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# GEOLOGY STUDIES

Volume 17, Part 2 – December 1970

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## Contents

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# Petrology and Petrography of Permian Carbonate Rocks Arcturus Basin, Nevada and Utah*

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ABSTRACT.—Carbonate rocks comprise most of the Wolfcampian and Leonardian rocks in the Arcturus Basin, Nevada and Utah. Formations recognized in this area are the Ferguson Mountain, Riepe Spring, Riepetown, Pequop, and Loray formations. The last named was not included in this study. Total thickness is about 5,000 feet. Major tectonic features which form boundaries of the Arcturus Basin and contributed clastic materials to it are the Antler orogenic belt on the west and the Southern Nevada Highland on the southwest; the Northeast Nevada Highland forms the northern margin and the Oquirrh Basin and Western Utah Highland limit the eastern side. The Arcturus Basin was probably connected to the Bird Spring Basin to the south by a narrow trough or accessway.

Field studies include ten measured stratigraphic sections. Petrographic analysis of samples from these sections have differentiated twelve principal rock facies. These are: (1) crinoid-bryozoan, (2) lime mud, (3) detrital quartz, (4) dolomite, (5) opthalmidid, (6) fusulinid, (7) undifferentiated skeletal, (8) oolite, (9) algal pellet, (10) molluscan, (11) dasyclad algae, and (12) intraclast. Most of these facies were recognized during microscopic examination of thin sections but they were confirmed and their composition refined by factor analysis of the petrographic data. Other rocks such as those with abundant brachiopods and corals are of lesser importance.

The crinoid-bryozoan and fusulinid facies are interpreted as having been deposited in the deeper water where circulation was good, however, this was probably at depths less than 100 feet. Some lime muds were deposited in very shallow water, probably intertidal in places. Others were deposited in water up to about 100 feet deep. Dolomites and oolites are interpreted as very shallow water deposits and some were probably supratidal at times. Collapsed oolites, probably the result of subaerial leaching, are fairly common. Undifferentiated skeletal facies likely represents deposition in quiet, deeper water flanking an area of high energy, which caused the reduction of the skeletal fragments to fine sand and silt size. Opthalmidid, algal pellet, molluscan, dasyclad algae, and intraclast facies are interpreted to be shallow-water deposits.

Lithofacies maps were constructed using crinoids, lime mud, detrital quartz, skeletal grains, nonskeletal grains, dolomite, algae, and bryozoans for the poles of the facies triangles. These maps show the configuration of the Arcturus Basin during Wolfcampian and Leonardian time. The axis of the basin extends from the Moorman Ranch area west of Ely, Nevada, northeastward to the Ferguson Mountain-Gold Hill area south of Wendover. The axis is approximately parallel to the Antler orogenic belt-Northeast Nevada Highland axis.

Reconstruction of the depositional pattern is made more difficult by the fact that there is no prominent reef tract, deepwater basin, shelf edge, etc., to use for a reference point. The lithofacies maps showed consistent patterns of sedimentation and made the reconstruction possible.

Although fusulinids have served as the basis of past chronostratigraphic subdivisions of rocks, similar subdivisions may be made by careful petrographic work. Recognition of the principal facies and their relative water depth makes this subdivision possible. Withdrawal of the sea at the end of Wolfcampian time is recognized by the presence of oolites and other shallow-water facies at the top of the Wolfcampian section. Leonardian rocks are easily subdivided into three members in those sections where an evaporite appears in the middle unit. These sections unfortunately are rare. In others the withdrawal of the sea during middle Leonardian can be recognized by the appearance of dolomite, oolite, and other shallow-water facies at this time.

*A dissertation submitted to the faculty of the Department of Geology, Brigham Young University in partial fulfillment of the requirements for the degree Doctor of Philosophy.

Wolfcampian sedimentation began in the Ferguson Mountain depocenter, and by Medial Wolfcampian the sea had transgressed onto the shallow surrounding shelves. Subsequent withdrawals and advances of the sea during Late Wolfcampian and Leonardian time were widespread enough to affect broad areas and cause distinct and recognizable changes in the sedimentation throughout the basin.

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ILLUSTRATIONS

## INTRODUCTION

In recent years, an increasing number of workers have added to the knowledge of Permian stratigraphy of the eastern Great Basin. Several papers have appeared in scientific journals and likewise a number of theses have been completed dealing with various aspects of the stratigraphy. Most have been descriptive more than interpretive and have been concerned largely with determination of time-stratigraphic relationships of principal rock units. Fossils, especially fusulinids, have served as the basis upon which the biostratigraphic framework has been constructed.

Few studies have concentrated on the petrology and petrography of Permian carbonate rocks in this area. The present study is centered principally on a petrographic examination of the rocks using thin sections, acetate peels, and polished sections as well as hand specimens. It should be possible to add to the knowledge of the stratigraphy and depositional and environmental history of these rocks by judicious use of the basic concepts of carbonate sedimentation. The writer has attempted to do this and has used many of the ideas gained from the work done by many contributors in Recent carbonate sediment studies as well as his own observations of modern carbonate depositional processes.

Because of the great thickness of Permian carbonates in the eastern Great Basin, this study has been restricted to rocks of Wolfcampian and Leonardian ages. Despite this limitation, measured sections of more than 4,000 feet in thickness are common.

## ACKNOWLEDGMENTS

The writer wishes to express his gratitude and appreciation to the many people who aided him in this study. Dr. Harold J. Bissell suggested the project and served as adviser throughout the course of the investigation. He offered many suggestions and was especially helpful in introducing the writer to excellent stratigraphic sections in the field. Drs. Lehi F. Hintze and W. Kenneth Hamblin critically read the manuscript and contributed ideas for improvement. Research funds from Brigham Young University and the National Science Foundation helped defray the cost of field work.

## AREA OF STUDY

The area under consideration lies in east central and northeast Nevada and extreme western Utah (Text-fig. 1). Geologically, the area has been called the Butte-Deep Creek Trough by Steele (1959, p. 5), the Butte Basin by Stevens (1965, p. 139), the Hamilton Basin by Brill (1963, p. 309), and the Arcturus Basin by Bissell (1964a, p. 632).

## PREVIOUS WORK

Earliest work pertinent to the problem was done in the Robinson (Ely) Mining District by Lawson (1906) who vaguely defined the Ely Limestone (Penn.), and the overlying Arcturus Limestone (Text-fig. 2). Spencer (1917), working on the geology and ore deposits of the same area, redefined the lower boundary of the Ely Limestone and briefly described the Arcturus Limestone. Pennebaker (1932), used the name Rib Hill, a term proposed by Blanchard, for essentially the same strata called Arcturus Limestone by earlier workers.

Easton (1953, 1960, 1963) and his co-workers have made many contributions to the geology of the area. Knight (1956) studied the Moorman Ranch section, 31 miles west of Ely on U.S. Highway 50. His work primarily concerned fusulinid paleontology. Ehring (1957) noted that part of the upper Ely Limestone was in fact of Permian age in its type area. Seward (1962), Turner (1962), and Ward (1962) mapped and described the stratigraphy in parts of the Riepetown and Ruth quadrangles.

Barr (1957) studied the stratigraphy and paleontology of the Pennsylvanian and Permian rocks at Ward Mountain, south of Ely.

