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Correlation of Reef Calcarenites of the Pennsylvanian Paradox Formation, San Juan County, Utah

Jack Jordan

CORRELATION OF REEF CALCARENITES

JORDAN

CORRELATION OF

REEF CALCARENITES OF THE PENNSYLVANIAN PARADOX FORMATION, SAN JUAN CANYON, UTAH

By

Jack Jordan

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Geology

The University of New Mexico

1957

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of the University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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ILLUSTRATIONS

CORRELATION OF REEF CALCARENITES OF THE PENNSYLVANIAN PARADOX FORMATION, SAN JUAN CANYON, UTAH

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ABSTRACT

The San Juan Canyon in the Four Corners region of southeastern Utah is a relatively new area for geological study. It is so inaccessible that it has been, and still is, difficult to accumulate information systematically. The antecedent San Juan River has eroded into the Monument upwarp since early Tertiary time and has exposed a considerable thickness of Permian and Pennsylvanian strata. The Pennsylvanian system is represented by the Rico, Hermosa, Paradox, Pinkerton Trail and Molas formations; of which the Paradox formation is the subject of this paper. Representative of shelf sedimentation genetically related to the Paradox basin, the Paradox section contains evidence of reefing and reef destruction. The formation is dominantly limestone, with gypseous lentils in the eastern end of the area studied. These lentils wedge out westward in the eight miles between stratigraphic sections.

The limestone contains abundant organic fragmental and correlative zones of brachiopods, crinoids, fusulinids, gastropods, and pelecypods. These reef calcarenites, biostromes, and biohermal zones can be correlated through the three stratigraphic sections studied, even though the cross sectional length is 21 miles. Bioherms

discovered by earlier workers in one section can be traced to correlative bioclastic debris in the other two sections, and the biostromal lentils which supported biohermal growth can also be traced.

Photomicrographs taken of selected slides illustrate the characteristics of these organic zones. As a result of analyses of these stratigraphic sections and the characteristics revealed by thin-section study, a detailed stratigraphic cross section is presented to illustrate the correlation of the layers of reef material.

The conclusion may be drawn that important reef trends exist in the Paradox formation. These reefs trend generally northwest-southeast with little relation to the present structure along the southwest wedge-edge of the Paradox basin anhydrite-gypsum-salt facies of the middle member of the Paradox formation. The greater number of reefs appear to be equivalent to the middle and lower members of the Paradox formation, although there are significant trends at the top of the upper member. It is not yet determinable on the basis of surface samples available what type of reef may be found in the subsurface, but it is suspected that the reefs will be patch or barrier reefs with local thickening and zones of porosity important in the search for petroleum.

discovered by earlier workers in the [illegible] can be traced to correlative [illegible] in the other two sections, and the [illegible] relation [illegible] ported [illegible] proved [illegible].

Photomicrographs [illegible] and [illegible] illustrate the characteristics of [illegible] types [illegible] a result of analyses of [illegible] and the characteristics [illegible] study, a detailed study [illegible] is presented to illustrate the [illegible] of peat material.

The conclusion may be drawn that [illegible] trends exist in the Fruitland Formation. These [illegible] trend generally northwest-southeast with little relation to the present [illegible] along the [illegible] wedge-edge of the [illegible] features of the [illegible] formation. The [illegible] equivalent to the [illegible] Fruitland formation, although there are [illegible] at the top of the [illegible]. It is not [illegible] on the basis of [illegible] that [illegible] type of peat may be found in the [illegible], and it is expected that the [illegible] will be [illegible] with local [illegible] in the search for petroleum.

INTRODUCTION

Purpose and Scope

This thesis is a summation of lithologic analyses of three stratigraphic sections: the Danvers 1-X Harris-Federal test, the Honaker Trail locality, and the Raplee locality in San Juan Canyon, San Juan County, Utah (Fig. 1). In these localities, the Paradox formation as defined by Wengerd and Strickland (1954, p. 2169) has been studied, inasmuch as the formation is known to contain limestone bioherms ("reefs") (Wengerd, 1951) in conjunction with biostromal strata. This investigation is designed to add to the present knowledge of the Paradox formation by tracing the reef calcarenites through these three stratigraphic sections. Logs have been prepared and thin sections studied and photographed. A detailed stratigraphic cross section has been prepared from this analysis. (Fig. 2)

Location and Size of the Area

The area in which the Paradox formation is studied lies in the Four Corners region of San Juan County, Utah (Index Map, Fig. 1). The three stratigraphic sections lie along the canyon of the San Juan river for a distance of 21 miles across the southern end of the Monument upwarp (Fig. 2). The Slickhorn locality or Danvers 1-X

INTRODUCTION

Purpose and Scope

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Location and Size of the Area

The area in which the Paradox Formation is studied lies in the Four Corners region of San Juan County, Utah (index map, Fig. 1). The [illegible] lie along the canyon of the San Juan River [illegible] of 21 miles across the [illegible] (Fig. 2). The [illegible]

Harris-Federal test is in the NW¼NW¼NW¼ of Sec. 15, T. 40 S., R. 16 E.; 13 miles to the southeast is the Honaker Trail locality in the SW¼ Sec. 29, T. 41 S., R. 18 E.; the Raplee locality is eight miles farther east in Sec. 33-34, T. 41 S., R. 19 E. North to south the area covers about eight miles and the general orientation of the cross section is west to east.

Description of the Area

The San Juan River cuts generally westward across the southern part of the Monument upwarp. The river has cut deeply into the strata of the Colorado Plateau region and is virtually inaccessible except by boat. Two roads serve the region, one extending westward from Shiprock, New Mexico to Mexican Hat, Utah, and the other southerly from Blanding, Utah, through Mexican Hat and Monument Valley in Utah and Arizona. The physiography is one of high mesas, deep canyons tributary to the San Juan River, arroyos, buttes and other features typical of a semi-arid climate. The average annual rainfall is about seven inches, very little of which supports the through-flowing San Juan River. Almost all the water in the river comes from melting snow in the San Juan Mountains of Colorado. Since the

river is youthful, of high gradient, and great velocity, it transports a tremendous amount of material. The stream is antecedent and has entrenched its previous old-age pattern as it has cut downward through the Permian and Pennsylvanian strata. The paucity of wells in the region combined with the relative inaccessability makes the river's deep canyon the major exposure of the sedimentary rocks on the Monument upwarp.

The canyon has exposed the sediments from near the top of the Permian rocks to very nearly the bottom of the Pennsylvanian system, a thickness of about 2500 feet. It has been reported (Wengerd, 1955 b, p. 1) that differential erosion may have removed strata as young as the early Tertiary and the total thickness of Pennsylvanian to early Tertiary strata may have been as great as 4500 feet.

The biohermal trends are exposed by the San Juan River where it has entrenched the east flank and the axis of the Cedar Mesa-Halgaito anticline to the west of the Mexican Hat syncline. Geological evidence indicates that the present Monument upwarp did not exist as such in Pennsylvanian time (Gregory, 1938, p. 85), but instead the area was a stable shelf related to the Paradox evaporite basin. Such conditions appear favorable for the growth of reefs, and study of the area is important in the search for oil and gas.

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The [illegible] River where it has [illegible] the [illegible] axis of the Cedar [illegible] of the [illegible] indicates that [illegible] as [illegible] in Pennsylvanian time [illegible] but instead the [illegible] Paradox [illegible]. Such conditions [illegible] favor- able for the growth of [illegible] important in the [illegible].

Previous Work

Little detailed geological work was published on this relatively inaccessible area prior to 1950, but general descriptions have been published by Gregory (1911, 1916, 1917, 1938), Holmes (1875), Judd (1924), Longwell et al. (1923), Miser (1924, 1925), Prommel (1923), Richardson (1908), and Woodruff (1910).

Some of this early work was inspired by the Mexican Hat oil field discovery about 1907. During a boat trip down the river sponsored by John A.Frost and Frank A. Frost in 1950, biohermal trends were discovered by Sherman A. Wengerd who has published several articles on these trends as well as on the general geology of the region (see selected references). Since 1951, many oil companies have become interested in the general region and significant oil discoveries were made during 1954, 1955 and 1956 in the Blanding Basin to the east of the Monument upwarp. Two unsuccessful tests for oil have been drilled in the Slickhorn Canyon area, one of which is used as a stratigraphic section.

Sample System

The samples used for the analysis of this cross section through the Monument upwarp were collected by

Previous Work

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Some of this early work [illegible] can Hat oil field discovery [illegible] boat trip down the river [illegible] and Frank A. [illegible] in [illegible] discovered by [illegible] several articles on [illegible] general geology of the region [illegible] Since 1951, many oil companies have become interested in the general region and significant oil discoveries were made during [illegible] Basin to the east of the [illegible] cessful tests for oil have been [illegible] horn Canyon area, one of which [illegible] graphic section.

Sample System

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Sherman A. Wengerd and the numbering system initiated by him is continued through the logs and thin sections used in making this study. In the case of the Danvers Harris test the samples are not designated by a separate numbering system, but instead the drilling depth is used. The Honaker Trail and Raplee sections are hand collected and numbered from the level of the river upwards. This number is carried over to the thin section which was cut from a particular sample. Thus, a slide which carries the designation HT 13 has been taken from the collected sample of that number at Honaker Trail, and the designation R 22 indicates that the particular slide came from the Raplee stratigraphic section. Unfortunately there were no cores available from the Danvers-Harris test which was drilled with cable tools. In as much as it was impractical to make thin sections of those samples they were carefully examined with the binocular microscope and the best possible correlation attempted.

Method of Attack

Analysis of the lithologic characteristics of the Paradox formation, with emphasis on the calcarenite lentils is the prime purpose of this investigatioh. All the available samples were at hand, as were field logs

Sherman A. Wengerd and the numbering system [illegible]

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Analysis of the [illegible] of the

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the available samples [illegible]

made of the two hand sampled sections. This basic information and sample collection were made available for the purpose of obtaining initial lithologic controls to be used in the solution of the larger problem of delineating the shelf sediments and subsurface reefs related to the Paradox basin. Detailed logs were constructed from binocular and petrographic microscopic examination of the samples from the Paradox strata. Sample intervals containing calcarenite material were picked from these logs. Thin sections were made of certain samples. Photomicrographs were made of all slides, and some are presented to amplify points of interest. Utilizing these data the detailed lithologic-stratigraphic cross section was constructed (Fig. 2). The map (Fig. 1) shows the location of the measured sections as well as the bioherms mapped by Wengerd (1955 b, Fig. 10). The base map is an overlay of a photogeologic map prepared as part of a thesis submitted by James A. Smith dealing with another part of the general problem involving Paradox shelf strata.

Acknowledgments:

Appreciation is extended to Sherman A. Wengerd who served as major professor, advisor and reader, and who provided the samples used in this work; to A. Rosenzweig,

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Acknowledgments

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and Roger Y. Anderson who also read and corrected the first draft; and to James A. Smith for permission to use his map as a base. Special thanks go to the New Mexico Geological Society which provided funds for the preparation of thin sections.

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REGIONAL GEOLOGY

Stratigraphy

The rocks exposed in the San Juan Canyon area are Paleozoic in age, ranging from early Pennsylvanian to Permian. Cross and Spencer (1900, p. 48) called a mappable unit between the Devonian system and the overlying red beds the Hermosa formation. During later work further subdivisions were recognized and one of the latest of these papers on the Pennsylvanian stratigraphy is that of Wengerd and Strickland (1954) in which the Hermosa formation is subdivided as summarized below:

1. At the bottom of the system is the Molas formation, a highly complex transitional shale and limy siltstone found only where the Mississippian limestone is or was present beneath the Pennsylvanian strata. The Molas has been further subdivided into three members of late Atoka to Des Moines age.

2. Above the Molas formation is a limestone formation newly named by the authors of the paper as the Pinkerton Trail formation. The formation wedges to the west and contains a detrital facies which is best developed in the Cedar Mesa anticline on the Monument upwarp.

HISTORICAL GEOLOGY

Stratigraphy

The rocks exposed in the [illegible] area are Paleozoic in age, ranging from early Pennsylvanian to Permian. Cross and Spencer (1900, p. [illegible]) [illegible] a mappable unit between the [illegible] and the overlying red beds, the Hermosa formation. During later work further subdivisions were [illegible] and one of the latest of these papers on the Pennsylvanian stratigraphy is that of Wengerd and Strickland (1954) in which the Hermosa formation is subdivided as summarized below:

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2. Above the Molas formation is a limestone [illegible] ation newly named by [illegible] of the lower [illegible] the Pinkerton Trail formation. This formation [illegible] the west and includes a [illegible] developed in the deeper [illegible] upward.

3. The Paradox formation is a cyclic sequence made up of black shale, dolomite, siltstone and limestone, but whose most significant lithology is thick salt, with thin anhydrite and gypsum. It is entirely Cherokee in age and originally may not have been more than 5000 feet in thickness, although flowage has increased thicknesses to twelve thousand feet in certain salt-core anticlines along the axis of the basin.

The Paradox formation is further divided into three members. The lowermost of these is made up predominantly of anhydrite, gypsum, black shale, and dolomite. The middle member is the thick salt member. The upper member is almost everywhere present over the Paradox basin and is made up of brown dolomite, limestone and white to gray anhydrite, gypsum and black shale.

4. The Hermosa formation lies above the Paradox and has two facies, carbonate at the bottom and clastic at the top. The carbonate facies is related to the lesser prominence of the Uncompahgre uplift during earlier Hermosa time. Renewed activity during later time caused a wedge-shaped formation of clastics which flooded in from the Uncompaghre uplift to the northeast.

5. Uppermost of the Pennsylvanian system is the

3. The Paradox formation has a variable sequence [illegible] made up of black shale, dolomite, siltstone and lime-stone, but whose most significant lithology is rock salt, with thin anhydrite and [illegible]. It is [illegible] Cherokee in age and originally may not have been more than 5000 feet in thickness, although flowage has increased thicknesses [illegible] in certain salt-core anticlines along the axis of the basin.

The Paradox formation [illegible] three members. The lowermost of these [illegible] predominantly of anhydrite, gypsum, black shale, [illegible] dolomite. The middle member is the [illegible]. The upper member is almost everywhere [illegible] Paradox basin and is made up of [illegible] dolomite, limestone and white to gray [illegible], [illegible] shale.

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5. [illegible]

Rico formation considered by Wengerd and Strickland to be transitional between the Hermosa formation below and the Permian Cutler above. This assumption is dictated by fossil evidence (Woodruff, 1910). The formation is represented by approximately 400 feet of maroon arkosic sandstone and some limestone and claystone.

Structure and Physiography

The most prominent feature in the region is the Monument upwarp (Miser, 1924, p. 131), a large flexure extending from the northeastern Black Mesa basin in Arizona northward toward the Paradox salt valley in Utah, and flanked on the east by the Blanding basin and on the west by the Kaiparowits basin. The upwarp is pre-Tertiary, post-late Cretaceous (Gregory, 1938, p. 85) and the regional uplift continued into Tertiary time causing entrenchment of the antecedent San Juan River.

Within the upwarp are several long north-trending folds. On the eastern flank are the en echelon Raplee, Lime Ridge, and Fish Creek anticlinal folds, while on the crest lie the Gypsum Creek, Halgaito-Mitten Butte, Cedar Mesa and Bullet Springs anticlines. These crestal folds are symmetrical although the east limb of the upwarp is steep as defined by the Comb Ridge hogback.

Rico formation considered by [illegible] to be transitional between the Hermosa [illegible] and the Permian Cutler above. [illegible] by fossil evidence ([illegible]). The formation is represented by approximately 400 feet of [illegible] arkosic sandstone and some limestone [illegible].

Structure and Physiography

The most prominent feature in the [illegible] Monument upwarp ([illegible]) extending from the northeastern [illegible] Arizona northward [illegible] Utah, and flanked on the east by the [illegible] on the west by the [illegible] pre-Tertiary, post-late Cretaceous ([illegible] p. 35) and the regional uplift continued [illegible] time causing entrenchment of the [illegible] River.

Within the upwarp are several [illegible] folds. On the western flank are the [illegible] Lime Ridge, and Fish Creek anticlinal folds; on the crest lie the [illegible] Cedar Mesa and [illegible] folds are asymmetrical, although the east limb of the upwarp is steep as defined by the [illegible]

The San Juan Canyon shows a maximum depth through the Mitten Butte-Cedar Mesa anticline of about 1500 feet. This added to the approximately 800 feet of relief from the rim of the canyon to the top of Cedar Mesa results in a total relief of about 2300 feet in the vicinity of Honaker Trail.

Structural relief of the Monument upwarp is on the order of 3000 feet (Kelley, 1955, p. 27). The generally northerly trend of the folds mentioned above follows the pattern of small structural features on the Colorado Plateau. It may be noted also that there is a system of joints trending east-west in the vicinity of the Raplee anticline and the Mexican Hat syncline.

