownish-gray, fine-grained, unfossiliferous	8
14. Dolomite, brownish-gray, weathers light-gray, fine-grained; contains patches or zones of small, whole brachiopods; brachiopods may be replaced by silica	2
13. Dolomite, brownish-gray, weathers light-gray, fine-grained, unfossiliferous, occurs in beds 30 to 60 cm thick; contains chert in nodules and thin seams	11
12. Siltstone, brownish-gray, calcareous, argillaceous, unfossiliferous; occurs in beds 45 to 80 cm thick	5
11. Dolomite, silty, dark-gray, weathers light-gray in beds 45 to 90 cm thick, contains chert in seams (8 cm thick)	9

	Thickness (m)
10. Siltstone, brownish-gray, calcareous, occurs in beds 30 to 60 cm thick	8
9. Dolomite, light-gray to pinkish gray, fine-grained, unfossiliferous	8
8. Dolomite, medium-gray, weathers light-gray, fine-grained, in beds 0.5 to 1.5 m thick; contains chert seams (1-4 cm thick); interbedded with siltstone, brownish-gray, calcareous, in beds 30 to 60 cm thick	10
7. Siltstone, brownish-gray, weathers light-yellow, unfossiliferous	3
6. Dolomite, light-gray, fine-grained, unfossiliferous; interbedded with siltstone, calcareous, gray to brown, weathers light-yellow, in beds 60 cm thick	4
5. Dolomite, light-gray to buff, fine-grained, unfossiliferous, in beds 30 to 60 cm thick	6
4. Limestone, medium-gray, weathers light-gray, fine-grained, in beds 30 cm thick; locally contains brachiopods; contains chert in thin (1-5 cm thick), discontinuous seams	3
3. Limestone, medium-gray, weathers light-gray, fine-grained; fusulinids common	2
2. Limestone, light- to medium-gray, fine-grained, in beds 30 to 45 cm thick; brachiopods common	5
1. Limestone, medium-gray, fine-grained; fusulinids common in a few beds; interbedded with dolomite, tan to light-gray, fine-grained, unfossiliferous, in beds 30 to 60 cm thick; contains brown-weathering, black chert in nodules and discontinuous seams 1 to 10 cm thick	37

	Thickness (m)
Partial thickness of Bird Spring Member D at Lee Canyon	221
Base of section: truncated by fault.	

Wheeler Wash, Southern Section

Section measured in NW 1/4, NE 1/4, Section 36, T. 19 S., R. 54 E., Mt. Stirling 15-minute quadrangle, Clark County, Nevada.

Top of section: Bird Spring Formation truncated by erosion.

	Thickness (m)
16. Limestone, dark-gray, weathers to mottled light-gray, fine-grained, in beds 1 to 3 m thick; fusulinids common, patches of syringoporoid corals and horn corals common	17
15. Limestone, gray, fine-grained, unfossiliferous, in beds 1 to 1.3 m thick; interbedded with limestone, brown; fusulinids abundant	17
14. Limestone, dark-brown, weathers tan, fine- to medium-grained; fusulinids common	5
13. Limestone, medium-gray, fine-grained, massive; contains small patches or zones of syringoporoid corals and horn corals; few beds silty locally	29
12. Limestone, medium- to dark-gray, fine-grained, in beds 60 cm thick; crinoids common, brachiopods sparse, syringoporoid corals sparse .	5
11. Limestone, light-gray, fine-grained, in beds 1 m thick; fusulinids common, bryozoans sparse, horn corals sparse	24
10. Dolomite, light-gray to brown, fine-grained, unfossiliferous; cut by numerous calcite veinlets	9