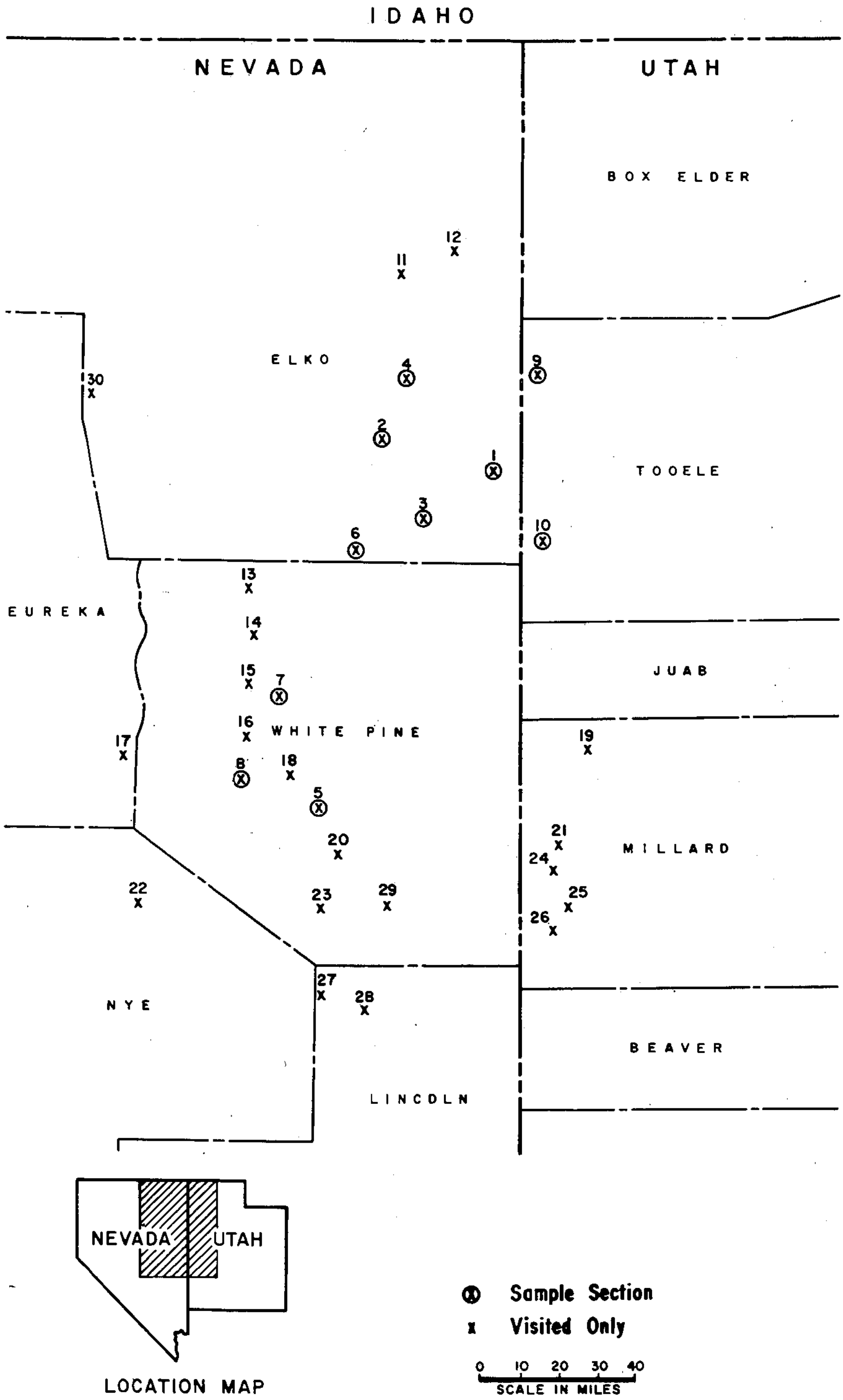
Much of the Permian stratigraphic terminology in use today in the eastern Great Basin has resulted from the work of Steele (1959, 1960). He proposed the name Riepe Spring Limestone for the Permian part of the Ely, renamed the 1,000 plus feet of the Rib Hill Formation the Riepetown Sandstone; coined the name Pequop Formation for a thick section of limestones and sandstones of Leonardian age in the Pequop and Butte Mountains and proposed the name Loray Formation for the overlying silty, evaporitic section.

Bissell (1960, 1962a, 1962b, 1964a, 1964b, 1967, 1970) and his students have contributed many significant papers dealing with Permian rocks. Berge (1960) and Slade (1961) published on the stratigraphy and fusulinid paleontology at Ferguson Mountain. Berge described and named the Ferguson Mountain Formation. Slade, in an admirable paper, described and figured the prolific fusulinid fauna. Hodgkinson (1961) studied the stratigraphy at Gold Hill and the Leppy Range. Robinson (1961) published on the biostratigraphy and fusulinid paleontology in the Pequop Mountains. He presented a geologic map of the area showing the location of his reference section for the Pequop Formation.

Dott (1955) described the section at Carlin Canyon and added regional correlation and studies. Fails (1960) also studied in this area and introduced additional terminology. Hose and Repenning (1959) studied the stratigraphy in the Confusion Range of western Utah. These writers included about 100 to 350 feet of Wolfcampian age carbonates in the Ely Limestone and use the name Arcturus Formation for the overlying carbonates, sandstones, and gypsum. Wilson and Langenheim (1962), in the Ward Mountain area south of Ely, added to the knowledge of the stratigraphy and coral paleontology. Brill (1963) studied the stratigraphy of a large area from the Colorado Plateau to the Butte

TEXT-FIGURE 1.—Index of stratigraphic sections.

| *No.* | *Name* | *No.* | *Name* |
|---|---|---|---|
| 1 | Ferguson Mountain | 16 | Robbers Roost |
| 2 | Brush Creek | 17 | Carbon Ridge |
| 3 | Dolly Varden Mountains | 18 | Radar Ridge |
| 4 | Central Pequop Mountains | 19 | Confusion Ridge |
| 5 | Rib Hill | 20 | Coke Ovens |
| 6 | Cherry Creek Mountains | 21 | Conger Range |
| 7 | Central Butte Mountains | 22 | Pancake Range |
| 8 | Moorman Ranch | 23 | Lund Area |
| 9 | Rishel (Pyramid) Peak | 24 | North Burbank Hills |
| 10 | Gold Hill | 25 | Burbank Hills |
| 11 | Northern Pequop Mountains | 26 | Garrison |
| 12 | Montello | 27 | Silver Springs |
| 13 | Maverick Springs | 28 | Cave Valley |
| 14 | Northern Butte Mountains | 29 | Horse Canyon |
| 15 | West-Central Butte Mountains | 30 | Carlin Canyon |


IDAHO
NEVADA
UTAH
BOX ELDER
ELKO
TOOELE
EUREKA
JUAB
WHITE PINE
MILLARD
NYE
BEAVER
LINCOLN
1
2
3
4
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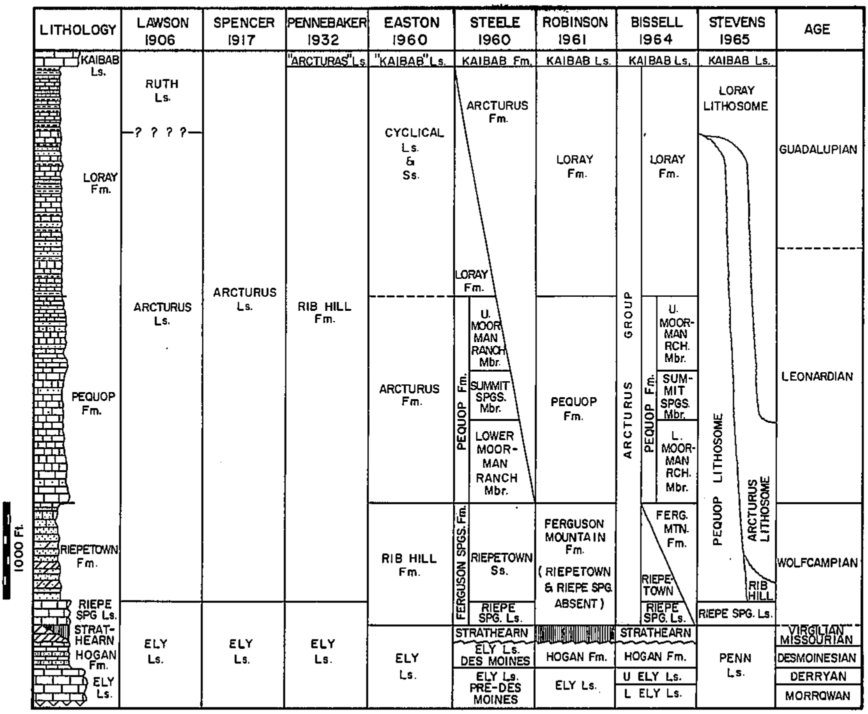
28
29
30
NEVADA
UTAH
LOCATION MAP
Sample Section
Visited Only
0 10 20 30 40
SCALE IN MILES




TEXT-FIGURE 2.—Correlation chart for Arcturus Basin.

Mountains. Stevens (1965) presented different concepts of the depositional history using lithosomes for the rock-stratigraphic units and stages to demonstrate his concept of the time-stratigraphic relationships. Roberts, *et al,* (1965) described the geology of the Oquirrh Basin of west central Utah and extended the western limits of this basin far into Nevada to include the Gold Hill-Ferguson Mountain-Pequop Mountain area.

Text-figure 2 shows the stratigraphic terminology applied by various workers as interpreted by the writer.

## TECTONIC SETTING

The major tectonic features dominating Wolfcampian and Leonardian sedimentation in this area are: (1) the Manhattan Geanticline (Nolan, 1943, Eardley, 1947), later called the Antler orogenic belt by Roberts (1951), which forms the western boundary; (2) the Northeast Nevada High (Steele, 1959) forms the northern boundary; (3) the east side is limited by the Oquirrh Basin and the West Central Utah Highland (Steele, 1960, p. 91) Bissell, 1962b, p. 1085). The southern limit of the area is not well defined. Bissell (1964a, p. 663) postulates the existence of a threshold or accessway into the Bird Spring—Spring Mountain Basin.

These positive areas contributed clastic sediments into the area during periods of their tectonic uplift and erosion. During quiescent periods carbonate sedimentation was dominant. It is probable that the Northeast Nevada High and the West Central Utah Highland were not always emergent but were periodically inundated and became shallow banks.