The San Juan Canyon along [illegible] [illegible] [illegible]
Nitsen Buttes-Sider [illegible] [illegible] [illegible] [illegible]
This added to the approximately 2,000 [illegible] [illegible]
from the rim of the canyon to the [illegible] [illegible]
results in a total relief of about [illegible] [illegible]
vicinity of [illegible] [illegible].

Structural relief of [illegible] [illegible] is on
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follows the pattern of [illegible] [illegible] [illegible]
Colorado Plateau. It may be [illegible] [illegible] [illegible]
a system of joints trending [illegible] [illegible] [illegible]
of the Raplee anticline and the [illegible] [illegible].

PARADOX FORMATION

History of Terminology

The rocks of the Paradox formation were included in the Hermosa formation as named by Spencer and mapped by Cross and Spencer (1900, p. 48). This original formation included all beds from the top of the Rico member of the Cutler formation down to the top of the Leadville formation of the Mississippian system, which was referred to by Spencer as being Devonian in age. The exact location was not given for the type section. Roth (1934, p. 945) suggested that a section of a composite nature could be measured in Sec. 26 and 35, T. 37 N., R. 9 W., La Plata County, Colorado. Roth's section was re-measured by Wengerd and Strickland (1954, p. 2162) in the course of their stratigraphic investigation of the Pennsylvanian system of the Four Corners region.

The black shale and anhydrite of the Hermosa at the type locality have been proved (Baker, Dane, and Reeside, 1933, p. 963) to be correlative with the thick evaporites of the Paradox formation in Gypsum and Paradox Valleys, and to be Des Moines in age. In 1944, Bass reduced the Paradox beds to member status within the Hermosa formation and proved the age to be Des Moines and Lampasas. This resulted in an unwieldy three-fold

PREVIOUS [illegible]

History of Terminology

The rocks of the Paradox Formation [illegible] included in the Hermosa formation as [illegible] by Cross and Spencer (1900, p. [illegible]) [illegible] Formation included all beds from [illegible] member of the Cutler Formation down to the top of the Leadville Formation of the [illegible] and was referred to by Spencer as being [illegible]. The exact location was not given for the type section. Roth (1934, p. 945) suggested that a section of a composite nature could be measured [illegible] Sec. 25, T. 37 N., R. 9 W., La Plata County, Colorado. [illegible] section was re-measured by Wengerd and [illegible] (1956, p. 2162) in the course of their [illegible] investigation of the Pennsylvanian [illegible] of the Four Corners region.

The black shale and [illegible] of the Hermosa at the type locality have been grouped (Baker, Dane, and Reeside, 1933, p. 963) to [illegible] evaporites of the Paradox [illegible] Valleys, and to be [illegible] reduced the Paradox [illegible] Hermosa Formation [illegible] and Lanpheer. This resulted in [illegible]

division of the Hermosa formation into upper, middle (Paradox), and lower members.

The present terminology as suggested by Wengerd and Strickland (1954, p. 2166) is:

Hermosa formation	
clastic facies	Wolfcamp, Virgil, and Missouri
carbonate facies	Wolfcamp, Virgil, amd Missouri, (Marmaton and locally Cherokee)
Paradox formation	
upper member	Marmaton and Cherokee
middle member	Cherokee
lower member	Cherokee
Pinkerton Trail limestone	Cherokee and Atoka
Molas formation	Locally lowermost Cherokee, Atoka and Morrow.

The newer terminology has been followed throughout this investigation.

Geologic History

The Paradox formation in general is basinal, with cyclic deposits of black shale, dolomite, gypsum, anhydrite and salt in the middle member and black shale, limestone, dolomite and anhydrite in the upper and lower members. Two significantly different lithologies are present, an

division of the Hermosa Formation into Upper, middle (Paradox), and lower members.

The present terminology as suggested by Wengerd and Strickland (1954, p. 2168) is:

Hermosa Formation	
clastic facies	Wolfcamp, Virgil, and Missouri
carbonate facies	Wolfcamp, Virgil, and Missouri, [illegible]
Paradox Formation	
upper member	Desmoines and Cherokee
middle member	Cherokee
lower member	Derryan
Pinkerton Trail limestone	[illegible]
Molas Formation	[illegible]

The newer terminology has been followed throughout this investigation.

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euxinic black shale and locally thickened carbonate sections indicating influx of normal marine water into the basin from the Cordilleran geosyncline on the west. All of these lithologies grade eastward and upward into fine-grained and coarse-grained arkosic sediments of Uncompahgre origin. According to Kelley (1955, p. 76) broad upwarping and mild tectonics in Devonian time created east-west arching across the Colorado Plateau's southern end and developed the broad shelf of the Cordilleran geosyncline which in Pennsylvanian time began to show the northwesterly trending positives of the ancestral Rockies. These are the Front Range, the Uncompahgre-San Juan, and Zuni positive elements. Further, the deeper basins developed adjacent to these asymmetrical highlands, thus we have the Paradox sag adjoining the Uncompahgre uplift. Strickland (Wengerd and Strickland, 1954, p. 2177) is of the opinion that in earliest Pennsylvanian time the Uncompahgre block rose out of the Pinkerton Trail seas, whereas Wengerd favors a post-Cherokee maximum rise of the coarse-clastic producing positive area.

The area of the San Juan Canyon remained a stable shelf and the deep basinal gypsum-salt-anhydrite-black shale facies were not deposited in so great a thickness in the section. In fact the gypsum that is present at

euxinite black shale in [illegible]
sections indicating [illegible]
the basin from the Cordilleran [illegible]
All of these lithologies grade [illegible]
into fine-grained and poorly-sorted [illegible]
of Uncompahgre origin. [illegible]
broad upwarping and mild [illegible]
created east-west trending [illegible]
southern end and [illegible]
Cordilleran geosyncline [illegible]
began to show the northeasterly [illegible]
the ancestral Rockies. These [illegible]
the Uncompahgre-San Juan, [illegible]
Further, the deeper basins [illegible]
asymmetrical highlands, [illegible]
now adjoining the Uncompahgre [illegible]
(Wengerd and Strickland, [illegible]
opinion that [illegible]
Uncompahgre block [illegible]
sent, whereas Wengerd [illegible]
rise of the [illegible]

The area of the [illegible]
shelf and the deep basin [illegible]
shale facies were not [illegible]
in the section. [illegible]

the Raplee locality wedges out east of the Honaker Trail locality in the vicinity of the Mexican Hat syncline. The thick middle member continues shoreward as a limestone shelf representative.

LOCAL CORRELATIONS

General Statement

The great distance between stratigraphic sections analyzed must be kept in mind in any attempt at correlation. The length of the cross section is twenty-one miles; thirteen miles between the Danvers 1-X Harris-Federal well and the Honaker Trail locality, and eight miles between the Honaker Trail and Raplee localities. Rapid lateral changes of lithology in individual beds are frequent in all shelf strata, hence no attempt is made to correlate individual beds except in rare cases of gross lithologic change, i.e. sandstone interspersed in limestone. Paleontologic correlation, except in a general sense, is beyond the scope of this paper. Changes in texture, chemical composition, and mineralogic composition are the main bases for correlation in the limestone section.

Lithology of Correlative Units

The presentation of correlation details will be accomplished in the following fashion. Strata between correlation lines on the cross section (Fig. 2) are given numbers and considered as lithologic units for purposes of correlation. This involved careful subdivision

of the stratigraphic section, based on lithologic characteristics. The description of each unit in the test well is given, followed by correlative characteristics of the same unit in the two surface sections. Units will be taken in order from top to bottom, beginning with unit number 15 at the top of the "Horn Point" limestone.

THICKNESS (IN FEET)

Slickhorn	Honaker Trail Beds 73-82	Raplee Beds 37-41	
86	82	59	Unit 15 is calcarenite at the Raplee locality and at the Honaker Trail locality (Fig. 3). The limestone is massive, fractured, and contains chert in two general zones: at the top and 60 feet from the top of the unit at Honaker Trail. A sandstone layer 6 to 8 feet thick occurs at both Slickhorn and Raplee localities and may be equivalent to gypseous limestone material in the Honaker Trail section. The limestone is dolomitic in the upper part and also below the lower chert zone. Fossil fragments are dolomitized with only a few exceptions. Fragmental fossil content at the Raplee locality is as high as 50 per cent in some lentils and the suites

Figure 3

Upper: Porous algal and coralline debris from bed No. 79, Honaker Trail locality. Note the microcrystalline dolomite. 62X. Plain polarized light.

Lower: Calcarenite from bed 41, Raplee locality, containing 30 per cent dolomitized fossil fragments, foraminifera and spherules. 62X. Plain polarized light.

[illegible] 5

[illegible] and megaline debris from bed

[illegible] locality. Note the microcrystal-

[illegible] X. Plain polarized light.

[illegible] from bed 41, [illegible],

[illegible] with [illegible] fossil fragments,

[illegible]. 63X. Plain polarized


HT 79


5
6

include brachiopods, fusulinids, corals and bryozoans. The base of this unit is separated from the subjacent unit by a silty limestone.

Slickhorn / Honaker Trail Bed 72 / Raplee Beds 35-36

19 24 17 Unit 14 is calcarenite, massive bedded, fine-grained matrix and medium to coarse fossil fragments. The unit is cherty at the top and dolomitic in amounts up to 10 per cent at Raplee locality. Feldspar content ranges from 25 to 40 per cent at Honaker and Raplee localities respectively. Some feldspar grains form centers for oolites. Thin section R 35 falls on a contact between calcarenite and algal reef material (Fig. 4). Orientation is not known. The limestone contains a significant number of crinoid columnals, in addition to fragments of brachiopods, corals, bryozoans, and possible ostracods (Fig. 4). Feldspar content decreases downward with accompanying increase in fossil content. Dolomite and feldspar content increases basinward (eastward) beyond greatest abundance of oolitic material indicating an environmental change from abundant carbonate deposition to one of less calcium carbonate deposition, and concurrently, coupled with accumulation of detrital material. This basinward zone has received fore-reef material

include brachiopods, trilobites, corals and bryozoans. The base of this unit is measured from the adjacent unit [illegible] localities.

19 24 17 Unit 14 is calcarenite, massive bedded, fine-grained matrix and medium to coarse fossil fragments. The unit is cherty at the top and dolomitic in amounts up to 10 per cent at Kaplan locality. Feldspar content ranges from 27 to 43 per cent at Hancock and Kaplan localities respectively. Some feldspar grains form centers for oolites. This section N 35 falls on a contact between calcarenite and algal reef material (Fig. 4). Orientation is not known. The limestone contains a significant number of crinoid columnals, in addition to fragments of brachiopods, corals, bryozoans, and possible ostracods (Fig. 4). Feldspar content decreases downward with accompanying increase in fossil content. Dolomite and feldspar content increases upward (westward) beyond greatest abundance of oolitic material indicating an environmental change from abundant carbonate deposition to one of less active carbonate deposition, and concurrently, coupled with accumulation of detrital material. This westward zone has received [illegible]

Figure 4

Upper: Arenaceous calcarenite from bed 72, Honaker Trail locality, containing fusulinids, corals, and crinoid columnals. Small white grains are feldspar. 62X. Plain polarized light.

Lower: Arenaceous calcarenite on left, porous reef material to right of vertical contact. Sample from bed 35 Raplee locality contains 5 per cent feldspar which is more abundant in the calcarenite. 62X. Plain polarized light.

from an area west of Honaker Trail. This unit at Slickhorn locality is probably back-reef limestone of fairly homogenous lithology.

Slickhorn / Honaker Trail Beds 70-71 / Raplee Bed 34

26 17 20 Unit 13. The detrital facies at the top of this unit may represent the bottom of the unit above. It is sandstone at Slickhorn, shale at Honaker Trail, and absent at Raplee locality. This detrital facies probably represents increased detrital sediment from the west inasmuch as grain size decreases eastward. At Slickhorn more than 75 per cent of the unit is limestone, with some fusulinids, crinoids and echinoid spines. A thin section (HT 70) at Honaker Trail shows lithographic to fine-grained limestone, 95 per cent calcite, 5 per cent quartz and a trace of feldspar. Fossil fragments of algae, brachiopods and fusulinids make up the only clastic material. There are also a very few fragments of corals, crinoids and pelecypods. The limestone appears to be of chemical deposition, subjected to a small amount of weathering after deposition. No evidence of other diagenetic activity is seen. In the Raplee section this unit is the

inasmuch

uppermost part of 125 feet of oolitic limestone. Detrital feldspar is present in amounts up to 3 per cent and there is silica in amounts up to 7 per cent. A large part of the silica is replacement material for fossils. The concentration of reef development probably shifted eastward in this unit, accompanied by a slight thinning in the Honaker Trail.

10 22 13 Unit 12. Eighty-five per cent sandstone with 15 per cent limestone at the Slickhorn locality, shows again the influx of detrital material from the west. Grain size decreases to the east as indicated by siltstone in the upper part of the unit at Honaker Trail locality. The lower 12 feet is dolomitic with from 15 to 20 per cent siltstone. At Raplee locality the unit is a dolomitic oolite. Mineralogically, the rock is about 20 per cent dolomite and calcite cement. The remaining 80 per cent of the rock is equally divided, half calcareous oolites and half siliceous oolites. (Fig. 5) The siliceous oolites appear to be the result of replacement of calcareous oolites by silica in a diagenetic stage prior to cementation. The upper three feet of the unit is a limestone

Slickhorn

Honaker Trail Beds 67-69

Raplee Beds 32-33

Figure 5

Upper: Limestone conglomerate from bed 33, Raplee locality. Oolites and rounded particles in very fine-grained matrix. Fossil material is highly altered and rounded particles are of original limestone. 62X. Plain polarized light.

Lower: Replacement of oolites by silica in Bed 32, Raplee locality. 135X. Plain polarized light.


5
7
9


2 3 4 5 6 7 8 9

conglomerate (Fig. 5), containing foraminifera, brachiopods and other fragments, as well as calcareous oolites. The reef zone is laterally narrower in the unit and floods of detrital material may have inhibited reef development and spread basinward supplying nuclei for oolites and silica for diagenetic processes. The narrower zone of reef development continued to migrate eastward and must have been very near to the Raplee locality to cast debris (such as shown in Fig. 10) onto the top of the unit.

20 32 16 Unit 11. At the Slickhorn locality this unit of sandstone has a medial 7-foot fossiliferous limestone bed. No thin sections were made of the fine-grained limestone in the Honaker Trail section. This limestone was probably deposited under circumstances which restricted reef growth. Great abundance of fossils in the Raplee samples from this unit indicates that reef development has moved further basinward, to or beyond the location of the Raplee locality. The biostromal and calcarenitic limestone contains about 45 per cent quartz (Fig. 6) and feldspar which may have settled

Slickhorn
Honaker Trail Beds 64-66
Raplee Beds 31A-31B

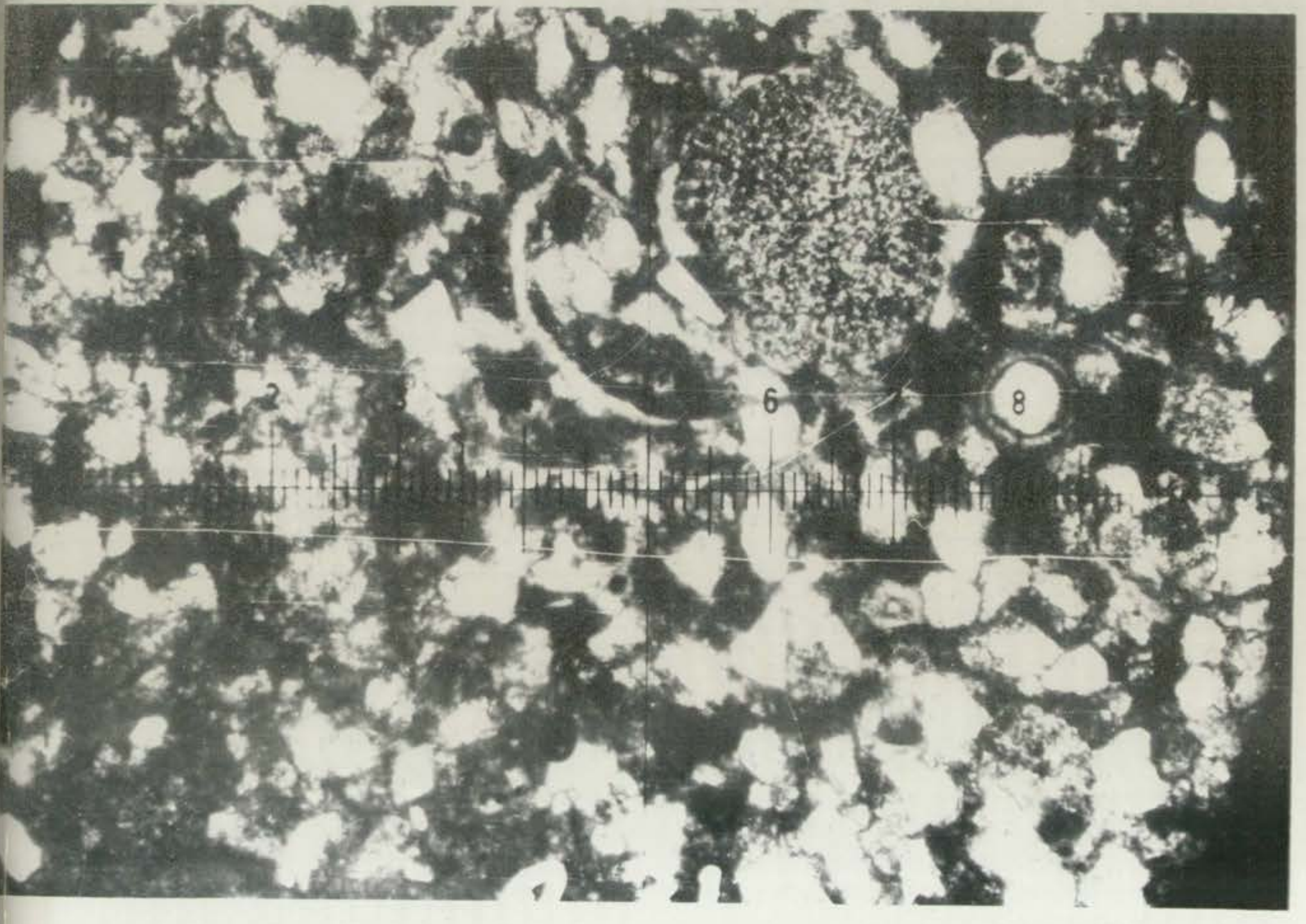
conglomerate (Fig. 5), consisting fragments, stromatolites and other fragments, as well as calcareous oolites. The reef mass is laterally narrower in the south and floods of detrital material may have inhibited reef development and spread laterally consisting mainly of oolites and pellets for biogenic fragments. The narrower zone of reef development would seem to migrate eastward and might have been very near to the Sedan locality to cast debris such as shown in (Fig. 10) onto the top of the unit.