	Thickness (m)
9. Limestone, light- to medium-gray, massive, fine-grained, unfossiliferous	44
8. Limestone, medium-gray, thick-bedded; horn corals sparse, syringoporoid corals sparse, brachiopods sparse	17
7. Limestone, medium-gray, fine-grained, unfossiliferous; interbedded with limestone, silty, light-gray to tan, fine-grained, unfossiliferous	5
6. Limestone, medium-gray to brownish-gray, in beds 1 to 1.5 m thick; crinoids common, horn corals sparse; contains chert in nodules and as discontinuous seams (5-8 cm thick)	21
5. Limestone, medium-gray, weathers light-gray, in beds 30 to 60 cm thick; crinoids abundant, fusulinids abundant	6
4. Limestone, light- to dark-gray, fine-grained, in beds 7 to 10 cm thick; crinoids common, bryozoans sparse, brachiopods sparse, fusulinids sparse; contains brown chert nodules	14
3. Limestone, medium-gray, fine-grained, massive; crinoids common, brachiopods sparse, horn corals sparse	9
2. Limestone, medium-gray, fine-grained, massive to thick-bedded; contains zones of abundant crinoids, otherwise fossil-poor	50
1. Limestone, medium-gray, fine-grained, thick-bedded; horn corals and brachiopods common in lower 3 meters, fusulinids sparse ; brown chert occurs as nodules and thin seams	11
Partial thickness of Bird Spring Formation, Wheeler Wash Southern Section	303

Thickness (m)

Base of section: lower part of Bird Spring Formation covered by Quaternary alluvium.

Wheeler Wash, Northern Section

Section measured in NE 1/4 NE 1/4, Section 19, T. 19 S., R. 55 E., Mt. Stirling 15-minute quadrangle, Clark County, Nevada.

Top of section: Bird Spring Formation truncated by erosion.

Thickness (m)

16. Siltstone, calcareous, brown, weathers tan to light-yellow, unfossiliferous; interbedded with limestone, medium-gray, fine-grained; crinoids sparse	56
15. Siltstone, calcareous, light-yellow; interbedded with silty limestone, and unfossiliferous limestone, medium-gray	25
14. Limestone, medium-gray, fine-grained; crinoids, fusulinids, and brachiopods common; contains gray chert as thin seams (1-4 cm thick) and nodules	55
13. Limestone, medium- to dark-gray, fine-grained, in beds 6 to 10 cm thick, laminae are 1-2 mm thick, unfossiliferous	15
12. Limestone, light- to medium-gray, fine-grained, in beds 1 to 2 m thick; crinoids and fusulinids abundant; interbedded with limestone, silty, tan to light-brown, in beds, 15 to 40 cm thick; individual beds may be unfossiliferous; contains gray chert, nodular, occurs common to infrequently	12

	Thickness (m)
11. Limestone, medium-gray, weathers light-gray, fine-grained, in beds 2 to 4 m thick, unfossiliferous; interbedded with limestone, silty, tan, occurs less frequently than medium-gray limestone; brown chert common, irregular lenses and thin seams (up to 10 cm thick)	55
10. Limestone, light- to medium-gray, fine-grained; crinoids and brachiopods abundant, fusulinids common; black to gray chert occurs as nodules and discontinuous lenses, 15 cm thick	11
9. Limestone, medium-gray, thick-bedded (2-4 m), unfossiliferous; interbedded with limestone, tan, silty, in beds 20 to 25 cm thick; gastropods and brachiopods common; gray chert common	13
8. Limestone, light-gray, fine-grained; small, whole gastropods common	2
7. Limestone, tan to light-gray, silty, fine-grained, unfossiliferous; interbedded with limestone, medium-gray, fine-grained; in beds 10 to 15 cm thick fusulinids common . . .	8
6. Limestone, medium-gray, fine-grained, thick-bedded; crinoids and brachiopods abundant, bryozoans common, fusulinids scarce; contains gray chert as nodules and discontinuous seams . .	87
5. Limestone, medium-gray, weathers light-gray, fine-grained; fusulinids and crinoids abundant	2
4. Limestone, dark-gray to black, fine-grained, weathers mottled-gray; in beds 45 to 90 cm thick, unfossiliferous	28

	Thickness (m)
3. Limestone, medium-gray, fine-grained, in beds 30 to 60 cm thick, unfossiliferous; interbedded with limestone, medium-gray; gastropods (up to 2.5 cm diameter) and crinoids common	7
2. Limestone, medium-gray, fine-grained; brachiopods and crinoids common, fusulinids scarce; contains gray chert in irregularly- shaped nodules and discontinuous seams, weathers brown	4
1. Limestone, dark-gray to black, weathers to medium-gray, thick-bedded; echinoderms common, fusulinids and brachiopods scarce	31
Partial thickness of Bird Spring Formation at Wheeler Wash, Northern Section	401

Base of section: the lower part of the Bird Spring Formation is covered by Quaternary alluvium.