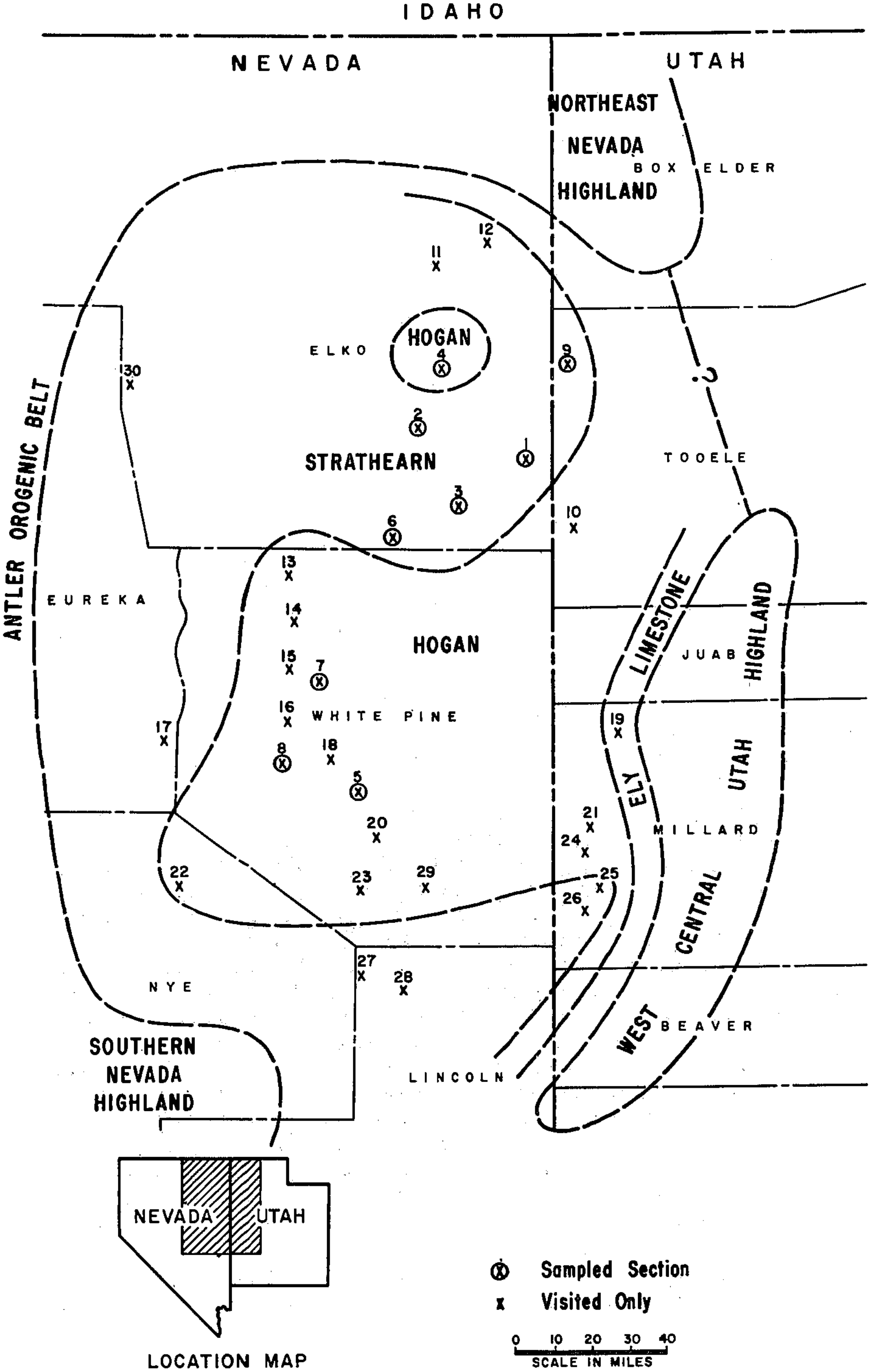
The area of interest is located within the Cordilleran Geosyncline as figured by Schuchert (1923, Fig. 12), which was later shown to consist of two major parts by Eardley (1947), separated by the north-south trending Manhattan Geanticline. Kay (1947) applied the term eugeosyncline to the area west of the Manhattan Geanticline and miogeosyncline to the area east of that feature. Most workers—Stevens (1963), Brill (1963), Barr (1957)—have followed the terminology set forth by Eardley and Kay and have placed the area of study within the miogeosyncline. Bissell (1962 a, p. 190) also applied this terminology, but in his paper pointed out that the Cordilleran area during Pennsylvanian and Permian time was not a simple geosyncline, seaway, basin, or trough, but "consisted of numerous basins, troughs, swells, positive areas, and other depocenters, and incipient-to-prominent highs, in addition to orogenic belts and welts within the geosyncline."

## FIELD WORK

Field work was carried out in the summers of 1961 and 1962. Operations consisted principally of the study, measuring, and sampling of selected stratigraphic sections. Numerous good stratigraphic sections have been measured by earlier workers such as Slade (1961) and Berge (1960) at Ferguson Mountain, Hodgkinson (1961) at Gold Hill, and Robinson (1961) in the central Pequop Mountains. These sections are coded on the outcrop by painted numbers and where possible the published intervals of these writers were used for measurements, and samples, as well as larger specimens from these intervals, were collected in the field. Notes on some intervals were kindly supplied by H. J. Bissell and other sections, e.g., those at Rib Hill, Murry Summit, Cherry Creek, Moorman Ranch, Rishel Peak, Dolly Varden, and east side Butte Mountains (part) were measured by the writer using a steel tape and Brunton compass.

The sampling interval varies according to type of stratigraphic section under investigation. In thick prominent limestones samples were taken in five- to ten-foot intervals depending upon the variability in observable texture and constituent content. In thin-bedded and platy sections where the same rock types were repeated many times in cyclical or repetitive sequences only a few samples representing the various rock types were taken in an interval which in many cases was several hundred feet thick. This was especially true in sections which were predominantly alternating thin beds of dolomite, dolomitic limestone, sandstone, and siltstone which characterizes much of the middle and upper members of the Pequop Formation. In most cases it was possible to collect representative rock types of intervals by sampling the principal lithologic breaks. About 1,500 samples representing about 32,800 feet of stratigraphic section were collected in this fashion. It is believed that most of the carbonate rock types present in this area of Wolfcampian and Leonardian age are represented in these collections. To a statistical purist, a closer and more regularly spaced sampling interval of perhaps five or ten feet would be more appealing. Had this been attempted, however, the problem would have become enormous and unwieldy.

The textural classification of carbonate rocks proposed by Dunham (1962) was adopted for this study. Facies types were noted empirically, confirmed, and




TEXT-FIGURE 3.—Paleogeologic map of pre-Permian surface.

| TEXTURAL CLASSIFICATION OF CARBONATE ROCKS | | | | |
|---|---|---|---|---|
| MUD-SUPPORTED | | GRAIN-SUPPORTED | | COMPONENTS BOUND TOGETHER DURING DEPOSITION |
| Less Than 10% Grains | More Than 10% Grains | More Than 10% Mud | Less Than 10% Mud | |
| MUDSTONE | WACKESTONE | PACKSTONE | GRAINSTONE | BOUNDSTONE |

*After Dunham (1962)*

TEXT-FIGURE 4.—Textural classification of carbonate rocks.

refined by factor analysis. Terminology used in this section on stratigraphy is defined in the section on petrography. Dunham's classification in modified form appears as Text-figure 4.

## STRATIGRAPHY

### General Statement

Permian rocks exceed 6,000 feet in thickness in the central part of the Arcturus Basin. Wolfcampian and Leonardian rocks alone account for most of this and attain a thickness of more than 4,600 feet in the Moorman Ranch area and similiar thickness can be measured in various surface sections in the Butte Mountains. Some sections are complete but most must be pieced together by making traverses across several fault blocks. Exposures are excellent and weathering is not a serious problem. Secondary cementation of limestone talus to form breccies of Pleistocene or Recent age, a problem in some arid areas, was encountered only in those sections once invaded by Pleistocene Lake Bonneville which left shoreline deposits. Little alteration of the limestones along faults was noted except at Rishel Peak where apparent hydrothermal alteration has oxidized the normally gray limestones to a brownish red.

### Pre-Permian Unconformity

A widespread unconformity of late Pennsylvanian age has been noted by several authors, notably Dott (1955, p. 2289), Steele (1959, p. 68), and Bissell (1964a, p. 632). The area under consideration here underwent uplift of epeirogenic proportions during late Desmoinesian time causing a cessation of carbonate sedimentation and widespread erosion of exposed sediments. Possibly a few negative areas such as parts of the Ferguson depocenter received continuous sedimentation. Slade (1961, Fig. 2) shows no post-DeMoines-pre-Virgil unconformity in his stratigraphic section at Ferguson Mountain.

Deposition of the Strathern Formation began with the return of the sea to parts of northeastern Nevada and adjacent areas in Utah in Missourian time.

This occurred only in the more negative areas which were apparently foredeeps along the Antler orogenic belt and Northeast Nevada High. Locally some carbonates of Missourian and Virgilian age were deposited in the Burbank Hills—Needle Range of Utah and the Egan Range of Nevada (Bissell, 1964a, p. 632). Sedimentation persisted in these negative areas during late Pennsylvanian time and continued on into the Wolfcampian. Continued subsidence permitted the sea to transgress the more positive shelf areas and inundate the entire Arcturus Basin by Medial Wolfcampian time.