20 32 16 Unit 11. At the [illegible] locality this unit of [illegible] not a medial 7-foot [illegible] limestone bed. At this section were made of the [illegible] limestone in the [illegible] Creek section. This limestone was probably deposited under circumstances which restricted reef growth. Great abundance of fossils in the Sedan samples from this unit indicates that reef development has moved further northward, to or beyond the location of the Sedan locality. The [illegible] and calcarenitic limestone contains about 45 per cent [illegible] (Fig. 6) and [illegible] which may have [illegible]

Figure 6

Upper: Calcareous oolites with very thick laminations from bed 31A, Raplee locality. Contains few fossil fragments. 62X. Plain polarized light.

Lower: Arenaceous limestone, fossiliferous and slightly oolitic, from Bed 31B, Raplee locality. 62X. Plain polarized light.



out of the detrital influx over the reef. The top three feet of sample 31A is oolitic (Fig. 6), possibly formed during detrital flooding, and lithified by redeposition of dissolved calcium carbonate.

Slickhorn
Honaker Trail Beds 57-63
Replee Beds 29-30

17 34 43 Unit 10. This unit at the Slickhorn locality represents the last of the intertonguing sandstone and limestone, and on this basis is believed to be the bottom of the upper member of the Paradox formation. In the Honaker Trail locality the top 12 feet of this unit is cherty and contains up to 30 per cent shale. The center 15 feet is highly fossiliferous limestone; inadvertently overlooked in collection of chips for thin sections. Probably this limestone is of back reef origin, and traceable eastward to a thick, massive limestone bed overlain by oolitic limestone as described in thin section R 30, and pictured in Figure 7. Note the thinness of laminations compared to the near reef oolites in Sample 31A (Fig. 6).

At the base of the unit the mode of deposition changed. Above this point the depositional sequence is indicative of a

out of the [illegible] [illegible] over the area. The [illegible] [illegible] [illegible] [illegible] [illegible] (Fig. 9), [illegible] [illegible] [illegible] [illegible], [illegible] [illegible] to [illegible] [illegible] of [illegible] [illegible] [illegible].

Unit IV. This unit at the Stinchcomb locality represents the last of the interfingering sandstone and limestones, and in this locality is believed to be the [illegible] of the upper member of the Portage formation. At the Hoboken Trail locality the [illegible] [illegible] of this unit is covered and [illegible] [illegible] [illegible] per cent shale. The [illegible] [illegible] [illegible] [illegible] ly [illegible] [illegible] [illegible] [illegible] overlooked in collection of [illegible] for this section, probably [illegible] [illegible], [illegible] of [illegible] most [illegible], [illegible] [illegible] [illegible] which, [illegible] [illegible] [illegible] [illegible] coquina limestones [illegible] [illegible] [illegible] [illegible] B 30, and [illegible] in Figure 7, [illegible] the thickness of limestone [illegible] [illegible] the [illegible] been [illegible] [illegible] in the [illegible].

At the [illegible] of the unit the [illegible] deposition changes. [illegible] this [illegible] the [illegible] [illegible] [illegible] [illegible] of the

Figure 7

Oolitic limestone, slightly fossiliferous, from Bed 30 Raplee locality. Laminations are much thinner in comparison with those on oolites of Figure 6, upper photo. Sample contains 25 per cent quartz and little-worn feldspar (euhedral crystals). 62X. Plain polarized light.


3 4 5 6 7

normal regressive and transgressive reef environment forming small patch reefs. From this point downward in the section, the strata appears to be sequential and cyclic. On the basis of this change the boundary is drawn between the upper and middle members of this Paradox shelf facies. Five sequences of deposition exhibiting similar history are distinguishable in the middle member and are discussed below.

60 48 33 Unit 9. The uppermost of the five middle member units is typical of the tripartite nature of each unit. At the top, the limestone is highly fossiliferous, calcarenitic, biostromal or biohermal. The middle is dolomite or dolomitic limestone. An appreciable percentage of silt in the carbonate lentils or a bed of siltstone or sandstone, characterizes the bottom part of the unit. Unit 9 contains, as the fossiliferous unit, the upper bioherm of the Honaker Trail section. To the west, the top of the unit at the Slickhorn locality is calcarenitic, cherty, fine-grained limestone. Chert and fossil content decrease downward through fine-grained, gray, gypseous

Slickhorn
Honaker Trail Beds 51-57
Raplee Beds 26-28

bonded pattern [illegible]

cavities and forming small patch reefs.

From this point upward in the section, the

strata appear to be [illegible].

On the basis of this change the boundary is

drawn between the upper and [illegible]

of both [illegible]. The sequence

of deposition exhibits similar [illegible]

distinguishable [illegible]

[illegible].

Unit 6. [illegible]

[illegible] units is typical of the [illegible]

nature of each unit. [illegible] the lime-

stone is mainly [illegible],

bioclastic or [illegible]. The unit is [illegible]

[illegible]

percentage of [illegible]

or a bed of siltstone or [illegible]

erizes the bottom part of the unit. [illegible]

contains, as [illegible] unit, [illegible]

[illegible] of the [illegible]. In the

west, the top of the [illegible]

[illegible]

limestone. Chert and [illegible]

dolomite [illegible]

limestone into a three-foot layer of dolomite, in turn underlain by eleven feet of calcareous sandstone constituting the bottom part of the sequence. At the Honaker Trail locality the dolomite layer is thicker and the detrital lower part of the section is represented by an increased percentage of silt in the dolomite. Further east, in the Raplee locality, the entire unit is massive limestone showing the sequential deposition by abundant, diagenetically-altered (Fig. 8) bioclastics at the top, which diminish downward accompanied by increasing detrital content. (See thin section reports for R 27 and 26 in Appendix B). The bottom part of the formation is stained by brown oil and contains about 15 per cent euhedral crystals (Fig. 8) which may reflect dolomite crystallization in fluid-filled cavities. This unusual occurrence of of single crystals of this comparatively large size was found only in this sample.

Figure 8

Upper: Dolomitized fossil fragments in very fine grained calcarenite from Bed 27, Raplee locality. 62X. Plain polarized light.

Lower: Euhedral dolomite crystals in porous limestone. The large pore at right is heavily stained with brown oil. Bed 26, Raplee locality. 135X. Plain polarized light.

[illegible]

[illegible] Fine

[illegible] County,

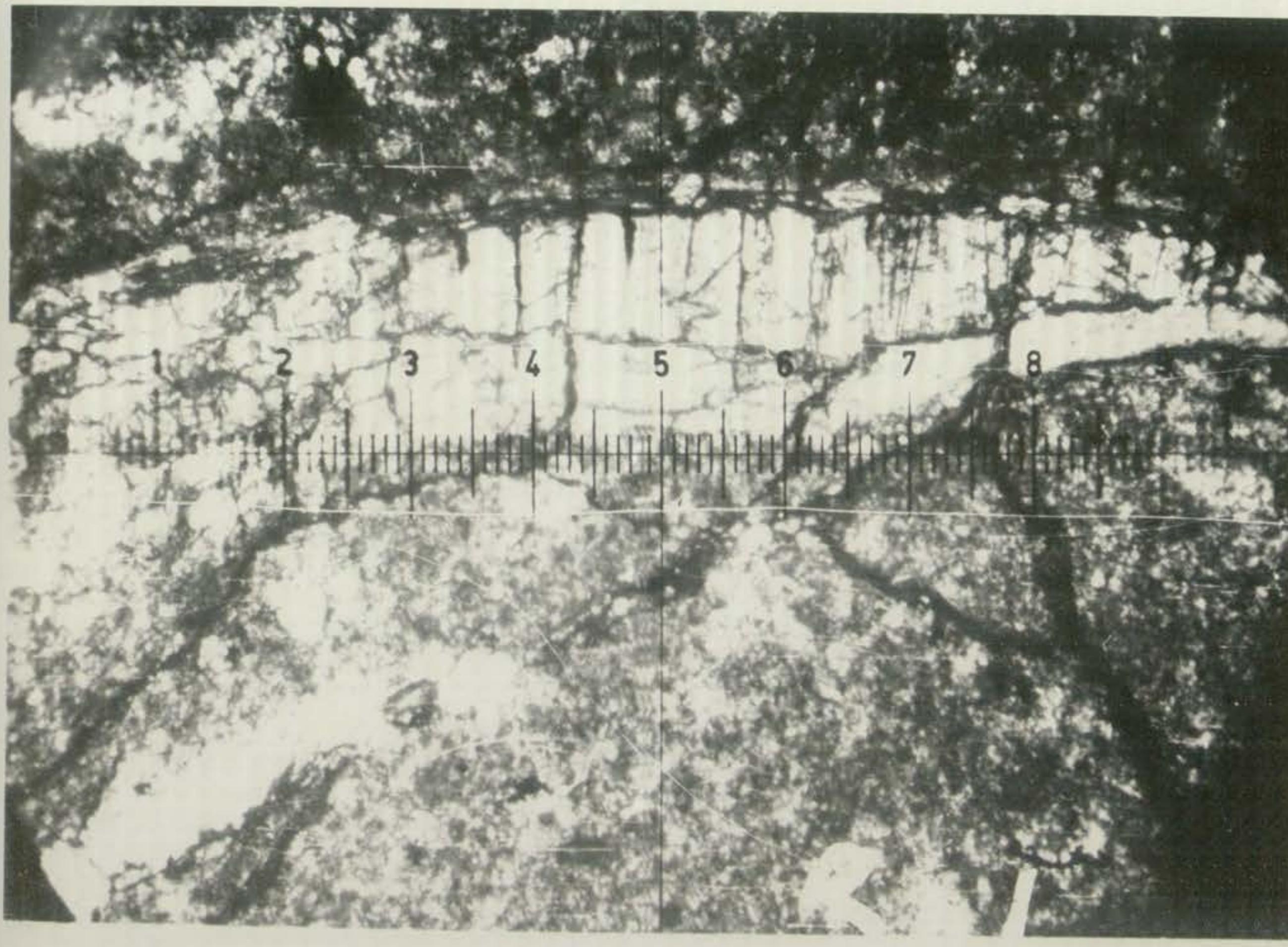
[illegible]

[illegible] Limestone,

[illegible] with brown

[illegible] polarized

[illegible]


1 2 3 4 5 6 7 8


3 4 5 6

53 34 38
Slickhorn | Honaker Trail Beds 48-50 | Raplee Beds 25-26

Unit 8. The second cycle is slightly thinner westward and the normal sequence is not distinguishable to the east in the Raplee locality. In the easternmost section this facies may represent the westernmost edge of a detrital influx from the Uncompahgre positive area. Detailed information probably would show a lateral facies change boundary between the Raplee and Honaker Trail localities in this area. The unit in the Slickhorn exhibits a normal sequence excepting that dolomitization continues higher into the fossiliferous part of the unit than is usual. At Honaker Trail the sequence is: upper fossiliferous limestone, central dolomite, and lower siltstone. An uncomformity in the thin-bedded dolomite may be equivalent to the detrital material in the Raplee section.

62 41 18
Slickhorn | Honaker Trail Beds 42-47 | Raplee Beds 23-24

Unit 7. Like most of the other units of the middle member of the Paradox formation, unit 7 is thicker to the west. The uppermost 16 feet of the unit in the Slickhorn locality is dolomite or highly dolomitic limestone which may properly belong to unit 8, but is below a silty limestone considered the basal part of unit 8. The next 15 or more feet is limestone; cherty, slightly dolomitic and

53 34 38 Unit 8. The upper [illegible] of this unit [illegible]
[illegible] of the [illegible], [illegible] the [illegible]
[illegible] to the [illegible] in [illegible]
ity. In the [illegible] it [illegible] than [illegible]
may represent the [illegible] of a [illegible]
inflow that the [illegible].
Detailed information probably would show a
lateral facies change boundary between the
[illegible] and Hoecker Trail localities in this unit.
The unit at the [illegible] shows a normal
sequence [illegible] that dolomitization continues
higher into the [illegible] than
than is usual. At Hoecker Trail the [illegible]
[illegible] dolomite,
dolomite, [illegible].
In the [illegible] dolomite may be [illegible]
to the [illegible] in the [illegible].
62 41 18 Unit 7. Like most of the other units of the
middle member of the [illegible] Formation, unit
7 is thicker to the north. The [illegible] is
[illegible] of [illegible] in the [illegible]
in dolomite [illegible],
which are [illegible] belong to unit [illegible], but is
[illegible]
part of unit 6. The [illegible]
[illegible]

abundantly fossiliferous in the center. No sample was available at the bottom of this fossiliferous calcarenite, hence the true thickness cannot be determined. The detrital part of this unit is probably a very thin bed of sandstone, represented in the well samples by from 10 to 15 per cent sand in the bottom 10 feet of the section. The intervening 21 feet is the unsampled interval and fine-grained, gray, non-fossiliferous limestone overlying the basal sequence.

In the Honaker Trail, unit 7, like unit 8 shows strata that seem to be superflous to the cyclic sequence. A fine-grained, gray, cherty limestone is equivalent to the uppermost dolomite of the Slickhorn section. This equivalent limestone makes up all of unit 7 in the Raplee locality and may represent conditions of limestone precipitation which restricted fossil growth, such as unfavorably cold water or quiet water with no bioclastic influx. The cyclic sequence at the Honaker Trail locality is thin, and not as well defined as the others. It may be seen only in the lower half of the unit. The upper 10 feet is fossiliferous

calcarenite (Fig. 9) underlain by an arenaceous limestone. This unit is separated from unit 6 by a disconformity.

To the east at the Raplee locality, the fossiliferous calcarenite, seen to be thinner at Honaker Trail, has either wedged out or undergone a facies change reflecting conditions unfavorable to faunal growth. The top of the unit is thinly bedded gypseous limestone with a chert layer. The bottom 11 feet is limestone, with shale content up to 35 per cent.

48 31 28 Unit 6. The same eastward change in lithology and faunal content as shown in unit 7 may be seen here, perhaps an indication that reef development has abated or shifted westward. Fairly normal cycle sequence in the Slickhorn locality is shown by fossiliferous and dolomitic calcarenite at the top; with dolomite and limestone in the middle; and at the base, a 14-foot cherty limestone containing traces of pyrite and biotite, probably due to an influx of continental detritus.

Slickhorn Honaker Trail Beds 38-41 Raplee Bed 22

At the Honaker Trail, fossil material is very scarce in unit 6. The upper one-third

Figure 9

Upper: Brachiopod fragment in fossiliferous, arenaceous limestone from bed 44, Honaker Trail locality. 62X. Plain polarized light.

Lower: Crinoid columnal and coral (?) fragments in detrital limestone from Bed 44, Honaker Trail locality. Limestone contains from 25 to 30 per cent feldspar and a few quartz grains. 62X. Plain polarized light.


HT44

is cherty, dolomitic limestone and dolomite; the middle one-third is a resistant, lithographic to fine-grained, gray to black limestone. The lower one-third is arenaceous limestone. No samples are available where the base of the unit should appear.