Mountain Springs Pass Section

Section measured in NE 1/4 SE 1/4, Section 24, T. 22 S., R. 57 E., Mountain Springs 15-minute quadrangle, Clark County, Nevada.

Top of section: upper part of Bird Spring Formation is covered by Quaternary alluvium.

	Thickness (m)
40. Limestone, light- to medium-gray, fine- grained, unfossiliferous; interbedded with dolomite, light-brown, fine-grained, unfossiliferous; units occur in beds 1 m thick . .	6

	Thickness (m)
39. Dolomite, light-gray to light-brown, fine-grained, unfossiliferous; contains white quartzine nodules (up to 2.5 cm); few beds contain scarce, silicified crinoid stems; black chert occurs as nodules, 2 to 8 cm thick	5
38. Limestone, light-gray, in beds 0.5 to 1 m thick; crinoids common	6
37. Siltstone, light-yellow-brown, unfossiliferous; interbedded with dolomite, light-gray, fine-grained; few beds contain large echinoderm spines that have been replaced by silica	7
36. Dolomite, light-gray to light-brown; contains black chert nodules	7
35. Limestone, light- to medium-gray, medium- to coarse-grained; crinoids and fusulinids abundant, gastropod? fragments common; fossils may comprise over 60 % of limestone components . .	3
34. Dolomite, light-yellow to light-brown, fine-grained; contains abundant quartzine nodules; large echinoderm spines common; black chert nodules common	11
33. Siltstone, tan to brown, calcareous, fine-grained; in beds 0.5 m thick; black chert nodules common	20
32. Dolomite, light-gray to light-yellow, silty, fine-grained, platy; in beds 0.25 to 1 m thick; black chert nodules common	8
31. Limestone, medium-gray, fine-grained; brachiopods common (up to 1.25 cm)	22
30. Dolomite, light-gray, fine-grained, unfossiliferous; contains white quartzine nodules (1 mm to 2 cm); black chert nodules common	6

	Thickness (m)
29. Siltstone, light-yellow, well-sorted; locally unfossiliferous, although trace fossils (worm trails ?) common	3
28. Limestone, dark-gray, fine-grained, unfossiliferous, in beds 1 m thick; crinoids and fusulinids common; crinoids and fusulinids occur in greater numbers than in underlying sequence; black chert nodules common	31
27. Limestone, dark-gray, fine-grained; crinoids and brachiopods common, fusulinids scarce; interbedded with limestone, light-brown, silty; fossil components same as above	16
26. Limestone, light-gray, silty, fine-grained; in beds 1 m thick; fusulinids common; interbedded with minor light-yellow siltstone	23
25. Limestone, medium- to dark-gray, fine-grained; fusulinids common; interbedded with limestone, light-gray, silty, unfossiliferous; contains gray chert nodules	25
24. Limestone, light-gray, fine-grained; crinoids common; interbedded with silty limestone and siltstone, tan to buff, unfossiliferous	20
23. Limestone, medium-gray, fine-grained, fusulinids abundant; gray chert nodules common . .	8
22. Limestone, medium-gray, fine-grained; crinoids common, horn corals scarce; fusulinids become abundant in uppermost beds; interbedded with limestone, light-gray, silty; brownish-gray chert occurs as nodules and as thin seams	50
21. Limestone, light-gray, fine-grained, in beds 1 to 2 m thick; brachiopods, crinoids, and bryozoans common; gray chert occurs as discontinuous thin seams up to 7 cm thick	35