Strathearn Formation

Dott (1955, p. 2248) proposed the name Strathearn Formation for a 1,200-1,500 feet thick sequence of quartz-silty or sandy limestones and thin chert-pebble conglomerates exhibiting prominent cross-stratification. The type section is in the South Fork of the Humbolt River, T. 33 N., R. 55 E., in Elko County, Nevada. The age at this location ranges from Missourian in its lower part of Wolfcampian in its upper part. Thus, Dott considers it to bridge the Pennsylvanian-Permian boundary. However, Bissell (1967) considers the age of the Strathearn Formation at nearby Carlin Canyon to be no younger than Virgilian, and that it is overlain by the 460-foot Riepe Spring Limestone. Steele (1959, p. 56) extended the limits of the formation southward into the Carbon Ridge area and eastward into the Wendover area.

The writer did not study the Strathearn Formation in detail because few rocks of probable Lower Wolfcampian age in the section measured could be assigned to this formation with any degree of certainty. Also the Strathearn appears to be more closely related sedimentologically to Pennsylvanian rocks than to Permian rocks. At Rishel Peak 82 feet of thin- to thick-bedded, light- to medium-gray sandy dolomite, light-gray dolomite and chert conglomerate were measured and assigned to the Strathearn. At the base is a conglomerate composed of chert and dolomite pebbles in a sandy dolomite matrix. It is believed this unit rests disconformably on siltstone and limestone of the Hogan Formation (Medial Desmoinesian) and is overlain by massive limestone of the Ferguson Mountain Formation.

Several sections, e.g., Cherry Creek, Moorman Ranch, Ferguson Mountain, and possibly Dolly Varden, contain silty dolomite with some siltstone and sandstone below rocks of known Wolfcampian age and above rocks of Desmoinesian age. These dolomite beds commonly are sparsely fossiliferous and difficult to date precisely. Where their age can be established as Desmoinesian they should probably be assigned to the Hogan Formation or a new formation. Where they are Missourian through Lower Wolfcampian in age they fit best in the Strathearn Formation. The writer does not favor the inclusion of these rocks as a member of the Riepe Spring Limestone because they are very dissimilar lithologically. Much additional study of the Pennsylvanian-Permian boundary needs to be done to bring about full understanding of these rocks.

Ferguson Mountain Formation

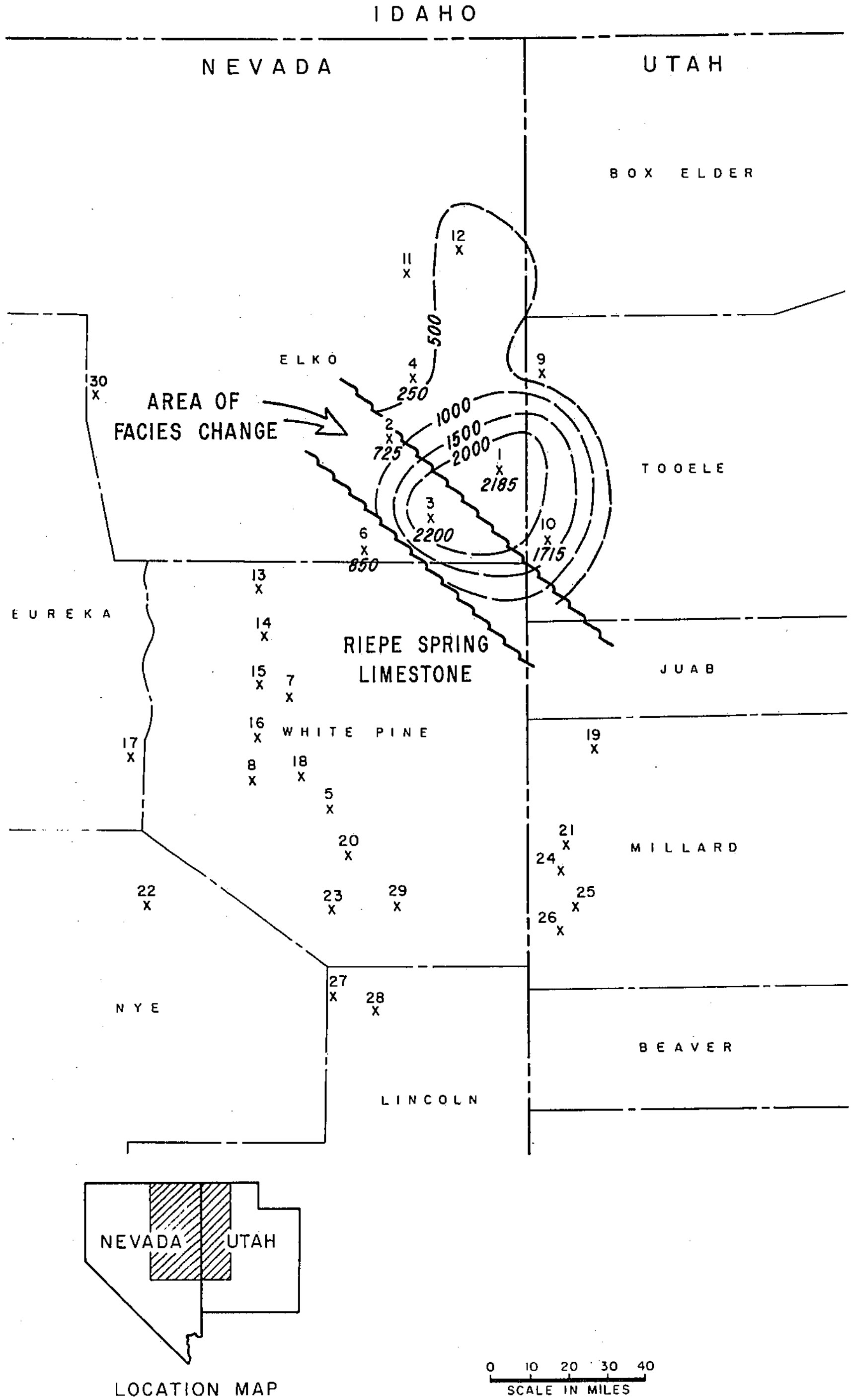
Berge (1960) proposed the name Ferguson Mountain Formation for 2,185 feet of massive to thick-bedded, ledge-forming skeletal limestone interbedded with thin-bedded, platy, slope-forming, sandy, argillaceous limestone. The type locality is at Ferguson Mountain, 20 miles south of Wendover, Elko County, Nevada. Here the formation rests disconformably on the Pennsylvanian Strathearn Formation and is overlain by the Pequop Formation of Leonardian age.

The lower boundary of the Ferguson Mountain Formation is not easily determined. Berge (1960) in his columnar section placed the lower boundary in the Virgilian at the top of what appears to be the Strathearn Formation of Dott (1955). However, in his text he proposed that the lower contact should be placed at the Virgilian-Wolfcampian boundary. Steele (1960) included 592 feet of Missourian rocks and 519 feet of Virgilian, placing the contact at the upper limit of the Ely Limestone. Slade (1961) chose the same lithologic break in the Pennsylvanian selected by Berge (1960) but extended the top of the Missourian upward to coincide with this horizon also. Thus these two workers include 166 feet of Virgilian rocks in the Ferguson Mountain Formation at its type locality and disagree only in the placement of the Missourian-Virgilian boundary. Bissell (1962b) measured only 125 feet of Virgilian rocks in his study of the type area, included them in the Ferguson Mountain Formation and stated that the formation rests on the Strathearn which is here Missourian.

The upper boundary of the Ferguson Mountain Formation is gradational with the overlying Pequop Formation and is usually picked at the horizon where thin-bedded sandstone, siltstone, and orthoquartzite common to the Pequop Formation begin to make their appearance. This gradational contact occurs near the Wolfcampian-Leonardian time boundary but the two do not necessarily coincide. There is a tendency among workers to place the contact at a thin biostrome of the coral *Durhamina* sp. ("*Corwenia*") but this coral is not present in all localities and thus cannot be relied upon. The most dependable method of locating the approximate boundary is to determine the first occurrence of Early Leonardian fusulinids, normally unquestionable species of *Parafusulina*. The genus *Eoparafusulina* (Skinner and Wilde, 1965, p. 73-83) normally occurs in rocks of Late Wolfcampian age, and could be mistaken for *Parafusulinia* if not carefully studied. Presence of *Monodiexodina* together with definitive *Parafusulina* should locate at least strata close to the base of the Leonardian. The contact can then be drawn at the most distinct lithologic break.

*Type Section.*— At this locality rocks of the Ferguson Mountain Formation are about 20 percent grainstone, 57 percent wackestone, 11 percent mudstone, 2 percent dolomite, and the remainder is composed of minor amounts of sandstone and siltstone. The principal constituents and their volume percentages are: lime mud 48, crinoids and echinoids 10, detrital quartz 8, pelletoid grains 6, fusulinids 5, corals 4, undifferentiated Foraminifera 4, dasyclad algae 3.

The lower 1,000 feet of the section is dominated by the fusulinid facies. However, most of the other widespread rock types are present with the lime mud, detrital quartz, ophthalmidid, and algal pellet facies most abundant. One ophthalmidid-bearing rock is made up almost wholly of fragments of this encrusting foram set in sparry calcite. Most of the rocks are dark- to medium-gray, thin- to medium-bedded wackestone with lesser amounts of mudstone and a few grainstone. One dolomite about 10 feet thick with rhombs up to 100 microns in diameter occurs about 700 feet above the base of the formation. In field observations many brachiopods, corals, and bryozoans are noted but these usually are not so abundant in thin section as those particulate grains noted above. One sample composed of brachiopod fragments well oriented in a limestone matrix, was noted about 1,050 feet above the base of the formation. Crinoids and echinoids are randomly scattered throughout the lower 1,000 feet but the crinoid facies is not well developed at this locality until about 1,100 feet above the base and samples containing up to 80 percent crinoid fragments




TEXT-FIGURE 5.—Isopach map of Ferguson Mountain Formation.

were found 300 feet higher. Thin biostromes of colonial corals occur at several horizons in the lower 1,100 feet.