At the Raplee anticline this unit is divisible into two parts, neither of which is fossiliferous. The upper 10 feet is a resistant, silty and dolomitic limestone; separated by 4 feet of thin-bedded silty limestone from the less resistant gypseous dolomite making up the lower part of the unit.

40 39 37 Unit 5. The thickness of this unit is probably uniform along the length of the cross section. The cyclic sequence may be seen only in the Honaker Trail section where the upper part of the sequence is the middle bioherm (Wengerd, 1955 b, Fig. 7), and the subjacent arenaceous fossiliferous calcarenite (Fig. 10A).

Slickhorn
Honaker Trail Beds 29-37
Raplee Beds 19-21

An example of the cyclic sequence may be seen in the series of thin sections, HT 36 through 30 made from samples of this lowermost unit of the middle member of the Paradox formation. HT 36 is taken from the part of the unit

ic chert, calcitic limestone and dolomite [illegible]
the middle [illegible] is a crystalline, fine-
grained to fine-grained, gray to black lime-
stone. The lower [illegible] is argillaceous lime-
stone [illegible] the [illegible]
base of the [illegible].

In the [illegible] section the unit is
divisible into three parts, the lower of which is
fossiliferous. The upper 10 feet is a resist-
ant, silty and argillaceous limestone, separated
by a zone of thin-bedded silty limestone
from the lower resistant and fossiliferous
making up the lower part of the unit.

40 39 37 Unit 5. The thickness of this unit increases
eastward along the length of the cross section.
The cyclic sequence occurs only in the
[illegible] section where the upper part
of the sequence is the [illegible] (Wengerd,
1955 b, Fig. 7), the principal [illegible]
fossiliferous, Calamites [illegible] (Fig. 12).

An [illegible] of the cyclic [illegible] may be
seen in the [illegible] of the [illegible]
through 30 units [illegible] of the [illegible]
unit of the cyclic [illegible] of the [illegible]
tion, 30 [illegible]

Figure 10A

Upper: Highly fossiliferous calcarenite bioclastic; contains fragments of corals, foraminifera and unidentified forms, many of which are highly altered. Bed 36, Honaker Trail locality. 62X. Plain polarized light.

Lower: Probable foraminifera with fragments of other fossils in calcarenite from Bed 35, Honaker Trail locality. 62X. Plain polarized light.

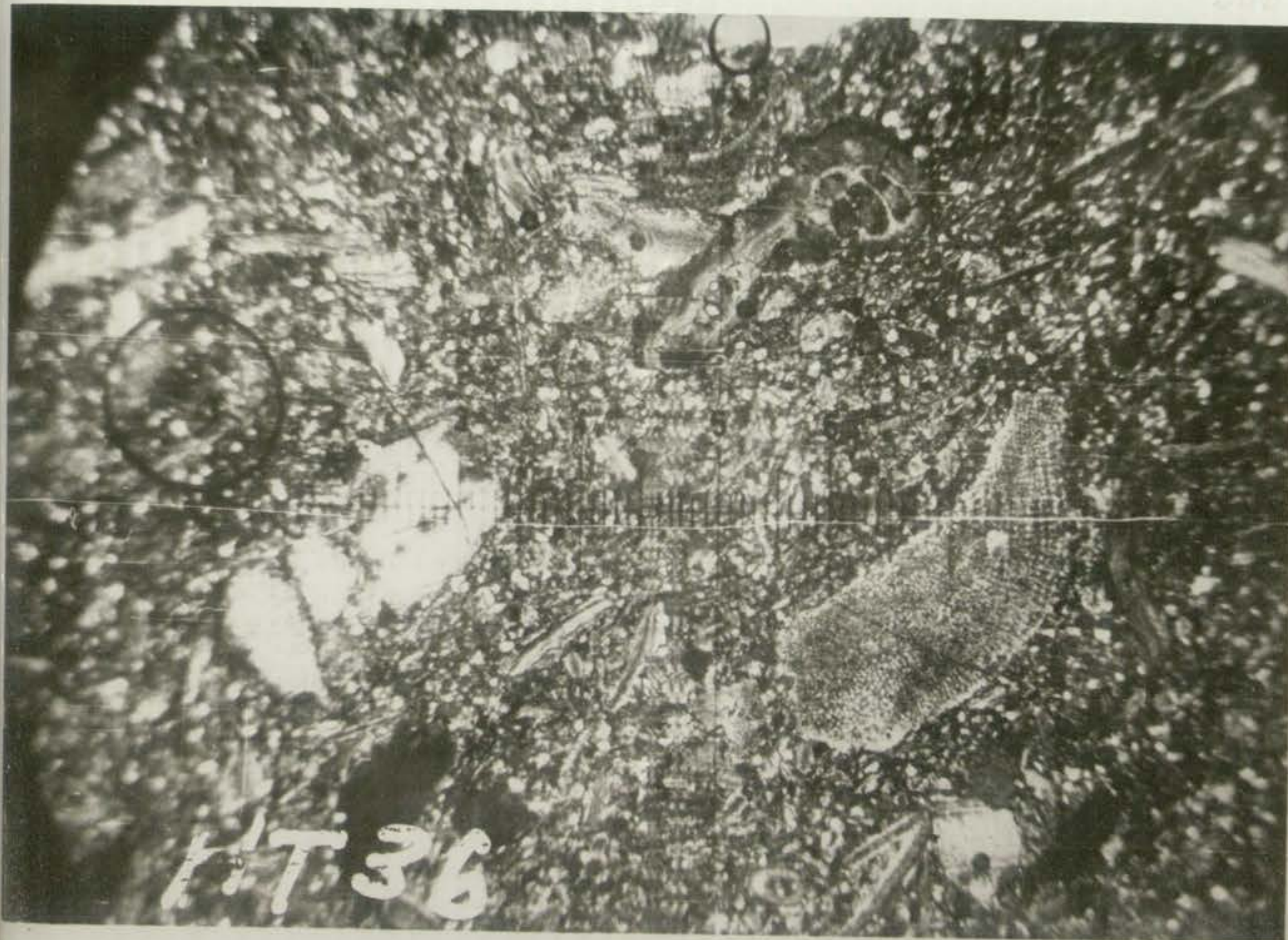

HT36

Figure 10B

Upper: Large crinoid columnal from Bed 35, Honaker Trail locality. 62X. Plain polarized light.

Lower: Brachiopods, ostracods and foraminifera in sandy calcarenite from Bed 35, Honaker Trail locality. 62X. Plain polarized light.

[illegible] Woonaker

[illegible].

[illegible] ...ters in

[illegible] locality.

36e

containing the middle bioherm; is gray, fine-crystalline to coarse-granular limestone containing corals, bryozoans, brachiopods and algae. Most of the coarse granular material is fossil fragments; it comprises cephalopods, corals (Chaetetes sp.), bryozoans, brachiopods, crinoids, fusulinids, and pelecypods. The bioherm sample contains about 30 per cent sand, and may have been flooded by detrital material. Most of the remaining 70 per cent is fossil fragmental, with a matrix of fine calcite. HT 35 was made from the limestone part of a sandstone and limestone bed. The limestone is almost all fragmental shells and calcite; possibly a biobreccia from a nearby reef. HT 34 is a gray dolomitic limestone with a moderate amount of fossil fragments, contains some euhedral calcite filling in vugs. HT 33 is a gray, lithographic to fine-grained limestone, 20 per cent fossils, 5 per cent chert, a trace of zircon, and the 75 per cent remaining is calcite. HT 31 is an areanceous limestone, not a calcarenite, equivalent to silty beds in the Raplee section. HT 30 is probably fore-

repetitions, the [illegible] which [illegible] a [illegible] of the [illegible] [illegible] cephalopods, [illegible] 23.1 per-cent, [illegible] and polychaetes. The [illegible] about 50 per cent [illegible] remaining [illegible] with a [illegible] from the [illegible] and [illegible] all fragments, [illegible] a [illegible] of shells, [illegible] not a [illegible]

reef talus, representing the top of the next cycle. So we see that HT 36 is the calcarenite, HT 35 through 33 are the central part of the sequence and HT 31 represents the detrital base of the sequence.

Raplee Beds 12-18

98 Gypsum lentil. At this point mention must be made of an important stratum not designated as a unit, and present only in the Raplee section. The westernmost extent of the middle Paradox gypsum-black shale sequence is represented by a wedge of gypsum and siltstone with lentils of limestone, calcarenites and dolomite. The wedge is ninety-eight feet thick at the Raplee locality and if represented at all at the Honaker Trail locality is only a thin lentil of siltstone. The uppermost bed of this wedge is white, fine-grained gypsum 31.5 feet thick, containing from 10 to 15 per cent dolomite. Beds 16 and 17 are the same except for from 25 to 30 per cent silt in the gypsum. Below this point, the gypsum contains limy, fossiliferous material. Limestone conglomerate apparently derived from a calcarenite in bed 14 contains a moderate amount of fossils including a probable

Dictyoclostus sp. Bed 13 is 42.5 feet thick, and composed of white gypsum with lentils of limestone (Fig. 11); some crinoid fragments, chert, and brown oil staining are present. The lowermost bed of the wedge is silty gypsum, slightly darker in color, ranging from buff to gray. Some pieces of limestone in this sample are crinoidal; others indicate mixed fossil assemblages and exhibit lineation of fragments. (Fig. 11) The limestones in the last two beds are indicators of entirely different water composition than that which precipitates gypsum. These limestones may be the result of a temporary influx of fresher marine water into an evaporite-depositing environment.

The bottom of the gypseous lentil is the bottom of the middle member of the Paradox formation. Basis for this is found in the sudden appearance of gypsum in dominant quantities in the Raplee section, with correlative disconformities in the Honaker Trail section. Additional information from other areas will be necessary to fix the boundary unequivocally.

[illegible]. [illegible] and [illegible] [illegible]
and [illegible] of [illegible] [illegible]
[illegible]
[illegible]
The [illegible]
[illegible]
[illegible]
In this sample the following pattern [illegible]
[illegible] and [illegible]
of [illegible]. [illegible], but the [illegible]
[illegible]
[illegible]
[illegible]
be the result of [illegible]
may be [illegible]
environment.

The [illegible]
be [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible].

Figure 11

Upper: Large fusulinid, more than 1.5 mm. in diameter. Filled with calcite, from calcarenite in gypsum lentil, Bed 14, Raplee locality. 135X. Plain polarized light.

Lower: Highly altered unidentified fossil fragments showing alignment. Sample from Bed 13, Raplee locality, also in the gypsum lentil. 62X. Plain polarized light.

[illegible] 8.

[illegible] more than 1.5 mm. in

[illegible] calcarenite in

[illegible] locality. 135X. Plain

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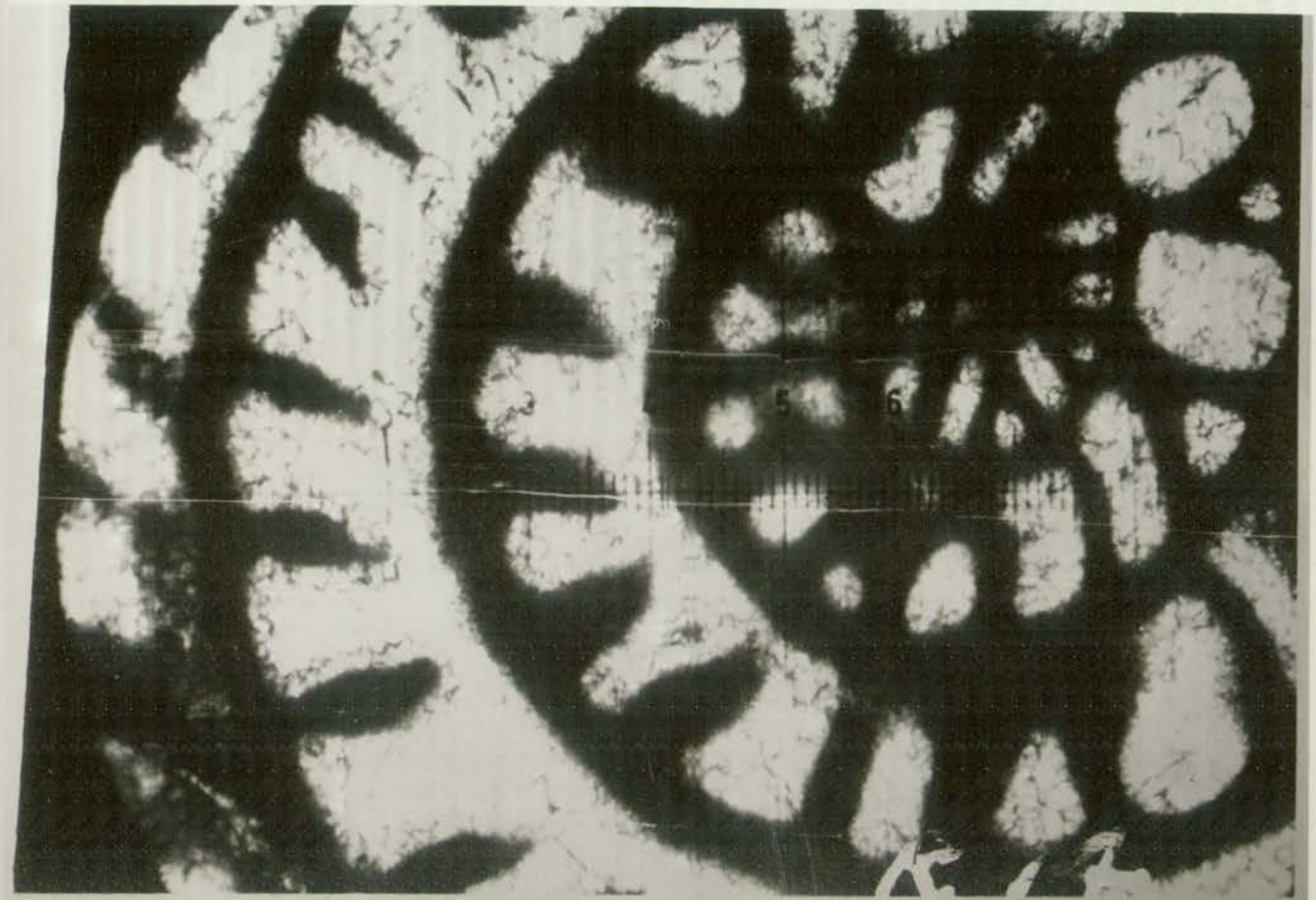
[illegible] Bed 13, [illegible] local-

[illegible] 62X. Plain polarized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Not all of the bottom of the Paradox formation is exposed in the Honaker Trail and Raplee localities, and although unit numbering begins at the level of river water at its low stage, unit 1 may not be the lowermost in the formation. Wengerd (unpublished log) has tentatively placed the bottom of the formation a little more than 40 feet above the river.

Slickhorn / Honaker Trail Beds 22-31 / Raplee Beds 10-11

20 39 37 Unit 4. The uppermost unit of the lower member is fossiliferous limestone, in places dolomitic and silty. In the Slickhorn section it is a calcarenite, with abundant corals, crinoids, brachiopods, pelecypods, and echinoid spines. In the center part it contains 10 per cent white chert and 15 per cent black shale with selenite crystals. The top and bottom of the unit contain as much as 10 per cent gypsum. Fragments of fossils are coarse and very abundant. In the Honaker Trail this unit lies between two disconformities and is transected by a third, so the great variation in lithology probably is due to unusual fluctuation of sedimentational conditions. Although predominantly limestone,

Not all of the section of the [illegible]
Formation, as exposed in the [illegible] Fall
and Rapids localities, was [illegible]
[illegible] of the [illegible] of [illegible]
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has tentatively [illegible] the [illegible] of the
Formation a little more than 400 feet above
the river.

20 39 37 Unit 4. The uppermost unit of the [illegible]
member is [illegible] Dolomite. [illegible]
dolomite and silty [illegible] the [illegible]
it is a [illegible] with [illegible]
[illegible], [illegible], and [illegible]
[illegible]. In the [illegible] 10
per cent white [illegible]
shale with [illegible]. [illegible] the
bottom of the unit [illegible] in the
[illegible]. [illegible]
coarse and very [illegible]. In the [illegible]
this unit lies [illegible]
and is [illegible]
[illegible]
[illegible]
[illegible].

the gross lithology is modified by a thin layer of dolomite in the center and is gypseous, cherty and fossiliferous downward in the unit. This lower member was eroded several times as shown by the several disconformities. In the Raplee section, the dolomitic limestone overlies one disconformity and contains another only four feet above. Correlation of these disconformities from section to section can be accomplished only generally with information yielded in this study, although presence of oolitic material above the base of this unit is used as a criterion in this case.