	Thickness (m)
20. Limestone, light-gray, fine-grained, fusulinids common, syringoporoid corals scarce; gray chert occurs as irregularly shaped nodules	11
19. Limestone, medium- to dark-gray, fine-grained, unfossiliferous	3
18. Limestone, light- to medium-gray, fine-grained; fusulinids common	1
17. Limestone, light- to dark-gray, fine-grained; bryozoans and crinoids common, brachiopods scarce; gray chert nodules common in a few beds .	22
16. Limestone, light- to medium-gray, fine-grained; horn corals sparse to common	6
15. Limestone, medium- to dark-gray, fine-grained; in beds 1 m thick; unfossiliferous	16
14. Limestone, light-gray, fine-grained; crinoids abundant, brachiopods, fusulinids, and bryozoans common	1
13. Limestone, medium- to dark-gray, fine-grained; unfossiliferous	8
12. Limestone, light- to medium-gray, fine-grained; horn corals sparse	11
11. Limestone, light-gray, fine-grained; fusulinids common, syringoporoid corals sparse	9
10. Limestone, light- to medium-gray, fine-grained; crinoids common; interbedded with minor siltstone, light-yellow	29
9. Limestone, medium-gray, fine-grained; abundant fusulinids	16

	Thickness (m)
8. Limestone, medium-gray, weathers light-gray; in beds 1 to 2 m thick; crinoids abundant, bryozoans common, fusulinids common to sparse; fossils may be replaced by silica	44
7. Limestone, medium-gray; in beds 1 to 2 m thick; fusulinids abundant; gray chert in discontinuous seams 4 to 6 cm thick	33
6. Limestone, medium-gray, fine-grained; in beds 1 to 2 m thick; crinoids and fusulinids common, horn corals sparse; interbedded with minor limestone, silty, light-gray, fine-grained; crinoids sparse to common; silty limestone more common in lower part of unit; gray chert nodules common throughout unit	100
5. Limestone, medium-gray, fine-grained; in beds 1 m thick; fusulinids sparse to common; interbedded with silty limestone, and calcareous siltstone, tan-to-light-gray; unfossiliferous; in beds 30 to 45 cm thick; chert nodules common	57
4. Siltstone, tan- to light-brown, calcareous; unfossiliferous; in beds 30 to 60 cm thick; interbedded with minor limestone, silty; in beds 30 to 60 cm thick; crinoids sparse to common, fossils may be replaced by silica	9
3. Limestone, medium-gray, fine-grained; in beds 1 to 2 m thick; crinoids and echinoderm spines common, fusulinids common to sparse; interbedded with minor siltstone, calcareous; in beds 30 to 60 cm thick; contains brownish-gray chert as nodules and thin seams (4 to 8 cm thick)	19
2. Limestone, medium-gray, fine-grained; in beds 30 to 60 cm thick; unfossiliferous; interbedded with siltstone, calcareous, tan to light-gray	19

	Thickness (m)
1. Limestone, light- to medium-gray, fine-grained; unfossiliferous; interbedded with minor siltstone, light-yellow	11
Partial thickness of Bird Spring Formation at Mountain Springs Pass	737
Base of section: unit overlies brown quartzite beds and minor limestone beds of the Indian Springs Formation	

Lovell Canyon Section

Section measured NW 1/4 NE 1/4 of Section 2, T. 21 S., R. 57 E., Mountain Springs 15 minute quadrangle, Clark County, Nevada.

Top of section: overlain by reddish soil and red sandstone talus of the Permian red beds.

	Thickness (m)
14. Sandstone, red-brown to yellow, very-fine-grained, well-sorted; quartz grains cemented by silica; interbedded with siltstone and mudstone; occurs in sets of horizontal laminae and cross-bedded laminae, silt-filled mud cracks; argillaceous	7
13. Covered interval of sandstone talus	61
12. Sandstone, reddish brown to yellow, platy, well sorted; cemented by silica, hematite-stained quartz grains; in low-angle cross-laminae 1 to 10 cm thick; interbedded with siltstone, yellow to red; mud cracks common . . .	15
11. Sandstone, reddish brown, very fine-grained, well-sorted quartzose sand grains; small, trough-cross-laminated, low-angle laminated and horizontal laminated set, 3 - 12 cm thick . .	16
10. Covered interval of sandstone talus	35