The crinoid and brachiopod facies become more important than the fusulinid facies about 1,100 feet from the base. Detrital quartz gradually increases from this point upward, pelletoid rocks are important and the first oolites occur at 1,350 feet and another well-developed oolite unit occurs at about 1,850 feet.

Beginning at 1,600 feet above the base, there are two massive limestones totaling 150 feet in thickness. In these rocks the crinoid, brachiopod and fusulinid facies, prominent in the lower portion, give way upward to the dasyclad, algal pellet, and ophthalmidid facies which diminishes upward until the oolite at 1,850 feet is reached. The crinoid and fusulinid facies again become dominant above this point until they give way to the detrital quartz facies near the top of the formation. The base of a *Durhamina* biostrome near the Wolfcampian-Leonardian boundary as determined from fusulinids is picked as the top of the Ferguson Mountain Formation in this area.

*Dolly Varden Section.*—In the Dolly Varden Mountains the writer measured about 2,200 feet of Ferguson Mountain Formation. This is a gross thickness because at least one tongue of the Riepetown Formation divides sections of typical Ferguson Mountain lithology. This relationship will be discussed in the section devoted to the Riepetown. The formation rests on about 750 feet of interbedded dolomite, silty dolomite, calcisiltite and sandstone. The unit is thin-bedded and unfossiliferous. One thin chert bed about 480 feet below the base of the Ferguson Mountain contains Medial Wolfcampian fusulinids (H. J. Bissell, personal communication). The Ferguson Mountain Formation is made up of about 39 percent wackestone, 33 percent grainstone, 17 percent packstone, 8 percent sandstone and siltstone, and 3 percent mudstone. The lower 520 feet is a thick-bedded to massive section of grainstone and packstone. The lower 225 feet of this massive section is composed of the crinoidal facies and is succeeded by 180 feet of a mixed crinoid-ophthalmidid facies. Above this is 50 feet of the crinoidal facies and the upper 65 feet is dominated by bryozoans but with abundant crinoids. Above this massive section is a 520-foot unit of thin- to medium-bedded cherty wackestone, silty mudstone, packstone, sandstone, and siltstone. The crinoidal facies is still dominant but some bryozoan and brachiopodal rocks are present also. This is succeeded by 340 feet of thick-bedded to massive grainstone and packstone which are much like the basal part of the section. Overlying this is 200 feet of hard, silty calcareous sandstone and quartzitic sandstone which is thin- to medium-bedded. The writer considers this to be a tongue of the Riepetown. Almost all of the rocks of the remainder of the section are sandy or silty. Overlying this Riepetown tongue is a 190-foot section of mudstone, sandy mudstone, and crinoidal grainstone. These beds are thick-bedded, medium to dark gray and cherty and are overlain by 140 feet of medium-brown, thin-bedded, platy, sandy wackstone, sandy mudstone, calcareous sandstone, and a few crinoidal grainstone which may also have some affinity with the Riepetown. These field relations agree with those of Bissell (1967) who observed that the Riepetown tongues out low in the Ferguson Mountain Formation in the Goshute Mountains, about 20 miles to the east, and cannot be recognized as far north as the Ferguson Mountain area. The uppermost 260 feet of the Ferguson Mountain Formation is characterized by dark-gray, thick-bedded to thin-bedded crinoidal, sandy wackestones and sandy, dolomite mudstones. The top of the formation is marked by a distinctive limestone bed containing abundant purplish chert in the form of nodules and small blebs. This is overlain by limestones containing the coral *Durhamina* which is here believed to indicate the base of the Pequop Formation.

*Rishel Peak Section.*—In this locality in T. 1 N., R. 18 W., Tooele County, Utah, the writer measured a thin section of Ferguson Mountain Formation resting on the Strathearn. *Schwagerina youngquisti* occurs about 70 feet above the base and dates this as upper Wolfcampian. The top of the formation is difficult to define because of the poor preservation of the fusulinids. *Durhamina* occurs 467 feet above the base, but here it is probably well up in the Leonardian. The Ferguson Mountain Formation is probably only about 100 feet thick at this locality and is late Wolfcampian in age. At least two faults intersect the measured traverse but these are believed to be minor and do not affect the thickness extensively. The faults are marked by brecciated zones which probably have been hydrothermally altered imparting a reddish color to the normally dark-gray limestones. The formation rests on an 82-foot section of light-gray dolomite, sandy dolomite and chert pebble conglomerate of the Strathearn Formation and is overlain by crinoidal limestones of the Pequop Formation.

Fifty-six percent of this thin Ferguson Mountain Formation is composed of grainstones and 44 percent wackestone. The undifferentiated skeletal facies is the dominant rock type. This is largely a result of the poor preservation of the particulate content due to the incipient recrystallization of these rocks. The loading of these samples on this factor is only moderately high (.66), so they are not well defined. Scattered fusulinids, crinoids, and bryozoans were noted in outcrop.

*Gold Hill Section.*—Hodgkinson (1961) measured 1,715 feet of Ferguson Mountain Formation at this locality. The section is very similar lithologically to that at the type locality. Factor analysis shows the crinoidal facies and fusulinid facies to be very abundant. The formation overlies a 60-foot section of dark brown to dark gray, weathering to medium brownish-gray to reddish-brown dolomitic siltstone, dolomitic limestone, and calcareous dolomite which is probably a thin Strathearn Formation. The lower 750 feet is composed of the massive- to thick-bedded crinoidal and fusulinid-bearing limestones so characteristic of this formation. The next 785 feet is predominantly these facies also but with several thin- to medium-bedded silty, argillaceous and cherty limestones interspersed. The top approximately 200 feet are massive, medium light brownish gray, weathering light olive-gray, grainstones and packstones of the fusulinid and crinoidal facies. A thin-bedded to platy, sandy limestone containing a *Durhamina* biostrome overlies this unit and indicates the base of the Pequop Formation.

*Pequop Mountain Section.*—In the central Pequop Mountains, only about 250 feet of Ferguson Mountain Formation is present at the locality examined by the writer in Section 34, T. 34 N., R. 65 E. The lower contact is sharp and distinct where the thick- to massive-bedded Ferguson Mountain rests on the thin-bedded Hogan Formation. A distinctive conglomerate about 20 feet thick and composed of chert and limestone pebbles is present near the top of the formation. Robinson (1961, p. 105) reports that an upper Wolfcampian fusulinid fauna is present at this locality. The overlying beds of the Pequop Formation contain a good biostromal development of the fasciculate coral *Durhamina* and the contact between these two formations is easily located at the base of this bed. This thin section is made up 31 percent of mudstones, 26 percent wackestones, 19 percent sandstone, 15 percent packstone, and 9 percent conglomerate. The lime mud facies is most abundant as indicated by factor analysis. A few brachiopods, corals, more abundant bryozoans, crinoidal debris, and fusulinids near the top of the formation are the principal particulate components. To the north the formation can be recognized at least as far as the Leach Mountains, Montello, Nevada, where about 500 feet of rocks believed to be the Ferguson Mountain Formation rest on the Strathearn Formation. Northwest from the type locality the Ferguson Mountain thins from about 2,200 feet to 250 feet in the central Pequop Mountains. This may be only a local thinning caused by pre-late Wolfcampian uplift of limited extent. Bissell (1962b, p. 1090) originally assigned 1,300 feet of calcisiltites, silty limestones, and calcarenites to the Ferguson Mountain Formation at Carlin Canyon, west of Elko, Nevada, but recently (1967) noted that the Riepe Spring Formation (460 feet) and the Riepetown Formation (1,100 feet) rather than Ferguson Mountain Formation is preferred terminology. Here, these formations contain fusulinids of Early, Medial, and Late Wolfcampian age.

The Ferguson Mountain Formation in most localities is characterized by the dark color of the limestones due in part at least to the preservation of considerable organic material. The type section with its coral biostromes, massive encrinites, and abundant fusulinids representing the entire Wolfcampian Epoch is a classic in Great Basin stratigraphy.

Text-figure 5 shows the isopachous thickness of the Ferguson Mountain Formation in locations studied. A small depocenter sharply defined on three sides is evident. The eastern limit is not well defined due to lack of control but here the Ferguson Mountain Formation must be limited by change in facies into the portion of the Oquirrh Formation of similar age. The location and extent of this facies change is not known but it must occur east of Gold Hill. Nolan (1935) applied the name Oquirrh Formation at Gold Hill to beds now known to be the Ferguson Mountain Formation (Bissell, 1962b, p. 1087). Roberts, *et al.* (1965), extended Oquirrh terminology into Gold Hill also. Steele (1960), and Hodgkinson (1961) recognized distinct differences between Oquirrh and Ferguson Mountain sedimentation and applied the latter name to this area.