13 11 18 Unit 3. Westward, in the Slickhorn locality, this unit is non-fossiliferous, fine-grained, gray limestone with 10 per cent shale and as much as 20 per cent black chert at the bottom. At Honaker Trail, the unit is thinner, with calcarenitic limestone in the top 5 feet and dolomite in the bottom 6 feet. The calcarenite is largely algal fragments and some foraminifera (Fig. 12). The base of the dolomite is cherty and non-fossiliferous, and overlies disconformably the unit below. In the

Slickhorn / Honaker Trail Beds 18-21 / Raplee Beds 7-9

Figure 12

Upper: High percentage (from 90 to 95 per cent) of weathered fossil fragments forming bioclastic calcarenite in Bed 21, Honaker Trail locality. 62X. Plain polarized light.

Lower: Possible reef contact in breccia from Bed 7, Raplee locality. Arenaceous calcarenite is in the upper part of the photograph and porous algal (?) reef is in the lower part. 62X. Plain polarized light.

Figure 12

[illegible] High percentage (from 90 to 95 per cent) [illegible] fossil fragments forming bioclastic [illegible] in Bed 21, Hooker Trail locality. [illegible] plane polarized light.

[illegible] Possible reef contact in breccia from Bed 7, [illegible] locality. [illegible] calcarenite is in the [illegible] part of the photograph and porous algal (?) [illegible] in the lower part. 62X. Plain polarized [illegible]

Raplee section, unit 3 is at the top of a zone of a downward increase in fossil abundance transitional to the great abundance in unit 2. The upper 6 feet is silty and shaly, gray, and contains only a few fossils. The remaining 12 feet is limestone; slightly dolomitic in the central part and shaly at the bottom. Fossil suites include: algae (Fig. 12), crinoids, brachiopods, fusulinids and other foraminifera.

9 35 14 Unit 2. This unit is thickest in the Honaker Trail locality and thins both eastward and westward. The unit is represented in the Slickhorn locality by limy, cherty dolomite, with from 10 to 15 per cent siltstone. The bottom four feet is siltstone containing some limestone and sand, and traces of selenite and muscovite, and may be found as far eastward as the Honaker Trail locality, but is equivalent to a disconformity in the Raplee locality. The greatest fossil content (Fig. 13) corresponds with greatest thickness in the Honaker Trail. The unit contains an abundance of whole and fragmental specimens of brachiopods, corals, foraminiffera, fusulinids, pelecypods, bryozoans,

Slickhorn

Honaker Trail Beds 10-17

Raplee Beds 3-6

[illegible]

2. The upper [illegible] and contains only [illegible] in the [illegible] Fossil [illegible] Formation.

9 35 14 Unit 3. [illegible]

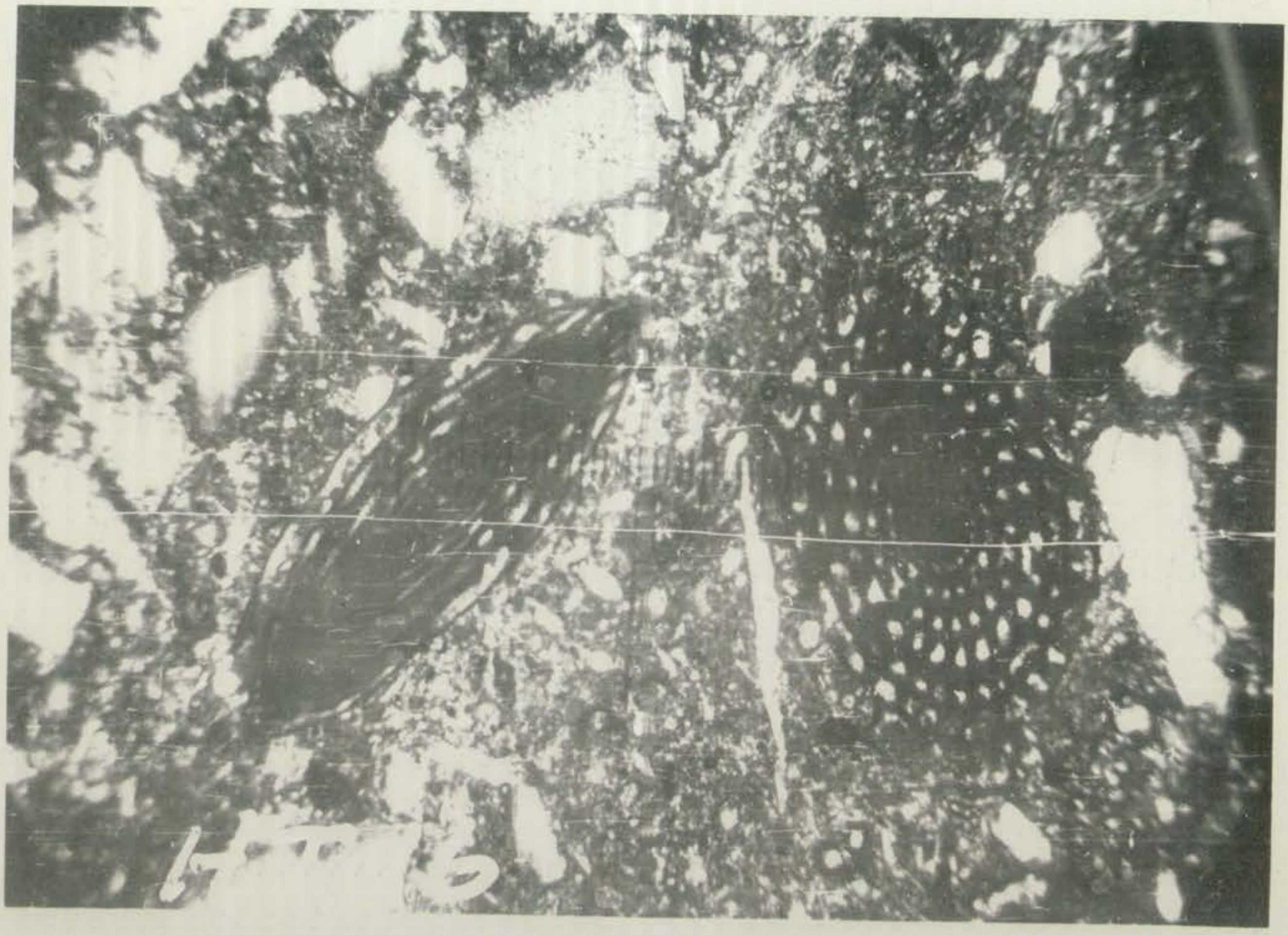
The [illegible] Formation, [illegible]

Figure 13

Upper: Fusulinids (Wedekindellina sp.) and other fossil fragments from Bed 16, Honaker Trail locality. 62X. Plain polarized light.

Lower: Brachiopods and bryozoan fragments from Bed 5, Raplee locality. 62X. Plain polarized light.

45a



and crinoids. These are present in varying amounts throughout the unit, with the exception of bryozoans, which occur principally in a zone in bed 14.

The upper eight feet of the unit is gray to buff calcareous shale and limestone lentils.. Thin sections in the limy parts reveal that fossils are distorted, suggesting strong compaction of lime muds during lithification. The next four feet is a calcarenite, and contains the bryozoan zone mentioned above. In this bed (No. 14) 70 per cent of the rock is whole and fragmental fossils. Silicification in minor amounts probably occurred during early diagenisis. One of two three-foot lentils of sandstone separates the upper half of the unit from the lower half and marks a change in fossil content. The 8.5 foot section immediately below this sandstone is much less fossiliferous than the upper half of the unit; it is a cherty, gypseous, dolomite. The remainder of the unit is abundantly fossiliferous, with fusulinids and other foraminifera and crinoids. The second of the two sandstone lentils, in the

and crinoids. [illegible] present in varying amounts throughout the unit, with the exception of bryozoans, which occur principally in a zone in bed 16.

The upper eight feet of the unit is gray to buff [illegible] and limestone lenticles. Thin sections of the [illegible] reveal that fossils are [illegible], suggesting abrupt compaction of the rock [illegible] lithification. The next four [illegible] and contains the bryozoan zone [illegible] above. In this bed [illegible] of the rock is made up of [illegible]. Silicification in other samples [illegible] occurred during early diagenesis. [illegible] two-three-foot [illegible] of [illegible] the upper half of [illegible] half and [illegible]. The 3.5 foot section [illegible] sandstone is much less [illegible] the upper half of the unit. It is [illegible], [illegible] unit is [illegible] fossiliferous [illegible] and other [illegible]. [illegible] of the two sandstone lenses [illegible]

center of this unit, does not have any apparent relation to the abundance of fossils beneath. The bottom of the unit is marked by a 1-foot bed of black siltstone (bed No. 10) underlying 5 feet of shale containing 10 per cent limestone and from 10 to 15 per cent siltstone.

At the Raplee locality unit 2 thins to only 14 feet and the detrital bottom layer is represented by a disconformity. Again the unit shows an abundance of fossils, including fusulinids and other foraminifera, brachiopods, pelecypods, bryozoans and possibly stromatoporoid hydrozoans (Fig. 13). The upper eight feet is limestone, slightly shaly and cherty, abundantly fossiliferous as above, and stained at the bottom by brown oil. The lower six feet is siltstone and limestone, buff and gray, fine-grained, with only a few fossils and some brown oil staining. The unconformity at the base is probably equivalent in time to the detrital material to the west and northwest.

Slickhorn
Honaker Trail Beds 1-9
Raplee Beds 1-2

32 49 8 Unit 1. This unit is not correlative at the bottom through all three sections, and is included in the discussion because it is of significance at the Slickhorn and Honaker Trail localities, and contains the lower bioherm of the Honaker Trail section. In all three sections the unit is limestone with minor modifying lithology. At the Slickhorn locality fossils and a small (5 per cent) amount of chert distinguish this limestone unit. Thin sections of the Honaker Trail samples show that fossils are abundant in bed 6; mostly bryozoans with a few brachiopods. Bed 6 is probably a biostrome. Bed 3 is that of the lower bioherm, containing algal limestone with brachiopods and ostracods. This limestone has been fractured, filled with calcite and partially recrystallized. Only a few feet of dolomitic limestone represent the upper part of the unit in the Raplee section. The top 18 inches is porous beneath the disconformity, probably due to submarine solution. Brown oil stains the limestone near the river. The bottom of this unit is not exposed at the Raplee locality.

CONCLUSIONS

General Statement

Certain minor conclusions involving lithology have necessarily been stated in the correlation of lithologic units. Influx of detrital materials from various directions indicates changed conditions of sediment source, transportation and deposition. Minor changes in chemical composition involve dolomitization of limestone, replacement of fossils by silica and dolomite and replacement of silica by calcite. These minor changes reflect the change in environment during and after lithification. Gross lithologic features such as texture, grain size, stable minerals, and sedimentary structures are those which provide clues to original depositional conditions.

Members of the Paradox formation exposed in the Monument upwarp by the San Juan River are characterized by different environments of original deposition. These environments have prevailed, at separate times, in the general structural framework of a shelf adjacent to a geosynclinal Pennsylvanian basin. As pointed out by Wengerd (1951) the shelf sedimentation was favorable for the formation of reefs by lime-secreting organisms. This work and later work by Wengerd and others proved

the existence of reefs (bioherms) in the strata exposed by the San Juan River. Even casual examination of samples from the strata shows intervals of tremendous abundance of fossils and fossil fragments in particular. These intervals are calcarenitic and in places biohermal or biostromal, according to structure.

Source and Relation of Allogenic Detrital Material

Presence of allogenic detrital material is not in itself an indication of back-reef sedimentation, even when associated with sediments of great reef potential. At least two directions of derivation of detrital material complicate the picture in the Paradox formation. Most of the thinner, more or less "pure" quartzose facies (that is not mixed in limestone) are derived from the landward or westward side of the reef zone at the southwest edge of the Paradox basin. A large part of the detrital material that dilutes the reef limestone, especially that on the basinward side may have come across the Paradox basin from Uncompahgre and San Luis sources. The large wedges of siltstone and silty gypsum in the middle member must have come from the highlands which stood on the northeast side of the Paradox basin.

This is the nearest source most often cited in literature dealing with Pennsylvanian positive areas (Kelley, 1955, p. 76).

Basis for Division into Members

The upper member of the Paradox formation represents a fairly continuous trend of reef development. At the top and bottom of the member the maximum reef development is near the Honaker Trail locality and the central part of the upper member appears to lie east of the Raplee locality, as indicated by the maximum accumulation of fossils and fossil breccia and by the increase in percentage and grain size of detrital material, principally sandstone, to the west or back-reef side of the zone of reef growth.

Mode of deposition determines the division of strata of the Paradox formation into three members. The upper member is represented by a more or less continuous trend of barrier reefs which shift eastward in the central part of the member as discussed above. In the middle member, five zones of fossiliferous, calcarenitic limestone, unevenly distributed vertically through the member indicate that deposition of these strata was cyclic, and that these are five cyclic lithologic sequences, comprising detrital material

at the bottom and dolomitic limestone at the top of each cycle. The upper part of the sequence is the fossiliferous, calcarenitic limestone, which in places is biohermal or biostromal. The five cycles of deposition are represented in the cross section by units 5, 6, 7, 8 and 9. The sequence is best exhibited in the Slickhorn and Honaker Trail sections, and is complicated by allogenic silt invasion and the deposition of evaporites in the Raplee section.

The lower member contains an abundance of fossils in almost all beds and may represent slow deposition with frequent interruption, as indicated by the several disconformities observed in the field. Not all of the member is exposed, and the lower part may be somewhat different.

Stratal Relationships of Reef Calcarenites

Fossiliferous calcarenites are horizontally widespread and can be correlated through many miles as demonstrated on the cross section. General characteristics are used in correlation and the importance of specific characteristics subdued. Lack of information prevents detailed discussion of continuity of individual characteristics except where expressed by beds below or above; that is, in instances where it is evident that

the depositional mode of the bed directly above or below has shifted horizontally.

A second lateral change is thickening or thinning of calcarenite beds, and a third is variation in concentration of fossil breccia. The first of these is cause and evidence of biohermal development; factors of development of faunal zones and erosional effects on these zones control the second. Detailed analysis of these lateral changes will not be possible until more sections are measured and nearby drilled tests are analyzed.

Age of the Paradox Formation

No attempt has been made to identify genus or species with the exception of some recurring fusulinids, probably *Wedekindellina* and *Fusulina* which occur principally in the lower part of the strata. These fusulinids are of Cherokee age and probably are equivalent to a zone of the same genera in the lower part of the Magdalena group east of Albuquerque, New Mexico (Needham, 1937, p. 15).

Summary of Conclusions

Correlation of reef calcarenites and accompanying strata helps to reveal the depositional history

the [illegible] above as below its [illegible].

[illegible] several [illegible] ning of [illegible] concentration of [illegible] is cause [illegible] of development of lateral [illegible] on [illegible] of these lateral [illegible] more [illegible] are analyzed.

Age of the [illegible] Formation

No [illegible] species with the exception of [illegible] probably [illegible] primarily [illegible] Franklinian [illegible] valent to a [illegible] of the [illegible] (Teichert, 19[illegible], p. [illegible]).

Summary of Conclusions

[illegible]

ing [illegible]

of the Paradox formation. Structurally situated high on the southwest sedimentational shelf of the Paradox Basin, the scene of deposition was subject to shifts in sea level, shore line, and break in slope. Disconformities in the limestone section, indicated by solution porosity and traces of weathering at the tops of beds, may represent only relatively short interuptions of deposition, as products of severe weathering are not often found in the section. This lack of evidence of severe weathering may be an indication that the disconformities are of submarine origin. Such surfaces could result from slowed deposition and subsea erosion on the shallow shelf. No evidence of active subaerial erosion was found, and some surfaces are marked by the presence of oolites, which are formed in shallow water. At least part of these disconformities are due to submarine erosion.

The lower member is exposed only in its upper part, and that part is abundantly fossiliferous. This could be accounted for by continued slow deposition near sea level, borne out by the appearance of several disconformities which indicate a lowering of sea level in relation to limestone deposition. Relatively little detrital material is present in the lower member of the Paradox formation exposed in the San Juan Canyon.

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The middle member represents a changed mode of deposition. The most significant feature is the introduction of a thick, silty gypsum wedge from the east, related to the southern part of the Paradox sedimentational basin. This thick wedge is the southwesternmost extension of the gypsum-salt-anhydrite-black shale sequence of the middle member in the Paradox basin. Not enough evidence is presently available to show the relationships of the gypsum wedge to the high-shelf limestones farther to the southwest. However, the wedge contains calcarenitic limestone and the relationship is probably an intertonguing one. The presence of calcarenite in a gypsum section is proof enough that depositional environment can change by the amount necessary to maintain an intertonguing relationship, or that mixing of products from two closely adjacent environments can take place near the break-in-slope which controls distribution of reefs.