	Thickness (m)
9. Limestone, light-gray, fine-grained; echinoderms and bryozoans sparse; massive to thick-bedded	29
8. Sandstone, light-orange to reddish brown, very fine-grained, unfossiliferous, well-sorted .	18
7. Limestone, silty, light- to medium-gray, fine-grained; generally unfossiliferous although echinoderms and pelecypods occur towards bottom of sequence; massive to thick-bedded . . .	89
6. Siltstone, yellowish brown, unfossiliferous, slightly calcareous; interbedded with limestone, medium-gray, fine-grained, unfossiliferous; in beds 30 cm to 3 m thick . . .	54
5. Siltstone, light-brown, calcareous; in beds 30 to 60 cm thick; horizontal laminations infrequently preserved	8
4. Limestone, medium-gray, weathers light-gray, fine-grained; gastropods sparse, otherwise unfossiliferous	15
3. Dolomite, light-gray, fine-grained, in beds 30 to 60 cm thick; contains common white quartzine nodules interbedded with nonquartzine-bearing dolomite beds that occasionally contain patches or zones of large (5 cm long, 4 mm diameter) echinoderm spines . . .	16
2. Siltstone, light-brown to yellowish brown, unfossiliferous, in beds .5 to 1 m thick	31
1. Dolomite, light-brown, fine-grained, unfossiliferous; contains common white quartzine nodules, black chert nodules	59
Partial thickness of section containing red beds and Bird Spring Formation	453
Base of section: lower part of Bird Spring Formation is covered by soil and talus.	

APPENDIX 2: FUSULINIDS OF THE BIRD SPRING FORMATION,
SPRING MOUNTAINS, NEVADA

Plate 1: Fusulinids of the Wheeler Wash, Southern Section and Member D
of the Lee Canyon Section

- Figure 1 Thompsonella? sp., x10 Southern Section, Wheeler Wash
- Figure 2 Triticites coronadoensis? or T. whetstonensis? , x10, Southern
Section, Wheeler Wash
- Figure 3 Triticites coronadoensis? or T. whetstonensis?, x10, Southern
Section, Wheeler Wash
- Figure 4 Triticites sp. B, x10, Southern Section, Wheeler Wash
- Figure 5 Triticites sp. B, x10, Southern Section, Wheeler Wash
- Figure 6 Triticites muddiensis, x10, Southern Section, Wheeler Wash
- Figure 7 Parafusulina apiculata?, x10, Lee Canyon Section
- Figure 8 Schwagerina sp. A, x10, Lee Canyon Section