### Arcturus Group

Lawson (1906) described the Arcturus Limestone as being of supposed Carboniferous age and overlying the Ely Limestone in the Robinson Mining District near Ely, Nevada. He also described a unit called the "Ruth Limestone" as the uppermost formation of these three. Spencer (1917) pointed out that the "Ruth Limestone" actually occurs much lower in the section than Lawson supposed and is in fact part of the Ely. Spencer noted that the name Arcturus was taken from the Arcturus mining claim near the town of Ruth, is about 400 feet thick and capped by volcanic rocks. He also presented a faunal list which is predominantly molluscan and described the sediments as being characterized by argillaceous, impure limestone which weathers to brilliant hues of yellow, orange, and red. His map shows the presence of Arcturus Limestone beginning about one-half mile down the southwest slope of the southernmost ridge at Rib Hill and trending northwest-southeast. Lawson's map was never published, the plates and printed maps having been destroyed in a fire; and as Wilson and Langenheim (1962, p. 496) point out, his interpretation of his Arcturus Limestone cannot be deciphered without his map. Spencer (1917, p. 26) had access to a manuscript copy of Lawson's map but stated only that his own map differed from that of Lawson in the distribution of the Arcturus. It is this writer's opinion that Spencer interpreted the Arcturus Formation as including only those upper argillaceous limestones and brilliantly hued, shaley beds which characterize the upper part of the section below the Kaibab Limestone and above the Ely. The lower dominantly carbonate portion and the underlying 1,000 feet of sandstone and thin dolomites and limestones at Rib Hill were included in the Ely Limestone as his map indicates. His lithologic descriptions, faunal list and map all appear to substantiate this interpretation which is slightly different from that of Wilson and Langenheim (1962, p. 497).

Pennebaker (1932, p. 164) redefined the top of the Ely Limestone and excluded the 1,000 plus feet of predominantly sandstone beds at Rib Hill and all overlying beds from this formation. He applied the name Rib Hill Formation to this sandstone sequence and overlying limestones and mudstones and extended the top of the formation to the base of what is now known as the Kaibab Limestone which is mistakenly called the Arcturas (sic) Limestone. He estimated the thickness at 3,200 feet. As thus defined, the Rib Hill Formation included the upper part of Lawson's and Spencer's Ely Limestone and all of their Arcturus Formation. Easton, *et al.*, (1953, Fig. 2, p. 147), presented a correlation chart which listed the basal part of this section and the upper part of the Ely Limestone as defined, as the Rib Hill Sandstone. Ehring noted that the upper Ely is of Permian age and proposed the name Murry Sandstone for the 1,000 plus feet of sandy beds at Rib Hill. This new name did not reach publication status.

Steele (1960, p. 100) pointed out that the upper 300 feet of the Ely Limestone at Rib Hill is middle Wolfcampian in age. He separated this unit from the Ely and named it the Riepe Spring Limestone. For the overlying 1,000 plus feet of sandy beds he proposed the name Riepetown Sandstone, pointing out that the previously applied name "Rib Hill Sandstone" is preoccupied. Steele (1959, p. 77) recommended abandonment of the name Arcturus Formation because of its poor exposure at the type locality and its uncertain definition. Later (1960, p. 103) he stated that the Arcturus has some practical value as a stratigraphic unit and applied the name to the limestones overlying the Riepetown Sandstone at Rib Hill and underlying the Kaibab or Loray Formation.

The writer believes that the term Arcturus as a formational name has no real value because of its poor and incomplete definition, obscure type section, and the resultant confusion as varoius writers attempted to interpret these earlier definitions. The best solution to the problem has been offered by Bissell (1964a) who proposed that the name Arcturus be given group status to include the well-defined Riepe Spring Limestone, Riepetown Formation, Pequop Formation, and Loray Formation in ascending order. This perpetuates the Arcturus name for strata in this area and gives it utility. The use of the term is thus extended downward in the section to include the now-recognized Riepe Spring Limestone. Since this latter unit is now known to be Permian in age, it logically should be grouped with the overlying Permian rocks. The writer believes Stevens (1967) erred in not including the Riepe Spring in his Arcturus Group.

Riepe Spring Limestone

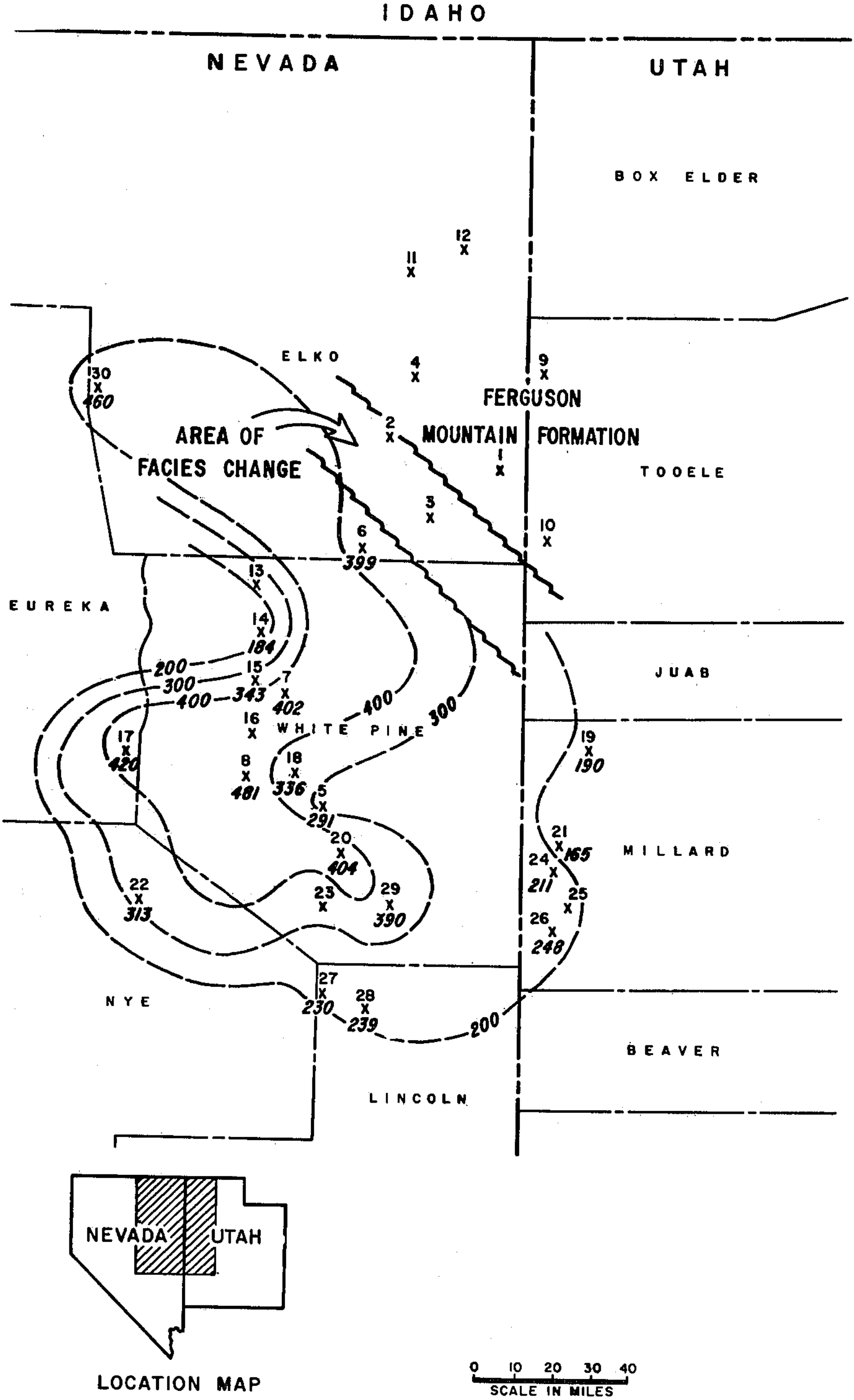
*General Statement.*—Steele (1960, p. 102) recognized the upper 300 feet of what heretofore had been called the Ely Limestone (Penn.) as actually being Permian in age. He renamed this unit the Riepe Spring Limestone and chose a section at the north end of Ward Mountain a few miles south of Ely as the type section. Here, the formation is 410 feet thick. The Riepe Spring is an easily recognized stratigraphic unit and is found over a wide area in east central Nevada and the Confusion Range area in Utah.

*Type Area Section.*—The Riepe Spring Limestone is well exposed at Rib Hill, T. 16 N., R. 62 E., near the town of Ruth, a few miles west of the Ward Mountain type locality. The writer measured a thickness of 433 feet near the tower on the crest of the hill. At this locality, the Riepe Spring disconformably overlies the Desmoinesian Hogan Formation and is overlain by the Medial Wolfcampian Riepetown Formation. The Riepe Spring at this location is also Medial Wolfcampian (Bissell, 1964a, p. 586).