The strata equivalent to and above the gypsum wedge are set off from the rest of the formation by a cyclic character of deposition. A cyclic sequence has been discussed earlier, and briefly is made up of an upper fossiliferous calcarenite (biostrome or bioherm), a central limestone which may be dolomitic, and a lower detrital bed or increased percentage of detrital

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material in the carbonates. This sequence probably represents periodic subsidence, causing initial deposition of clastics such as sand and silt below effective wave wear base, followed by a rapid building of limestone which may be changed to dolomite during lithification. Finally, during still-stand of the sea, organisms unhindered by great detrital influx, are given the opportunity to spread and develop. Five such cycles are represented in the middle member.

The upper member may have been developed when a balance between subsidence and deposition was an effective control on bottom conditions. The zone of maximum development of organisms can be seen to have shifted slightly eastward as the member built up, then as the middle of the member is passed, to return to the west. This is borne out by an increased abundance of sand, silt and shale in the central part of the unit at the westernmost stratigraphic section. Organic development is relatively constant and is fairly continuous upward through the member. No typical back-reef lithology is present among the reefs as Link (1950, p. 276) has said will appear in the case of a regressive sea, and the extension eastward refutes the possibility of a continuously transgressive sea. Continuous constant quantity of a relatively narrow

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reef zone necessitates approximate balance with subsidence. This narrow reef zone marks the boundary between two shifting environments, the saline environment of the Paradox basin on one side, and the environment of detrital influx on the other. The eastward and upward trend in the lower part of the upper member reflects the encroachment of the detrital environment. Reversal of the eastward trend in the upper half of the upper member reflects the shifting of the boundary away from the basin, probably due to slowed subsidence in the basin.

Known reefs of the Paradox formation are not large, are mounded in outline (Wengerd, 1951, p. 1046), and occur in linear trends. Whether or not these reef trends are larger or smaller in certain directions away from this area of localized investigation is not known; the chief importance is in their presence, and in the localized sedimentational environments which they create by their existence. If the reef trends thicken or enlarge, they may be important to the oil industry. Significant discoveries of oil have been made in correlative strata to the east near Desert Creek and Aneth, Utah, in the u,per member of the Paradox formation. With the incentive of economic

importance of these strata much more will be known about the Paradox formation in a relatively short time. It is hoped that this investigation will have contributed to increased knowledge of the Paradox formation, and will provide a frame of reference to the sedimentational complexities which characterize one section of the shelf of an evaporite-depositional embayment, the Paradox basin.

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APPENDICES

APPENDIX A

Lithologic Description of Measured Sections

Two of the three stratigraphic sections used in this study were measured on the wall of the San Juan River canyon. The location of the Raplee and Honaker Trail sections are previously described; the first section described is the easternmost and is measured through the Raplee anticline as cut by the San Juan River. Footage on the log is measured from the river level upwards and is the summation of the thicknesses of individual beds. Beds are numbered from the river level upwards and the uppermost in the Paradox formation is numbered 41.

Lithologic [illegible]

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Juan River canyon. The [illegible]
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is measured [illegible]
the San Juan River. [illegible]
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of the thicknesses of individual [illegible]. [illegible] are
numbered from the river level [illegible]
ment in the Paradox [illegible]

Raplee Section

Thickness (feet)	Description
21.5	Bed 41. Gray to black limestone, unevenly bedded, fine to medium crystalline, fossil fragments of medium grain size. Porosity is cavernous. Fragments of crinoids, brachiopods, and corals are abundant in the upper part and present in the middle and lower parts. Shale predominates in the lowermost three feet and is interbedded with limestone.
14	Bed 40. Gray limestone and gray-buff dolomite containing a two-foot layer of chert. Dolomite and limestone are fine to medium crystalline, showing fracture porosity. There are no fossils.
21	Bed 39. Gray to buff limestone, silty at the bottom; fine to medium-grained. Fossils increase in abundance downward, and suites include brachiopods, bryozoans, corals, crinoids, and many fragments. This limestone overlies disconformity.
Disconformity	
10	Bed 38. Gray, lithographic to fine-grained silty and cherty limestone containing only a few fossil fragments and traces of pyrite. Black chert content is as much as 20 per cent.
4	Bed 37. Gray limestone containing a moderate amount of brachiopod and crinoid fragments, no chert.
3.5	Bed 36. Gray, fine-grained to lithographic limestone containing abundant chert and a moderate amount of brachiopod, coral, and crinoid fragments.
13	Bed 35. Gray, lithographic to fine-grained limestone containing abundant corals and bryozoans and a few ostracods. Massive bedded limestone, cherty at the bottom, exhibiting solution and interfossil porosity. This is a biostrome.

Kaplee Section

Thickness (feet) Description

21.5 Bed 41. Gray to [illegible] limestone, [illegible] bedded, [illegible] medium [illegible], [illegible] fragments of [illegible] [illegible] [illegible] common. Fragments of [illegible], [illegible] and corals are abundant in the [illegible] and present in the middle and lower part. [illegible] in the lower [illegible] feet and is [illegible] with [illegible].

14 Bed 40. Gray limestone and [illegible] containing a two-foot layer of chert. Dolomite and limestone [illegible] crystalline, [illegible] crystals. There are [illegible] fossils.

21 Bed 39. Gray to gray limestone, [illegible] the bottom [illegible] to [illegible] [illegible] between is [illegible] covered, [illegible] [illegible], [illegible], crinoids, and [illegible] fragments. [illegible] [illegible] [illegible].

Disconformity

10 Bed 38. Gray, lithographic [illegible] silty and [illegible] [illegible] containing [illegible] a few small fragments [illegible] [illegible]. Black chert [illegible] [illegible] [illegible] [illegible].

4 Bed 37. Gray limestone containing a [illegible] amount of [illegible] and [illegible], no chert.

3.5 Bed 36. Gray, [illegible] to [illegible] limestone containing [illegible] [illegible] moderate amount of [illegible], [illegible] and crinoid fragments.

13 Bed 35. Gray, [illegible] to [illegible] limestone containing [illegible] [illegible] [illegible] [illegible], [illegible] and [illegible], [illegible] of [illegible] [illegible] [illegible] [illegible] [illegible] in a [illegible].

18.5 Bed 34. Gray, lithographic to medium-grained limestone, notable for the abundance of fusulinids, possibly Fusulina sp. in the uppermost part. The top part is a continuation of the biostromal layer above.

Disconformity

4.5 Bed 33. Gray, medium to coarse-grained limestone conglomerate, containing abundant oolites and a moderate amount of fusulinids. Porosity is increased by solution cavities.

7.5 Bed 32. Gray, fine to medium-granular limestone. Granular texture is due to the presence of siliceous oolites which occur only in this bed and at the top of the next. Oölites are due to silica replacement of calcareous oolites, some of which have had fragments of fusulinids as the centers.

6.5 Bed 31a. Gray, fine to medium-crystalline limestone, oolitic in the upper three feet, containing a moderate amount of fossil fragments.

11.5 Bed 31b. Gray, fine-grained limestone, silty in the center, cherty at the bottom. Fragments of corals, crinoids and fusulinids increase in abundance toward the bottom. The bottom two feet is a fusulinid and biostromal limestone.

13.5 Bed 30. Gray, fine to medium-crystalline limestone with siliceous interbeds. Fusulinids and gastropods are present in moderate amount and one form is probably a nautiloid cephalopod.

28.5 Bed 29. Very thick, gray limestone of fine-grained texture. There are only a few fossil fragments and some brown oil stain. Nodular and layered chert comprises 10 per cent of the top six feet and black to dark gray chert is almost as abundant in the bottom six feet.

25.5 Bed 28. Gray to black fine-grained limestone. The top 10 feet contains up to 10 per cent silt, has siliceous interbeds and a few brachiopods, possibly Dictyoclostus and Derbia sp. The lower half contains chert in amounts up to 10 per cent, while at the bottom are coarse grains and pebbles of limestone conglomerate.

Disconformity

7 Bed 27. Brown to gray, interbedded limestone and shale, fine-grained and abundantly fossiliferous. The middle third of the bed is shale and the upper and lower thirds are limestone. Fossil suites include brachiopods, corals, crinoids, and fusulinids, some of which are replaced by jasper. The relationship of the shale and limestone is much like intertonguing.

9.5 Bed 26. Gray, fine-grained limestone containing medium-granular fragments of corals and crinoids which decrease in abundance downward. This bed and the last one are in the fossiliferous parts correlative with the upper bioherm of the Honaker Trail section.

37.5 Bed 25. Buff siltstone with 40 per cent buff limy shale. Fine-grained, no fossils.

Disconformity

9.5 Bed 24. Brown to black, coaly, calcareous, shaly siltstone with brown oil staining. Very fine to fine-grained. No fossils.

24.5 Bed 23. Buff, fine to medium-grained siltstone in the top 10 feet containing 20 per cent buff shale. Silty, gypseous limestone, gray and yellow to brown in color, some green grains may be glauconite. Fine to medium-grained; no fossils.

12.5 Bed 22. Buff, fine-grained, gypseous, calcareous, shaly siltstone. Limestone nodules. No fossils.

5 Bed 21. Gypsum, very fine-grained, white, no fossils.

10.5 Bed 20. Upper three feet is dolomite, lower 7.5 feet is siltstone with 25 per cent gypsum. Gray to buff, no fossils.

21.5 Bed 19. Buff to gray; shale in top 4 feet, unevenly bedded, gray, fine-grained dolomite with a few fossil fragments in next 3 feet. The bottom 14.5 feet is 70 per cent siltstone and 30 per cent gypsum. No fossils.

31.5 Bed 18. White, fine-grained gypsum, 10 per cent gray fine-grained dolomite. No fossils.

2.5 Bed 17. Gray, fine-grained siltstone containing 10 per cent gray fine-grained dolomite, slightly gypseous. Exhibits unusual porosity; about 20 per cent in dolomite due to fracture and solution.

13 Bed 16. Buff to gray siltstone of fine grain size, containing 20 per cent gray dolomite interbeds. A few fossil fragments.

3.5 Bed 15. Gray limestone conglomerate, with chert layer at the top. Slightly gypseous, containing a few ostracods.

12 Bed 14. Gray siltstone in the top half and fine-grained fossiliferous dolomite in the bottom half, with 20 per cent gypsum in both. Fossil fragments may be <u>Dictyoclostus</u>. There are also many fragments of other forms.

Disconformity

42.5 Bed 13. White, very fine-grained gypsum, no fossils in gypsum, but an abundance of fusulinids and crinoids in limestone nodules and interbeds. Some chert and brown oil stain.

15 Bed 12. Buff to gray siltstone; a few fossils including a spirifer fragment replaced by jasper. Limestone nodules and interbeds show crinoidal limestone with brachiopod and coral fragments in abundance. Some brown oil stain.

7.5 Bed 11. Dark gray, lithographic to fine-grained, unevenly bedded limestone, gypsum to 10 per cent, dolomite shale interbeds and a very few brachiopod fragments.

9 Bed 10. Gray, fine-grained limestone, shaly at the top and dolomitic and oolitic in the bottom four feet. A few deformed and altered ostracods may be present.

Disconformity

6 Bed 9. Gray, silty limestone with shale partings up to about 10 per cent of the total, lithographic to fine-grained, scattering of oolites.

7 Bed 7. Unevenly bedded, buff to gray, lithographic to fine-grained limestone, cherty in the upper part and containing a few crinoids, brachiopod and other fossil fragments.

Disconformity

4.5 Bed 6. Massive, gray, silty, fine to medium grained calcarenite containing an abundance of fusulinids, brachiopods and foraminifera. Correlative with lower bioherm in Honaker Trail section.

3.5 Bed 5. Gray, fine to medium-grained calcarenite, cherty in the upper half, some brown oil staining, and abundant spirifers and other brachiopods, pelecypods and a possible hydroid.

4 Bed 4. Buff to gray siltstone with 30 per cent gray, fine to medium-grained calcarenitic limestone containing a few fossil fragments.

2 Bed 3. Brown to gray, fine to medium crystalline limestone with very few fossil fragments. Cherty to about 10 per cent. Brown color due to brown oil staining.

Disconformity

6 Bed 2. Gray, fine-grained limestone in the top half, silty dolomite in the bottom half, no fossils. Upper 18 inches porous due to solution.

4 Bed 1. Gray, fine-grained limestone with some brown oil stain.

River at low water

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522 feet of Paradox formation exposed in the Raplee anticline.

Honaker Trail Section

Thickness (feet)	Description
11	Bed 82. Gray, fine to medium-grained, massive limestone, slightly cherty, with a few brachiopod fragments and crinoid columnals. Near top of "Horn Point" limestone.
5	Bed 81. Buff, fine-grained limestone and dolomite in about equal proportions, no fossils.
8	Bed 80. Gray, fine to medium-grained limestone, moderately fossiliferous with forams, brachiopods and corals, probably _Chaetetes_ sp.
6	Bed 79. Buff, coarse-grained, calcarenitic, coraline biostromal limestone. Abundant coral, probably _Chaetetes_ sp.
17	Bed 78. Gray, fine-crystalline to medium-granular limestone containing 5 per cent blue-white chert and a moderate amount of forams, brachiopods and corals.
7.5	Bed 77. Dark gray, lithographic to medium-grained limy chert bed, no fossils.
8	Bed 76. Buff to dark gray shale, containing 30 per cent fine-grained dolomitic limestone. Moderate amount of fossil fragments, mostly brachiopod.
3	Bed 75. Gray, fine-grained limestone, moderate amount of brachiopods and crinoid columnals.
1	Bed 74. Buff, fine-grained limestone, abundant fusulinids and crinoid columnals, may be lower Cherokee in age.
3	Bed 73. Buff, fine-grained sandstone, subangular, well-sorted, containing 15 per cent limestone.
25.5	Bed 72. Gray, massive, lithographic to fine-grained limestone, many fossil fragments becoming abundant toward the bottom. Some

green material in calcarenite zones may be glauconite.

5 Bed 71. Buff, thin-bedded, fine-grained sandstone, subangular, fair sorting, no fossils.

12 Bed 70. Gray, lithographic to fine-grained limestone, moderately fossiliferous toward the top; fragments of brachiopods, pelecypods, and a few fusulinids.

9.5 Bed 69. Sixty per cent buff, fine-grained sandstone and 40 per cent gray, fine-grained limestone. Sandstone is subangular to subrounded and fair to well-sorted.

11.5 Bed 68. Sixty per cent gray limestone as above, and 40 per cent buff sandstone as above. No fossil material.

1 Bed 67. Buff, fine-grained sandstone, calcareous, subangular to subrounded, fair sorting, slightly ferruginous.

14 Bed 66. Gray, fine-grained arenaceous limestone, massive-bedded.

16 Bed 65. Gray, fine-grained limestone containing 5 to 10 per cent shale and traces of pyrite.

5.4 Bed 64. Gray, fine-grained limestone containing 10 per cent medium-grained buff sandstone, no fossils.

11.8 Bed 63. Cherty, dolomitic limestone and sandstone. Lithographic to fine-grained gray limestone and dolomite in equal amounts containing 5 to 10 per cent chert make up 90 to 95 per cent of the bed; fine-grained sandstone the other 5 to 10 per cent.

6 Bed 62. Black, carbonaceous shale, calcareous, with a 2-foot bed of fine-grained limestone at the top.

1.3 Bed 61. Gray, fine-grained, arenaceous limestone equivalent to Girty 168 (Woodruff, 1910).

4 Bed 60. Gray, fine to medium-grained, moderately fossiliferous calcarenite. Fossil material includes brachiopods, pelecypods and fragments of these.

2 Bed 59. Buff, fine crystalline to medium-granular calcarenitic limestone with a moderate amount of fossil fragmental material.

5.5 Bed 58. Gray, calcarenitic limestone, coarsely granular in fine crystalline matrix. Coarse grains are abundant fragments of brachiopods and pelecypods.

5 Bed 57. Lithographic to fine-grained gray limestone, containing no fossils.

5.5 Bed 56. Buff shale and sandstone. Shale dominates sample to about 75 per cent; fine-grained, subangular, poorly sorted sand makes up the other 25 per cent.

4 Bed 55. Gray, argillaceous fine to medium-grained limestone.

11 Bed 54. Gray to buff, fine-grained, argillaceous dolomite. No fossils.

16 Bed 53. Upper bioherm. Buff to gray, fine-grained limestone. May contain glauconite. No fossil material in this sample. Chert in amounts of 5 to 10 per cent. Mounded structure is significant and this bed is (Wengerd, 1955 b) correlative with bioherms.

11 Bed 52. Buff, fine to medium-grained shaly sandstone, subangular, poorly sorted, and containing about 15 per cent limestone, and calcareous cement.

4 Bed 51. Gray, lithographic to fine-grained dolomite.

19.5 Bed 50. Gray, fine-grained limestone. Chert in amounts to 15 percent, a few crinoid

columnals and unidentified fragments. Bottom 3 feet is dolomite with no chert and no fossils.