PLATE I

Plate 2: Fusulinids of the Wheeler Wash, Northern Section

Figure 1 Schwagerina elkoensis, x10, Northern Section, Wheeler Wash

Figure 2 Schwagerina elkoensis, x10, Northern Section, Wheeler Wash

Figure 3. Schwagerina eolata?, x10, Northern Section, Wheeler Wash

Figure 4 Schwagerina eolata?, x10, Northern Section, Wheeler Wash

Figure 5 Schwagerina eolata?, x10, Northern Section, Wheeler Wash

PLATE 2

1

2

3

4

5

Plate 3: Fusulinids of the Wheeler Wash, Northern Section

Figure 1 Parafusulina?, x10, Northern Section, Wheeler Wash

Figure 2 Parafusulina?, x10, Northern Section, Wheeler Wash

Figure 3 Parafusulina?, x10, Northern Section, Wheeler Wash

Figure 4 Staffella?, x10, Northern Section, Wheeler Wash

Figure 5 Staffella?, x10, Northern Section, Wheeler Wash

Figure 6 Schwagerina elkoensis?, x10, Northern Section, Wheeler Wash

Figure 7 Schwagerina sp. C, x10, Northern Section, Wheeler Wash

Figure 8 Schwagerina sp. B, x10, Northern Section, Wheeler Wash

PLATE 3

Plate 4: Fusulinids of the Mountain Springs Pass Section

Figure 1 Triticites californicus, x10, Mountain Springs Pass

Figure 2 Triticites californicus, x10, Mountain Springs Pass

Figure 3 Triticites californicus, x10, Mountain Springs Pass

Figure 4 Triticites californicus, x10, Mountain Springs Pass

Figure 5 Triticites sp. A, x10, Mountain Springs Pass

Figure 6 Triticites muddienseis, x10, Mountain Springs Pass

Figure 7 Triticites muddienseis, x10, Mountain Springs Pass

PLATE 4

Plate 5: Fusulinids of the Mountain Springs Pass Section

- Figure 1 Paraschwagerina sp. A, x10, Mountain Springs Pass
- Figure 2 Paraschwagerina sp. B, x10, Mountain Springs Pass
- Figure 3 Schwagerina aculeata, x10, Mountain Springs Pass
- Figure 4 Schwagerina aculeata, x10, Mountain Springs Pass
- Figure 5 Schwagerina modica?, x10, Mountain Springs Pass
- Figure 6 Stewartina uber, x10, Mountain Springs Pass
- Figure 7 Pseudofusulinella sp. A, x10, Mountain Springs Pass
- Figure 8 Schwagerina aculeata var. plena, x10, Mountain Springs Pass
- Figure 9 Triticites beedeii? or T. confertus?, x10, Mountain Springs Pass
- Figure 10 Triticites beedeii? or T. confertus?, x10, Mountain Springs Pass
- Figure 11 Triticites beedeii? or T. confertus?, x10, Mountain Springs Pass

PLATE 5

1

2

4

3

5

6

7

9

10

11

8

APPENDIX 3: PETROGRAPHIC ANALYSIS OF ROCK SAMPLES

The following tables list the rock samples that were collected and studied petrographically. The major components of the rock are listed along with major fossil groups. Classification of the rock types is based upon the components contained in the rocks, and the names are based on the carbonate rock classification systems developed by Dunham (1962) and Wilson (1975).

The rock samples are numbered according to their location in the measured sections. Table 1 lists rock samples from the Wheeler Wash area and Lee Canyon area; Table 2 from the Lovell Canyon area; and Table 3 from the Mountain Springs Pass area.

APPENDIX 3: TABLE 1.
ROCK SAMPLES FROM THE WHEELER WASH AREA AND THE LEE CANYON AREA

SAMPLE NUMBER	COMPONENTS (% OF ROCK)					CLASSIFICATION	COMMENTS
	Micrite*	Sparite	Quartz Silt/Sand	Peloids	Carbonate Grains**		
WW-1	73	5	2		20	Bioclastic Wackestone	E(A), Br(A), I(C)
WW-2	53	7		<1	40	Echinoderm-Bearing Lithoclastic Wackestone-Packstone	Intraclasts (rip-up clasts) (A), E(C)
WW-3	73	1			27	Bioclastic Wackestone	E(A), Br(A), B(S-C), O(S), Fo(S)
WW-4	80	5	3		12	Fusulinid Wackestone	Fu(C), E(C), B(S), Microspar (A)
WW-5	75	5	3		17	Fusulinid Wackestone	Fu(C), E(C), Fo(S-C), B(S), Horn Coral (S)
WW-6		10				Wavy Laminated Dolomite	Dolomite (90%), Wavy bands = Algal Laminations?
WW-7	75	4	1		20	Bryozoan Wackestone	Br(A), E(C), B(S), Fo(S)
WW-8	55	7	3		35	Whole Bryozoan-Bearing Echinoid Floatstone	E(A), Fu(C), Br(C)
WW-9	78	4	15		3	Fusulinid-Bearing Silty Lime Mudstone	Fu(C), Pelecypods (S), E(T)
WW-10	65	7	18		10	Fusulinid-Bearing Silty Lime Mudstone	Fu(C), E(C), Pelecypods (S)
WW-11	75	7	3		15	Coralline Bioclastic Wackestone	E(S-C), Horn Coral (S-C), Fo(S)