At Rib Hill the Riepe Spring Limestone is composed of 45 percent wackestones, 37 percent grainstones, and 18 percent packstones. The lower 50 feet is thick-bedded to massive, medium grayish brown packstone made up mostly of Foraminifera of the ophthalmidid, fusulinid, and endothyrid groups. *Bradyina* sp. is also present. Scattered crinoid ossicles, *Thysanophyllum* fragments, a few dasyclad, and *Tubiphytes* pieces are notable. Overlying this is an 85-foot section of thin- to medium-bedded, medium grayish brown wackestone with a fauna much like the underlying unit but with a finer texture. In the top 20 feet of this unit, the corals *Thysanophyllum* and *Syringopora* are prominent in outcrop. This unit also contains some well-preserved encrusting bryozoans. The next 60 feet contains a fauna similar to the underlying units with prominent corals but is thick-bedded. The top 233 feet is thick-bedded to massive, medium-gray to medium grayish brown grainstones, packstones, and wackestones with fewer corals than below and with good examples of the distinctive algal pellet, dasyclad algae-ophthalmidid facies. The corals although not as prominent in outcrop are seen as comminuted fragments in thin section; especially in the top 50 feet of the section.

The contact with the overlying Riepetown is very sharp and conformable where the thick and massive-bedded, gray and brown limestones of the Riepe Spring are in distinct contrast with the overlying reddish and yellowish-brown sandstones of the Riepetown.

*Moorman Ranch Section.*—The writer's measured section of the Riepe Spring Limestone at Moorman Ranch is in Section 6, T. 17 N., R. 59 E., in a small strike valley approximately about a mile north of U.S. Highway 50. Good exposures of the formation, which here strikes about N. 20° W. and dips about 43° E., are found near the base of the east-facing side of the valley. The formation rests on approximately 200 feet of limestones, dolomites, and thin chert-pebble conglomerates which overly typical beds of the Hogan Formation. This dolomitic section is probably an upper member of the Hogan Formation as pointed out by Bissell (1964a, p. 587). The assignment of these beds to an upper member of the Hogan Formation is based on the presence of *Wedekindellina* which established a Desmoinesian age for these beds (Bissell, personal communication). The base of the Riepe Spring is drawn at the upper of two thin chert-pebble conglomerates immediately below limestones of typical




TEXT-FIGURE 6.—Isopach map of Riepe Spring Limestone.

Riepe Spring lithology. This is at best an arbitrary boundary because an underlying dolomite contains an echinoid fauna like that of the overlying Riepe Spring Limestones. The lower boundary problems of the Riepe Spring are brought about by the widespread unconformity due to regional uplift in late Des Moines time. This uplift followed by irregular erosion and deposition during Late Pennsylvanian and Early Wolfcampian time caused the Medial Wolfcampian Riepe Spring to be deposited on rocks of varying ages and lithologies. The contact is easily drawn when it rests on the siltstones, sandstones, and sandy limestones of the typical Hogan; but where it rests on Missourian or Virgilian rocks of the Strathearn or on atypical Hogan rocks, the problem is more difficult. Dolomitization of this interval adds to the complexity of problem.

The writer measured 461 feet of Riepe Spring at Moorman Ranch. The base of the formation is marked by a thin two-to-three foot thick chert-pebble conglomerate. Above this is a 120-foot section of thick-bedded to massive, medium grayish brown to light-brown wackestones, packstones, and grainstones with prominent echinoid spines, *Thysanophyllum* corals and *Omphalotrochus* gastropods displayed on the weathered surface. In thin section the lower 25 feet of this unit is a dense, fine-grained wackestone made up of oriented fragments of echinoids and corals and a few bryozoans set in a micritic matrix. A few endothyrid and ophthalmidid foraminifera are also present. Overlying this is a 95-foot section of similar appearing limestone which contains the algal pellet and ophthalmidid facies, the latter with subordinate amounts of echinoid and coral debris. A few examples of pelleted muds are present which contain echinoid and coral fragments. Overlying this basal limestone unit is a 138-foot section of interbedded calcareous, dolomitic and argillaceous siltstones, sandstones, and silty lime mudstones which separates the lower limestones of the Riepe Spring from an upper limestone unit which is also considered to be part of the Riepe Spring. This upper limestone unit is about 223 feet thick and consists of two thick limestones of the crinoid-bryozoan grainstone facies separated by about 50 feet of sandy limestones and sandstones. Some previous writers have placed this upper limestone unit in the Riepetown and have drawn the upper boundary of the Riepe Spring at the top of the lower 125-foot limestone section at this locality. The writer chose to include this upper limestone unit in the Riepe Spring because it contains the coral *Thysanophyllum* sp. which is very common in other Riepe Spring limestones and also because at other localities such as the Central Butte Mountains, Radar Ridge, and the Cherry Creek Mountains, thick crinoidal grainstones and packstones are very common in Riepe Spring sections. The inclusion of these crinoidal beds immediately above more typical Riepe Spring lithologies as defined by the type section, makes this formation much more mappable over a wide area. These thick crinoidal units can be traced northward from the Moorman Ranch area through the Cherry Creek Mountains and into the Dolly Varden Mountains where they are present in typical Ferguson Mountain section. These limestones, along with their overlying beds of the Riepetown, seem to offer the best means of working out the intertonguing relationships between Riepe Spring—Riepetown sections and Ferguson Mountain sections.

*Central Butte Mountains Section.*—This section is located about 4 miles north of the 30-mile Ranch and is in the NE/4 of T. 20 N., R. 60 E. At this locality the writer measured a 400-foot section of the Riepe Spring. The section here consists of 57 percent wackestones, 29 percent mudstones, 11 percent packstones, and 3 percent grainstones. In outcrop crinoids, fusulinids, bryozoans, and brachiopods are present in descending order of abundance.

The lower 148 feet is composed of thick- to thin-bedded light-brown, weathering to light reddish brown packstones and grainstones and wackestones which contain the distinctive algal pellet and ophthalmidid facies noted at Rib Hill and the echinoid-*Thysanophyllum* facies found in the lower part of the Riepe Spring at Moorman Ranch. Succeeding units contain the crinoidal facies and a distinct oriented brachiopod wackestone. The sandstones at Moorman Ranch are replaced by thin-bedded very sandy limestones in the Central Butte Mountains. Thus it can be seen that this Butte Mountain section has some of the attributes of both the Rib Hill and Moorman Ranch sections and occupies a sedimentologically intermediate position between these two sections.

*Cherry Creek Mountains Section.*—An excellent section of late Pennsylvanian and early Permian rocks is exposed on the east side of the northern Cherry Creek Mountains near the McDermitt Ranch. The writer's measured section begins on a prominent spur with many dolomite ledges in the NE/4 of T. 26 N., R. 63 E., and steps northward into the SE/4 of T. 27 N., R. 63 E. near the ranch headquarters. The section begins with about 600 feet of massive, medium- to light-gray dolomite, dolomitic limestone, and cherty dolomite of uncertain age. This dolomitic section overlies beds of known Desmoinesian age of the Hogan Formation, and underlies beds of known Wolfcampian age of the Riepe Spring Limestone. It is probable that these dolomitic beds are equivalent to beds of similar lithology in the Dolly Varden Mountains and in the Moormon Ranch area where they have been designated as an upper member of the Hogan Formation (Bissell, 1964a, p. 578). No fossils were found in this sequence. The beds are cherty in part and weather to a hackley texture.

The Riepe Spring Limestone is 499 feet thick at this location in the northern Cherry Creek Mountains. A tabulation of the various carbonate types shows that it contains 47 percent mudstone, 34 percent wackestone, 13 percent grainstone, and 6 percent packstone. The section is particularly interesting because it exhibits distinct sedimentological elements of the typical Ferguson Mountain Formation lithologies found in the Dolly Varden and Ferguson Mountain area to the northeast, and also contains some lithologies which characterize the Riepe Spring Limestone in the Moorman Ranch and Rib Hill areas to the south. The Ferguson Mountain-like lithologies, are the dark-colored, sandy crinoid, and fusulinid facies. The Riepe Spring-like lithologies are the ophthalmidid and echinoid-coralline facies. The latter two facies are found mostly in the lower 112 feet of the section.

The lower 112 feet of the section is thin- to medium-bedded, medium-gray and grayish brown, weathering to light gray mudstones, wackestones, and packstones which are sandy and dolomitic in the bottom 40 feet. They are easily separated from the underlying dolomitic section of the Hogan Formation because they are fossiliferous and contain *Pseudoschwagerina* which dates them as Wolfcampian. Scattered crinoids, fusulinids, and bryozoans including *Penniretepora* can be found in well-exposed outcrops. No large colonies of *Thysanophyllum* were found in outcrop, but several thin sections display fragments of coral septa which resemble those found in other Riepe Spring localities where *Thysanophyllum* is present. This 112-foot unit resembles the lower 125-foot limestone section in the Riepe Spring at Moorman Ranch. The overlying 171 feet consists of medium- to dark-gray, weathering to medium-gray, platy to thin-bedded, organic-rich mudstones which contain sponge(?) spicules. This section is probably equivalent to the middle sandy unit found in the Riepe Spring at Moorman Ranch and probably represents a continuation of the transition from the sandstones at Moorman Ranch to the sandy limestones at the Central Butte Mountains locality to mudstones at this Cherry Creek location. The top 116 feet of the Riepe Spring is made up principally of massive ledges of the crinoidal facies which in various samples is modified by minor to substantial amounts of bryozoans, fusulinids, ophthalmidids, and *Tubiphytes*. An ophthalmidid grainstone occur within this section and the fusulinid facies is present at the top. This upper 116-foot unit is the most prominent part of the section and can be traced northward into the bottom of a transverse canyon where the overlying Riepetown and Pequop Formations are well exposed.