Disconformity

4.5 Bed 49. Buff to gray, fine-grained dolomite.

5 Bed 48. Dark gray, lithographic to fine-grained, silty dolomite.

16.4 Bed 47. Buff to black, fine-grained limestone; dolomitic at the top and containing up to 10 per cent chert in the remaining 14 feet.

4.4 Bed 46. Gray, lithographic to medium-grained limestone, argillaceous and with a moderate amount of unidentified fossil fragments.

5 Bed 45. Gray, fine-grained limestone and dolomite in equal parts. Non-fossiliferous.

10 Bed 44. Gray, fine-grained limestone with a central 1-foot bed of coarse sandstone. The top 4 feet of the limestone is abundantly fossiliferous, containing fragments of crinoids and brachiopods and unidentified material. Abundance decreases toward the bottom. In the top part, the coarse texture is due to fossil fragments and coarse calcarenite.

2 Bed 43. Gray, fine-grained limestone, few fossil fragments.

4 Bed 42. Gray, fine-grained limestone, very few fossil fragments.

Disconformity

5.5 Bed 41. Gray, fine-grained, cherty limestone, psuedo-oolitic because of tiny nodules of chert in amounts up to 15 per cent.

4.5 Bed 40. Gray, lithographic to fine-grained dolomite, barren of fossils.

colonies and microfossils [illegible]. Bottom 3 feet [illegible]

Disconformity

4.5 Bed 10. [illegible].

5 Bed 46. Dark gray, lithographic [illegible] [illegible].

10.4 Bed 47. [illegible] oolitic [illegible] at 10 per foot [illegible].

4.4 Bed 45. Gray, lithographic to [illegible] limestone [illegible].

5 Bed 44. Gray, fine-grained limestone with [illegible] in equal parts. [illegible].

10 Bed 44. Gray, fine-grained [illegible] limestone [illegible]. The top 4 feet of the [illegible] fossiliferous, [illegible] crinoid [illegible] and brachiopods [illegible] abundant [illegible] fossil [illegible].

2 Bed 43. Gray, fine-grained limestone, few fossil fragments.

4 Bed 42. Gray, fine-grained limestone, few fossil fragments.

Disconformity

5.5 Bed 41. Gray, fine-grained [illegible] pseudo-oolitic [illegible] 10 feet [illegible].

4.5 Bed 40. Gray, lithographic [illegible] colonies, [illegible] of fossils.

12 Bed 39. Black, lithographic to fine-grained cherty limestone. Chert in amounts up to 5 per cent

5 Bed 38. Buff sandstone, fine-grained, subangular, fair sorting, containing 15 per cent fine-grained, gray, fossiliferous limestone with crinoid columnals and brachiopod fragments. Slightly calcarenitic.

3 No sample

4 Bed 37. Dark gray limestone, fine to lithographic, containing a few fossil fragments.

8 Bed 36. Middle bioherm. Gray, coarsely granular calcarenite cemented by lithographic to fine-grained calcite. Superabundance of fossils including: corals; bryozoans, possibly of the family *Tubuliporidae*; and brachiopods.

8 Bed 35. Sixty per cent highly fossiliferous limestone and 40 per cent fine-grained sandstone. Coarse-grained texture is due to calcarenitic nature. Fossil suites are: brachiopods, pelecypods, and a possible nautiloid cephalopod.

4 Bed 34. Gray, lithographic to fine-grained limestone containing abundant brachiopod and pelecypod fragments.

Disconformity

10 Bed 33. Gray, calcarenite, lithographic to coarse-grained. Cherty up to 5 per cent and containing forams, brachiopods, possible *Spirifer* sp.

8 Bed 32. Equal parts gray, fine-grained limestone and buff siltstone, due to facies change laterally in sampled area. Limestone is calcarenitic, containing a moderate amount of fossil fragments.

1 Bed 31. Buff, fine-grained, arenaceous limestone.

2.5 Bed 30. Gray limestone and calcarenite with gypseous soil. Abundant brachiopods, pelecypods and corals.

4 Bed 29. Gray, dolomitic limestone with a moderate amount of brachiopod and pelecypod fragments. Lithographic to fine-grained.

1 Bed 28b. Gray, gypseous shale. Fine-grained.

3 Bed 28a. Buff to red, fine-grained, subangular, poorly sorted, highly calcareous sandstone. No fossils.

2.5 Bed 27b. Gray, fine to medium-grained limestone, containing "detrital dolomite" according to field log.

Disconformity

2.5 Bed 27a. Dark gray, thin-bedded lithographic limestone and medium-grained calcarenite containing a few brachiopod fragments.

2.5 Bed 26. Dark gray, lithographic to fine-grained limestone with a few brachiopod fragments.

5 Bed 25. Gray, fine-grained to coarsely crystalline, recrystallized calcareous dolomite.

5.5 Bed 24. Gray, fine to medium-grained and medium granular, cherty, calcarenitic limestone. No fossils.

1.5 Bed 23. Gray, fine to coarse-grained dolomite, no fossil material. Calcarenitic.

3.5 Bed 22. Gray, coarse to gravelly calcareous conglomerate, calcirudite, with a moderate amount of fragments of pelecypods, corals and brachiopods.

Disconformity

4 Bed 21. Gray, lithographic to fine-grained limestone calcarenite. Coarse fragments of algae, and foraminifera.

1 Bed 20. Gray, fine-grained dolomite, arenaceous and argillaceous.

4.5 Bed 19. Light gray, fine-grained dolomite.

1 Bed 18. Gray, lithographic to fine-grained limestone, with as much as 15 per cent chert.

Disconformity

4 Bed 17. Gray shale with coarsely calcarenitic nodular and interbedded limestone, some brown oil staining. Abundant spiriferoid brachiopods, corals, crinoids, and foraminifera in limestone. "Lower Des Moines."

2 Bed 16. Gray calcarenite, fine to coarse-grained. Abundant *Fusulina* sp. brachiopods, pelecypods and foraminifera.

2 Bed 15. Buff calcareous shale, calcarenite nodules as above calcarenite.

4 Bed 14. Gray, fine-grained limestone, cherty. Both limestone and chert are fossiliferous. Same suites as Bed 16 with the addition of bryozoans. Chert effervesces in HCl due to calcareous fossils.

3 Bed 13. Buff, fine-grained sandstone, subangular, fair sorting with 25 per cent fine-grained limestone.

8.5 Bed 12. Gray, cherty up to 10 per cent, gypseous up to 5 per cent, lithographic to fine-grained dolomite, containing fossil suites as in Bed 14. Fossils are abundant in the chert.

7.9 Bed 11. Gray, fine and coarse-grained calcarenite with sand layer in bottom of upper half. Bed contains fusulinids, crinoid columnals and foraminifera. (Possibly the identification is faulty or misread, may be another sample from Bed 16).

1 Bed 10. Black siltstone, somewhat sandy.

6.5 Bed 9. Gray, lithographic to fine-grained,

calcarenitic limestone. Coarser material contains greatest abundance of coral, fusulinid and brachiopod fragments.

1	Bed 8. Gray siltstone.
7	Bed 7. Gray, lithographic to fine-grained, cherty, unevenly-bedded limestone. Chert in amounts up to 5 per cent.
1	Bed 6. Gray, fine-grained limestone. Zone of tubuliporoid bryozoans in moderate abundance. Calcarenitic.
11.5	Bed 5. Gray, fine-grained limestone. Few fossil fragments and a trace of pyrite.
2.5	Bed 4. Gray to buff, fine-grained arenaceous limestone.
9.5	Bed 3. Lower bioherm, gray to brown, grain size ranges from lithographic to medium. A moderate amount of fossil fragments are present.
1	Bed 2. Gray, lithographic to fine grained limestone with a few fragments of fossils.
7	Bed 1. Buff, fine-grained, slightly dolomitic and arenaceous limestone.

558 feet of Paradox formation exposed at Honaker Trail.

APPENDIX B

Description of Thin Sections

In measuring the sizes of particles or fossils in the photographs, the following figures should be used. By the use of a stage micrometer the number of divisions per millimeter in the ocular scale were determined and the actual size in millimeters can be determined from the photos.

All pictures are taken with low-power objective unless otherwise designated. For these, 4.05 large divisions on the ocular scale is equal to one millimeter.

For photographs taken with the medium-power objective, 8.0 divisions in the ocular scale are equal to one millimeter.

For photographs taken with the high-power objective, 35.0 divisions are equal to one millimeter, or conversely, one division in the ocular scale is one thirty-fifth of a millimeter.

The low power objective and the ten power eyepiece produce a magnification of approximately 62 diameters, and the medium power about 135 diameters. These magnifications are calculated from the photographs in the figures.

In both the sections from which thin sections could be made, the samples are numbered from the river level, the lowermost end of the stratigraphic section. Thus, the descriptions begin at the top of the section studied and also with the highest numbered slide obtained. The Raplee section begins with R 41, and the Honaker Trail with HT 79.

Raplee Section

R 41. Hand specimen: Gray to black limestone, unevenly bedded, fine to medium crystalline, fossil fragments of medium grain size. Porosity is cavernous. Fragments of crinoids, brachiopods, and corals are abundant in the upper part and present in the middle and lower parts. Shale predominates in the lowermost part and is interbedded with limestone.
Thin section: Gray-black cherty limestone, fine to medium-crystalline, very fossiliferous in the upper five feet. Brachiopod fragments abound and there are corals, fusulinids, and a thin scattering of gastropods. Most of the fossil material is dolomitized, making up a total of about thirty per cent of the rock. The dolomitized fragments lead to the interesting speculation that they were dolomitized before being included in the limestone in which they are now found. There are also porous zones which seem to be reef material, and it is suggested that this material is derived from a reef contact zone: most likely at the bottom because of the abundance of dolomitized fragments.

R 39. Hand specimen: Gray to buff limestone, silty at the bottom; fine to medium-grained. Fossils increase in abundance downward; suites included are brachiopods, bryozoans, corals, crinoids and many fragments.
Thin section: Gray-buff dolomite, slightly silty at the bottom, texturally fine to medium-crystalline, moderately to abundantly fossiliferous. Fossil suites include: bryozoans, corals, and gastropods. About 20 per cent of the material is calcite, the rest, including the fossils, is dolomite. Diagenesis of fossiliferous lithographic limestone to produce dolomite with some lineation of grain.

R 37. Hand specimen: Gray limestone containing a moderate amount of brachiopod and crinoid fragments, no chert.
Thin section: Gray dolomite, containing moderate amounts of brachiopod, crinoid, coral and pelecypod fragments, most of which are somewhat altered by dolomitization.

Replee Section

R 41. Hand specimen: Grey to black limestone, unevenly bedded, fine to medium crystalline, fossil fragments of medium grain size. Porosity is cavernous. Fragments of crinoids, brachiopods, and corals are abundant in the upper part and present in the middle and lower parts. Shale predominates in the lowermost part and is interbedded with limestone.
Thin section: Grey-black cherty limestone, fine to medium-crystalline, very fossiliferous in the upper five feet. Brachiopod fragments abound and there are corals, fusulinids, and a thin scattering of gastropods. Most of the fossil material is dolomitized, making up a total of about thirty per cent of the rock. The dolomitized fragments lead to the interesting speculation that they were dolomitized before being included in the limestone in which they are now found. There are also porous zones which seem to be reef material, and it is suggested that this material is derived from a reef contact zone; most likely at the bottom because of the abundance of dolomitized fragments.

R 39. Hand specimen: Grey to buff limestone, silty at the bottom; fine to medium-grained. Fossils increase in abundance downward;, which included are brachiopods, bryozoans, corals, crinoids and many fragments.
Thin section: Grey-buff dolomite, slightly silty at the bottom, texturally fine to medium-crystalline, moderately to abundantly fossiliferous. Fossil suites include: bryozoans, corals, and gastropods. About 30 per cent of the material is calcite, the rest, including the fossils, is dolomite. Diagenesis of fossiliferous lithographic limestone to produce dolomite with some alteration of grain.

R 37. Hand specimen: Grey limestone containing a moderate amount of brachiopod and crinoid fragments, no chert.
Thin section: Grey dolomite, containing moderate amounts of brachiopod, crinoid, coral and pelecypod fragments, most of which are somewhat altered by dolomitization.

R 36. Hand specimen: Gray, fine-grained to lithographic limestone containing abundant chert and a moderate amount of brachiopod, coral and crinoid fragments.
Thin section: Gray, lithographic limestone containing chert in appreciable quantities. Thin section has been cut from cherty part of the limestone, so that the moderate amount of brachiopods and corals observed in the hand specimen has diminished to only a very few. Mineralogically the sample contains only about 30 per cent calcite, 30 per cent chert and about 40 per cent feldspars. Much of the calcite is in fossil fragments. Most likely the result of diagenetic silicification of a calcarenite with a lithographic matrix, still partially cemented by calcite.

R 35. Hand specimen: Grey, lithographic to fine-grained limestone containing abundant corals and bryozoans and a few ostracods. Massive bedded limestone, cherty at the bottom, exhibiting solution and interfossil porosity. This is a biostromal layer.
Thin section: The thin section chanced to fall on a contact between limestone and algal reef material and contains a few fossils, mostly algal material. Contains 5 per cent feldspar and quartz, and a slight amount of brown oil staining. The limestone contains a higher percentage of quartz and feldspar than the reef material.

R 34. Hand specimen: Gray, lithographic to medium-grained limestone, notable for the abundance of fusulinids, possibly Fusulina sp., in the uppermost part. The top part is a continuation of the biostromal layer above.
Thin section: Begins a series of thin sections taken from oolitic fossiliferous limestone continuing down to R 27. This top part is gray, fusulinid limestone, lithographic to medium-crystalline. The thin section seems to be from a place where the fossil content is sparse, although the limestone is very oolitic. Although essentially calcite, the limestone contains about 3 per cent feldspar and 7 per cent silica and a trace of hematite.

Some of the silica is chert replacement of fossils and some is euhedral quartz. The laminations on the oolites are thicker in this top layer of oolitic limestone, perhaps indicating that the reef has grown seaward or that the seas have increased capacity to deposit lime.

R 33. Hand specimen: Gray, medium to coarse-grained limestone conglomerate, containing abundant oolites and a moderate amount of fusulinids. Porosity is increased by solution cavities. Thin section: A gray limestone made up of weathering products of a fossiliferous, lithographic limestone, recemented by fine crystalline calcite. In addition to the grains of the original limestone there are oolites that have fragments of fossil material as centers. The fossils in the older material show signs of alteration, either before or during transportation.

R 32. Hand specimen: Grey, fine- to medium-grained limestone. Granular texture is due to the presence of siliceous oolites which occur only in this bed and at the top of the next. Oolites are due to silica replacement of calcareous oolites, some of which have had fragments of fusulinids as the centers. Thin section: A calcarenite, although possibly somewhat removed from a reef. This is an oolitic limestone of unusual characteristics. Mineralogically this rock is made up of about 20 per cent calcite cement, 40 per cent calcareous oolites and about 40 per cent siliceous oolites. It is possible that this rock is a collection of particles derived from the diagenesis of a fossiliferous limestone, silicified and later weathered, acted upon by solution and redeposition of calcite and silica.

R 31B. Hand specimen: Grey, fine-grained limestone, silty in the center, cherty at the bottom. Fragments of corals, crinoids and fusulinids increase in abundance toward the bottom. The bottom two feet of the bed is a fusulinid and biostromal limestone. Thin section: Silty, cherty, grey limestone, lithographic to fine-grained. Fossils in

Some of the silica is chert replacement of fossils and some is euhedral quartz. The laminations on the oolites are thicker in this top layer of oolitic limestone, perhaps indicating that the reef was grown seaward or that the seas have increased capacity to deposit lime.

R 33. Hand specimen: Gray, medium to coarse-grained, limestone conglomerate, containing numerous oolites and a moderate amount of crinoidal fragments. Porosity is increased by solution cavities.
Thin section: A gray limestone made up of rounded fragments of a fossiliferous and oolitic limestone, cemented by fine crystalline calcite. In addition to the grains of the original limestone there are oolites that have fragments of fossil material as centers. The fossils in the older material show signs of alteration, either before or during transportation.

R 32. Hand specimen: Gray, fine- to medium-grained limestone. Oolitic texture is due to the presence of siliceous oolites which occur only in this bed and at the top of the reef. Oolites are due to silica replacement of limestone oolites, some of which have fragments of crinoids as the center.
Thin section: A calcarenite, although possibly somewhat removed from a reef. The siliceous oolitic character of unusual characteristics. Essentially this rock is made up of about 50 per cent calcite cement, 40 per cent limestone oolites and about 10 per cent siliceous oolites. It is possible that this rock is a redeposition of particles derived from the first cycle oolitic limestone, silicified and later weathered, acted upon by solution and redeposition of calcite and silica.