* Includes Microspar
** Includes Intraclasts
and Bioclasts

Fu = Fusulinids
Fo = Unidentified Foraminifera
B = Brachiopods
Br = Bryozoans

E = Echinoderms
(mostly Crinoids)
O = Ostracodes

(A) = Abundant
(C) = Common
(S) = Scarce
(T) = Trace

APPENDIX 3: TABLE 1. (CONTINUED)
ROCK SAMPLES FROM THE WHEELER WASH AREA AND THE LEE CANYON AREA

SAMPLE NUMBER	COMPONENTS (% OF ROCK)					CLASSIFICATION	COMMENTS
	Micrite*	Sparite	Quartz Silt/Sand	Peloids	Carbonate Grains**		
WW-12	25	19	1		55	Coralline Rudstone	Horn Corals (C)
WW-13	65	3	2		30	Coralline-Fusulinid Bioclastic Wackestone	Fu(C), E(C), B(C), Horn Corals (S-C) Syringoporoid Corals (S-C)
WW-14	60	3	2		25	Bioclastic-Fusulinid Wackestone	E(C), Fu(C), B(C), Br(S)
WW-15	55	5			40	Bioclastic-Fusulinid Wackestone	Fu(A), E(C), B(C)
WW-16	50	3	2		45	Bioclastic-Brachiopodal Wackestone	Fu(C), B(C-A), E9C, Br(S)
WW-17	72	3	2		23	Pelecypodal Wackestone	Pelecypods (A), E(S) Br(S)
WW-18	25		75			Calcareous Siltstone	
WW-19	65	5	2	8	20	Peloidal Pelecypodal Wackestone	Pelecypods (A)
WW-20	60	5			35	Fusulinid Wackestone	Fu(A), E(S)
WW-21	60	2	2	1	35	Bioclastic-Fusulinid Wackestone	Fu(A), E(A-C), B(C)
WW-22	55	5			40	Bioclastic-Fusulinid Wackestone	Fu(C), Fo(C), Br(C), E(C), B(C)

* Includes Microspar
** Includes Intraclasts
and Bioclasts

Fu = Fusulinids
Fo = Unidentified Foraminifera
B = Brachiopods
Br = Bryozoans

E = Echinoderms
(mostly Crinoids)
O = Ostracodes

(A) = Abundant
(C) = Common
(S) = Scarce
(T) = Trace

APPENDIX 3: TABLE 1. (CONTINUED)
ROCK SAMPLES FROM THE WHEELER WASH AREA AND THE LEE CANYON AREA

SAMPLE NUMBER	COMPONENTS (% OF ROCK)					CLASSIFICATION	COMMENTS
	Micrite*	Sparite	Quartz Silt/Sand	Peloids	Carbonate Grains**		
WW-23	65		20		15	Bioclastic Silty Lime Wackestone	Fo(C), E(C), Br(C)
WW-24	53		40		7	Fossil-bearing Silty Lime Mudstone	E(C), O(C)
WW-25	55	5	7	7	23	Silty Peloidal Bioclastic Wackestone	E(C), Fo(C), Whole Pelecypods (C), Fu(S), Girvanella algae
WW-26	79	1	5		15	Bioclastic Wackestone	O(A), Br(C), B(C), Girvanella? algae
WW-27	53	7			40	Bioclastic Wackestone	E(A), Fo(C-A), Fu(C), Br(C), O(S)
WW-28	20	15		10		Peloidal Fusulinid Packstone-Rudstone	Fu(A), Fo(C), Br(C), E(C), O(S), B(S)
LE-3	10	20		40		Pisolithic Chert - Pebble Dolomite	

* Includes Microspar
** Includes Intraclasts
and Bioclasts

Fu = Fusulinids
Fo = Unidentified Foraminifera
B = Brachiopods
Br = Bryozoans

E = Echinoderms
(mostly Crinoids)
O = Ostracodes

(A) = Abundant
(C) = Common
(S) = Scarce
(T) = Trace

APPENDIX 3: TABLE 2.
ROCK SAMPLES FROM THE LOVELL CANYON AREA

SAMPLE NUMBER	COMPONENTS (% OF ROCK)					COMMENTS
	Micrite*	Sparite	Quartz Silt/Sand	Peloids	Carbonate Grains**	
LO-1			95			Hematite-stained Quartz Arenite
LO-2	45	4	1	30	20	Hematite stain/cement (5%) E(A), Br(C), Fo(C), Pelecypods (C), O(T)
LO-3	30		12	50	6	Crinoid-bearing Peloidal Packstone Micrite occurs as microspar
LO-4	43		5	50	2	Silty Peloidal Packstone
LO-5	35	5	10	45	5	Silty Peloidal Packstone Pelecypods (S-C), O(S), E(S-C), Br(S)
LO-6A	78	7	15			Silty Lime-Wackestone
LO-6B	45		55			Calcareous Siltstone
LO-7	70		30			Silty Lime-Wackestone
LO-8	75	3	<1	7	15	Peloidal-Ostracode Lime-Wackestone O(C), Calcite-filled fenestrae (A)
LO-9	82	1	17			Silty Lime Mudstone Thin laminae

* Includes Microspar
** Includes Intraclasts
and Bioclasts

Fu = Fusulinids
Fo = Unidentified Foraminifera
B = Brachiopods
Br = Bryozoans

E = Echinoderms
(mostly Crinoids)
O = Ostracodes

(A) = Abundant
(C) = Common
(S) = Scarce
(T) = Trace

APPENDIX 3: TABLE 3.
ROCK SAMPLES FROM THE MOUNTAIN SPRINGS PASS AREA

SAMPLE NUMBER	COMPONENTS (% OF ROCK)				CLASSIFICATION	COMMENTS
	Micrite*	Sparite	Quartz Silt/Sand	Peloids Grains**		
MS-1		60	<1	40	Bioclastic Grainstone	E(A), Fu(C), Br(C), FO(S); partially dolomitized
MS-2	70		<1	30	Fusulinid-Bioclastic Wackestone	F(A), E(A), Br(C)
MS-3			5		Dolomite with Quartzine Nodules	Dolomite = 90%
MS-4			10		Silty Dolomite	Dolomite = 90%
MS-5	15		<1	25	Skeletal-bearing Dolomite	E(A), B(A), Br(C-A), Dolomite = 60%
MS-6	60	7		33	Foraminiferal Wackestone	FO(A), O(C)
MS-7			<1		Dolomite with Quartzine Nodules	Dolomite >95%; Irregular lamination
MS-8	60	5	<1	35	Fusulinid Wackestone	FO(A), Fu(A)
MS-9	60	2	<1	38	Brachiopodal Wackestone	B(A), Fu(C), Br(S), E(S)
MS-10	60	3		37	Bioclastic Wackestone	Br(A), B(C-A), Fu(C), E(C), O(S)
MS-11	75	5		20	Fusulinid Wackestone	Fu(C), E(C)
MS-12	75	5	3	17	Bioclastic Wackestone	E(C), B(C)

* Includes Microspar
** Includes Intracclasts
and Bioclasts

Fu = Fusulinids
Fo = Unidentified Foraminifera
B = Brachiopods
Br = Bryozoans

E = Echinoderms
(mostly Crinoids)
O = Ostracodes

(A) = Abundant
(C) = Common
(S) = Scarce
(T) = Trace

APPENDIX 3: TABLE 3. (CONTINUED)
ROCK SAMPLES FROM THE MOUNTAIN SPRINGS PASS AREA

SAMPLE NUMBER	COMPONENTS (% OF ROCK)					CLASSIFICATION	COMMENTS
	Micrite*	Sparite	Quartz Silt/Sand	Peloids	Carbonate Grains**		
MS-13	83	2			15	Bioclastic Wackestone	E(A), Fo(C), Fu(S-C)
MS-14	70	3	3		14	Bioclastic Wackestone	E(A), Fu(C), Br(S)
MS-15	86	2	<1		12	Bioclastic Wackestone	E(A), Fu(C), Fo(C), B(C), Br(S)
MS-16	60	5	2		33	Bioclastic Wackestone	E(A), Br(C), Fu(S)

* Includes Microspar
** Includes Intraclasts
and Bioclasts

Fu = Fusulinids
Fo = Unidentified Foraminifera
B = Brachiopods
Br = Bryozoans

E = Echinoderms
(mostly Crinoids)
O = Ostracodes

(A) = Abundant
(C) = Common
(S) = Scarce
(T) = Trace