R 31. Hand specimen: Gray, fine-grained limestone, mainly of the matrix. Quartz [illegible]. Fragments of fossils, crinoids and brachiopods. Increase in limestone toward the bottom. The bottom of the [illegible] is a fossiliferous and bioclastic limestone.
Thin section: Gray, massive, gray limestone, [illegible] of [illegible]. Crinoids [illegible]

moderate quantity, increasing toward the bottom. Abundant corals, fusulinids and crinoids. Some corals may be Chaetetes sp. About 55 per cent of the material is calcite, about 25 per cent feldspar and about 20 per cent quartz. An occasional calcareous oolite appears.

R 31A. Hand specimen: Gray, fine to medium-crystalline limestone, oolitic in the top three feet, containing a moderate amount of fossil fragments. Thin section: Gray, fine to medium-crystalline, containing a few fossil fragments, very oolitic in the top three foot. Mineralogically, the material is 95 per cent calcite, of which the thin section shows almost all to be in the oolites, not more than 10 to 15 per cent cement. The other 5 per cent is quartz and feldspar in about equal amounts.

R 30. Hand specimen: Gray, fine to medium-crystalline limestone with siliceous interbeds. Fusulinids and gastropods are present in moderate amounts and one form is probably foraminifera.
Thin section: Oolitic limestone, generally about the same as the sample just above, but containing up to 25 per cent quartz and feldspar. Also the oolites exhibit thinner layers of calcite.

R 27. Hand specimen: Brown to gray, interbedded limestone and shale, fine-grained and abundantly fossiliferous containing brachiopods, crinoids and fusulinids, some of which are replaced by jasper.
Thin section: Brown-gray, lithographic limestone containing an abundance of crinoids, corals, brachiopods, and fusulinids. Some of the fossils are dolomitized and silicified, some are replaced by jasper and most of the fossils appear to have been washed into cracks in a chemically deposited, fractured and weathered limestone, and were possibly accompanied by some brown oil.

R 26. Hand specimen: Gray, fine-grained limestone containing medium granular fragments of corals and crinoids, which decrease in abundance downward. This bed and the last one are correlative in the fossiliferous parts with the upper bioherm in the Honaker Trail.

Thin section: This gray, fine-grained limestone contains almost 5 per cent of brown oil; the other 95 per cent is equal parts of quartz and calcite with trace amounts of feldspar and hematite. The brown oil occurs in the calcite and with it we find euhedral crystals of calcite on the order of one-fourth to one-half millimeter in size in a normally fine-grained limestone.

R 14. Hand specimen: Gray siltstone in the top half, and fine-grained fossiliferous dolomite in the bottom half, with 20 per cent gypsum in both. Organic remains may be *Dictyoclostus* sp., also many fragments.
Thin section: This thin section comes from a very fine-grained limestone that is associated with siltstone and gypsum and shows a moderate amount of fossil fragments in hand specimen, and up to 40 per cent fossil fragments in thin section. The cement and limestone between these fragments is ultra-fine-grained.

R 13. Hand specimen: White, very fine-grained gypsum, no fossils in gypsum, but an abundance of fusulinids and crinoids in limestone nodules and interbeds. Some chert and brown oil stain.
Thin section: This section has much the same locale as the last except that the bed from which it is taken is pure gypsum with the exception of a small amount of limestone. The limestone is cherty, fossiliferous and stained with brown oil. Fusulinids abound in the limestone and there are also present crinoid stems and *Chaetetes* sp. Calcite makes up 85 per cent of the limestone and more than half of this is contained in fossils. Dolomite (3 per cent), feldspar (from 5 to 10 per cent), and quartz (5 per cent) are the other mineral constituents. There is also some brown oil staining. Note that the quartz, feldspar and oil seem to congregate.

R 12. Hand specimen: Buff to gray siltstone; a few fossils including a spirifer fragment replaced by jasper. Limestone nodules and interbeds show crinoidal limestone with brachiopod and coral fragments in abundance. Some brown oil stain.
Thin section: Made from the calcareous material

[illegible]

8 14. [illegible]

8 13. [illegible]

8 12. [illegible]

in a siltstone, this calcarenite contains abundant fossils, mainly crinoids with some brachiopods and corals, algae and a few gastropods. The mineral composition is 85 per cent calcite, 10 per cent dolomite and 3 to 5 per cent brown oil. This is an excellent example of a reef calcarenite. The fossils and fragments are encrusted with calcite and dolomite mineralization, and show very definite lineation, see Fig. 11.

R 7. Hand specimen: Unevenly bedded, buff to gray, lithographic to fine-grained limestone, cherty in the upper part and containing a few crinoids, brachiopods and other fossil fragments.
Thin section: Buff-gray, lithographic to fine-grained limestone containing a moderate amount of algae, brachiopods and corals, with lesser amounts of crinoids and gastropods. The material is very porous and the pores are lined with calcite and dolomite and a trace of hematite. This is a biobreccia containing large pieces of algal reef material.

R 6. Hand specimen: Massive, gray, silty, fine to medium-grained calcarenite, containing an abundance of fusulinids, brachiopods and foraminifera. Correlative with the lower bioherm of the Honaker Trail section.
Thin section: Gray, finely crystalline limestone containing an abundance of the following fossils: algae, brachiopods, corals, and fusulinids. Almost entirely calcite, not far removed from a reef.

R 5. Hand specimen: Gray, fine to medium-grained calcarenite. Cherty in the upper half, some brown oil staining, and abundant spirifers and other brachiopods, pelecypods and a possible hydroid.
Thin section: Probably a fore-reef limestone with abundant and tremendously varied fauna, containing algae, brachiopods, corals, crinoids, fusulinids, pelecypods, and spines resembling echinoid spines. Brown oil stain and structures resembling stromatoporoids are also present. Aside from calcite, there is 5 percent dolomite and about 2 per cent feldspar which is authigenic and largely found inside the shells of fossils. The oil occurs largely in fractures and was probably post-lithification.

Honaker Trail Section

HT 79. Hand specimen: Buff, coarse-grained, calcarenitic, coraline, biostromal limestone. Abundant corals, probably Chaetetes sp.
Thin section: A buff, coarsely granular, algal, coraline limestone with large fragments of brachiopod shells. All the material is calcite, either as original coral and algal material or as later brachiopod and calcite filling material. The limestone is very porous; a few pores are filled. The limestone can be definitely classed as biostromal reef development.

HT 72. Hand specimen: Gray, massive, lithographic to fine-grained limestone, many fossil fragments, becoming abundant toward the bottom. Some green material in calcarenite zones may be glauconite.
Thin section: A light gray, lithographic to finely crystalline calcarenite containing abundant fusulinids and algal material with moderate amounts of brachiopods, corals and crinoids, oolitic up to 25 per cent. Quartz in trace amounts to 2 per cent amounts and feldspar up to 25 per cent, most grains of which are the cores of oolites.

HT 70. Hand specimen: Gray, lithographic to fine-grained limestone, moderately fossiliferous toward the top; fragments of brachiopods, pelecypods and a few fusulinids.
Thin section: Gray, lithographic to fine-grained limestone, containing moderate amounts of fragments of algae, brachiopods, and fusulinids, with thinly distributed corals, crinoids, and pelecypods. The material is 95 per cent calcite, 5 per cent quartz and a trace of feldspar. The calcite not included in the fossil fragments is generally non-clastic. This is not a calcarenite but a chemical limestone, subjected to some diagenetic change such as weathering at the top. The fossil fragments included are not sufficient evidence in themselves for classifying this as a true calcarenite.

HT 53. Hand specimen: Upper bioherm. Buff to gray, fine-grained, may contain glauconite. No fossil material in this sample. Chert in amounts of 5 to 10 per cent. Mounded structure is significant and this bed is correlative with bioherms (Wengerd, 1955 b).
Thin section: A buff-gray limestone containing 12 to 13 per cent feldspar and 5 per cent quartz. This is a very porous limestone and is equivalent to the upper bioherm (Wengerd, 1955 b, Fig. 7). Only a few fossils are present. However this sample was not collected from the bioherm, but from an equivalent layer across the canyon. A chemically deposited limestone, later fractured and the fractures filled with calcite.

HT 46. Hand specimen: Gray, lithographic to medium-grained limestone, argillaceous and with a moderate amount of fossil fragments.
Thin section: A gray, lithographic to medium-crystalline argillaceous limestone containing almost no fossils other than a few distorted, calcite-filled ostracods. Composition is 95 per cent calcite and 5 per cent authigenic feldspar, which fills cracks in the limestone Not a reef calcarenite.

HT 44. Hand specimen: Gray, fine-grained limestone with a central one-foot bed of coarse sandstone. The top four feet of the limestone is abundantly fossiliferous, containing fragments of crinoids and brachiopods and unidentified material. Abundance decreases toward the bottom. In the top part the coarse texture is due to fossil fragments and coarse calcarenite.
Thin section: A gray, finely crystalline to coarsely granular limestone containing an abundance of corals, bryozoans and brachiopods, and a moderate amount of algae. Corals are generally fragmental, but some forms may be Chaetetes sp. This slide comes from the middle bioherm (Wengerd, 1955b, fig. 7), and is from an algae-coral reef that was apparently filled with sand. Mineral composition is 70 per cent calcite and 30 per cent quartz.

HT 35. Hand specimen: Sixty per cent highly fossiliferous limestone and 40 per cent fine-grained

sandstone. Coarse-grained texture is due to calcarenitic nature. Fossils are: brachiopods, pelecypods and a possible nautiloid cephalopod.
Thin section: A gray-buff sandstone and limestone in hand sample, only the limestone is studied here. Texture is medium-crystalline, and the limestone contains abundant brachiopods, moderate crinoids, fusulinids and pelecypods, and thinly distributed cephalopods and corals. This is a biobreccia of near reef origin. The mineral composition is almost entirely calcite with a trace of hematite.

HT 34. Hand specimen: Gray, lithographic to fine-grained limestone containing abundant brachiopod and pelecypod fragments.
Thin section: A gray, dolomitic limestone, lithographic to fine-crystalline, containing only a moderate amount of brachiopod fragments in thin section in company with thinly distributed bryozoans and ostracods. No minerals other than calcite were noted although some euhedral calcite crystals are present in the slide as inclusions or fillings of vugs.

HT 33. Hand specimen: Gray calcarenite, lithographic to coarse-grained. Cherty to 5 per cent and containing foraminifera, brachiopods; possible Spirifer sp.
Thin section: A gray limestone, lithographic to fine-crystalline, with 5 per cent chert and a trace of zircon. About 20 per cent of the calcite in the sample is in the form of brachiopods and algae, brachiopods being the most numbrous. The reef calcarenite is probably the result of the lithification of a very pure lime mud containing many fragments of fossils, later subjected to some diagenesis and filling by calcite.

HT 31. Hand specimen: Buff, fine-grained, arenaceous limestone.
Thin section: An arenaceous limestone, not a calcarenite, but roughly equivalent to the silty section in its upper part in the Raplee stratigraphic section. This limestone may be the result of distant transportation of very fine limestone mud, perhaps carried in suspension.

HT 30. Hand specimen: Gray limestone and calcarenite with gypseous soil. Abundant brachiopods, pelecypods and corals.
Thin section: This limestone is gray, highly fossiliferous fore-reef talus probably transported only a short distance from the growth zone, with a layer of gypsum soil at its top. The limestone contains abundant algae, brachiopods, and corals with a moderate amount of pelecypods. The fossils are for the most part whole and relatively unaltered, indicating that they have not traveled far.

HT 24. Hand specimen: Gray, fine to medium-grained and medium-granular cherty, calcarenitic limestone. No fossils.
Thin section: This is an algal reef. The limestone is gray and almost entirely composed of algal material. Mineralogically the limestone is 95 per cent calcite and 5 per cent quartz. Formerly the algal reef was very porous but it is now filled in with crystalline calcite.

HT 23. Hand specimen: Gray, fine to coarse-grained dolomite, no fossil material.
Thin section: Gray, dolomitic, fine to medium-grained limestone composed of 60 per cent calcite, 20 per cent dolomite and 20 per cent quartz.

HT 22. Hand specimen: Gray, coarse to gravelly, calcareous conglomerate, calcirudite, with a moderate amount of fragments of pelecypods, corals and brachiopods.
Thin section: A gray limestone, lithographic, containing a moderate amount of brachiopods and corals, and an abundance of algae. The slide is a large block of algal material. It is difficult to determine from the slide if the rock is algal reef with other fossil forms filling the cracks or if it is a limestone conglomerate and the other forms exposed are merely around the edge of an algal particle. According to the field log, the layer is a calcareous conglomerate, so the block we have sectioned is probably a particle of the original algal material.

HT 21. Hand specimen: Gray, lithographic to fine-grained limestone calcarenite. Coarse fragments of algae and foraminifera.
Thin section: A gray limestone. As many of the reef calcarenites and reefs, it shows two grainsizes, coarse granular fossil material and lithographic to fine-grained calcite filling the pores. This sample shows considerable strain, and may have been subject to distortion after it had lithified. It is algal reef material whose vugs and pores are filled with calcite.

HT 17. Hand specimen: Gray shale with coarsely calcarenite nodular and interbedded limestone, and some brown oil stain. Abundant spiriferoid brachiopods, corals, crinoids, and foraminifera in limestone.
Thin section: From a gray shale containing considerable limestone has been chosen a sample of the limestone which contains many fossils. The limestone contains a moderate amount of algae, bryozoans and corals, and an abundance of brachiopods, both fragmental and whole though distorted. The corals are solitary forms and may be dolomitized; indicated by the interference colors they show under crossed nicols.

HT 16. Hand specimen: Gray, calcarenite, fine to coarse-grained. Abundant Fusulina sp., brachiopods, pelecypods and foraminifera.
Thin section: A grey, finely crystalline and coarse granular cherty limestone. This sample is equivalent to Girty 166 (Woodruff, 1910) and has been identified as being lower Cherokee in age. An abundant assemblage of fossils includes fusulinids, brachiopods and pelecypods, with a moderate amount of bryozoans. No minerals other than calcite are observed, 70 per cent of which is in the form of fossil material. This bioclastic has undergone little diagenetic change except for some silicification.

HT 15. Hand specimen: Buff calcareous shale, calcarenite nodules as above calcarenite.
Thin section: This thin section was cut from limestone selected from a buff, calcareous shale. The material is about 30 per cent fossils, many fragments of algae and brachiopods with some bryozoans and corals. Whole fusulinids

and gastropods are present in moderate amounts. The limestone in the shale probably had its origin as fossil material and lime collected in lentils in the shale.

HT 14. Hand specimen: Gray, fine-grained limestone, cherty. Both limestone and chert are fossiliferous. Same suites as bed 16 with the addition of bryozoan. The chert effervesces in HCl due to the inclusion of calcareous fossils. Thin section: Gray, cherty limestone, finely crystalline with abundant fusulinids, brachiopods and pelecypods in hand samples and only moderate amounts of algae, pelecypods, and foraminifera in thin section. No minerals other than calcite are observed, and the limestone is oolitic and contains many vugs, lined with and filled with calcite.

HT 11. Hand specimen: Gray, fine and coarse-grained calcarenite with sand layer in bottom of upper half. Bed contains fusulinids, crinoid columnals and foraminifera. (Possibly the identification is faulty or misread, may be another sample from HT 16).
Thin section: Gray limestone, medium crystalline, containing abundant fusulinids and brachiopod fragments, with thinly distributed coral fragments and gastropods. Mineralogically, the rock is almost all calcite with 2 per cent gypsum. The layer from which this limestone sample was taken contains 20 per cent sand and silt.

HT 9. Hand specimen: Gray, lithographic to fine-grained limestone, calcarenitic. Coarser material contains greatest abundance of coral, fusulinid and brachiopod fragments.
Thin section: Gray, lithographic to fine-grained limestone containing a moderate amount of corals, fusulinids and brachiopods, which are more abundant in the coarser material. In the thin section may be seen tubuliporoid bryozoans and a very questionable *Halysites* sp. coral. Almost all calcite with trace amounts of feldspar and quartz.

HT 6. Hand specimen: Gray, fine-grained limestone. Zone of tubuliporoid bryozoans in moderate abundance. Calcarenitic.

Thin section: Gray, finely crystalline limestone containing an abundance of tubuliporoid bryozoans and a few brachiopod fragments. Occassionally a fragment of a bryozoan colony may be observed and the interstices are filled with calcite. This is a biostromal layer and the last samples have contained bryozoans of the same type, so that the biostrome may be dominantly the result of bryozoan growth.

HT 3. Hand specimen: Lower bioherm, gray to brown, grain size ranges from lithographic to medium. A moderate amount of fossil fragments are present.
Thin section: A gray-brown slightly arenaceous limestone of lithographic to medium grain, containing only a few fossil fragments. Some brachiopods and possible ostracod fragments are present. The limestone is dominantly calcite, very vuggy, vugs lined with crystals and fractures filled with calcite. There are some oolites and about 5 per cent quartz with a trace of euhedral feldspar crystals. The limestone is a chemical precipitate, perhaps near reef, later fractured and filled, and subjected to some recrystallization.

2 Maps in pocket

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