*Brush Creek Section.*—This section was measured in the Southern Pequop Mountains in the NE/4 T. 31 N., R. 64 E., in Elko County. The Riepe Spring is exposed in the bottom of the canyon of Brush Creek near its mouth about eight miles northeast of Spruce Mountain. The base of the section is concealed, or perhaps downdropped below the canyon bottom by faulting, but a nearly complete section is exposed.

The Riepe Spring - Ferguson Mountain intertonguing relationship is very evident at this location. Both lithologies are found here but the writer prefers to designate the lower 562 feet of this section as the Riepe Spring because of the presence of similar limestone types and because the overlying 1,500 feet of predominantly sandstones, siltstones, and sandy limestones is best called Riepetown Formation rather than Ferguson Mountain Formation. This interpretation restricts the Ferguson Mountain Formation to a rather small area.

The Riepe Spring is composed of 34 percent grainstones, 29 percent wackestones, and 27 percent packstones at Brush Creek. The basal 70 feet is a medium-gray, massive, cherty, pelleted wackestone modified by ophthalmidids, crinoids, and brachiopods. A few fusulinids are also present. The overlying 150 feet is dark-gray, thin-to medium-bedded, pelleted wackestone with abundant ophthalmidids and scattered quartz sand. *Schwagerina wellsensis* occurs in this unit. The next 85 feet is medium-gray to medium brownish gray, thin-bedded to massive, cherty wackestones, packstones, and a few grainstones. The fusulinid facies with a pelleted mud as the matrix is common in this suite of rocks. *Thysanophyllum* occurs in outcrop and scattered fragments of septa of this coral are found in thin section. The scattered grainstones are the crinoidal facies which also contain broken and abraided schwagerinid fusulinids and a few coral and brachiopod fragments. The overlying 215 feet is made up of medium-dark-gray, weathering to medium-gray, thin- to thick-bedded sandy packstone with abundant brown and black chert. The principal rock type is a very fine-grained criniodal packstone with up to 20 percent quartz sand varying from .1 to .35mm in diameter. The algal pellet facies is also present in this section. Scattered fusulinids are found in outcrop. The top 52 feet is medium-gray, medium- to thick-bedded to massive wackestone, and packstone with the pelleted mud and crinoidal facies making up the majority of the rock types. *Thysanophyllum* and fusulinids are noticeable in outcrop.

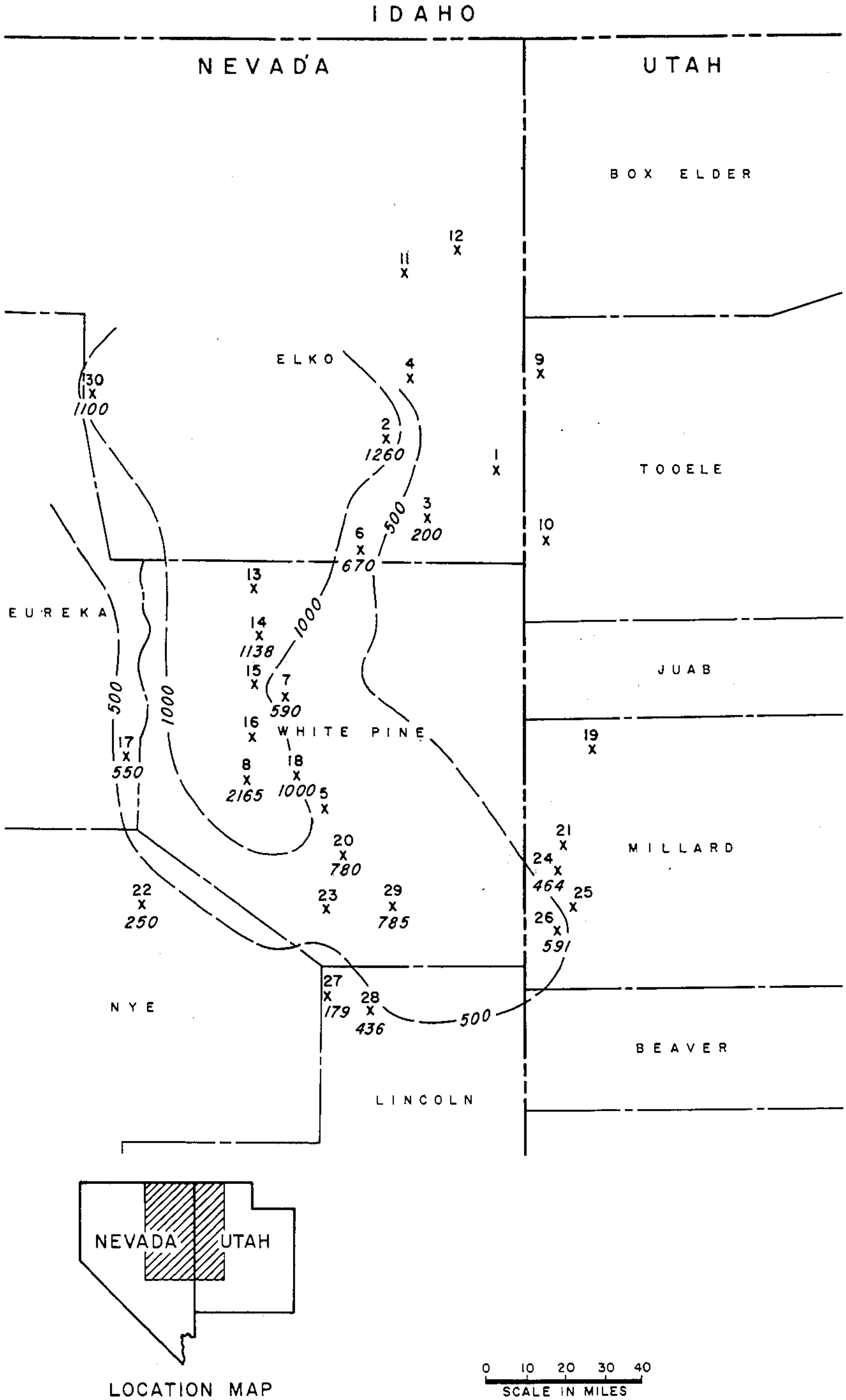
Text-figure 6 is an isopach map of the Riepe Spring Limestone. A northeast-southwest trending trough-shaped depocenter is outlined. This trend, however, is modified by several northwest-southeast trends which cause the trough to become restricted in width near Ely and expanded in width along an axis connecting the Burbank Hills section in Millard County, Utah, with the Horse Canyon section in White Pine County, Nevada, and the Carbon Ridge section in Eureka County. A similar cross trend extends northwestward into the Carlin Canyon area, but this trend is accentuated by the facies change northeastward into the Ferguson Mountain Formation. If Riepe Spring age rocks of the Ferguson Mountain Formation were included in this isopach, the Riepe Spring depocenter would become even more trough shaped as Steele (1959, p. 5) suggested.

Riepetown Formation

*General Statement.*—The Riepetown Sandstone was named by Steele (1960) for a section of rocks formerly called the "Rib Hill Sandstone," a name which was preoccupied as Steele pointed out. The type locality is at Rib Hill in Section 21, T. 16 N., R. 62 E., White Pine County, a few miles west of Ely. The name is taken from the town of Riepetwon (spelled Reipetown by Spencer in U.S.G.S. Professional Paper 96, Plate II) located in Section 8 of the same township. The Riepetown Sandstone is a valid mappable unit, but should be designated the Riepetown Formation since a large portion of the rocks at its type locality and elsewhere is not sandstone but limestone and dolomite.

Typically, the formation is a slope former consisting of thin- to medium-bedded, yellow-brown to light-brown, fine-grained calcareous sandstones and siltstones interbedded with thin- to thick-bedded sandy limestone and dolomite with some cherty, micritic limestones.

*Type Section.*—The writer measured 993 feet of Riepetown at the type locality at Rib Hill. Steele (1960) reported a thickness of 1,008 feet in his description of this section. The lower contact with the Riepe Spring Limestone near the top of the hill is sharp and well defined. The top of the Riepe Spring is a massive, medium-gray, cherty limestone and the lower Riepetown is medium to light-gray-brown, weathering reddish-brown and yellow-brown, thin-bedded calcareous siltstone and silty lime mudstone. This lower unit is 275 feet of rather monotonous interbedded siltstones, lime mudstones, and calcareous fine-grained to very fine-grained sandstones. One mudstone contains very small sponge (?) spicules. This section is transitional from the underlying carbonate deposition to the coarser clastics overlying. The next unit measured is a 192-foot-thick section which is much like the underlying except for several thin calcareous dolomites which are interbedded with the sandstones and siltstones. These dolomites are dark brown, weathering to bluish-gray. Most of the matrix, which was formerly lime mud, is now very fine-grained dolomite, but the original particulate content remains, although dolomitized in part. These are scattered fusulinids, crinoids, bryozoans, brachiopods, and pellets making up as much as 20 percent of the rock. This section is succeeded by 136 feet of interbedded sandstones and a few thin sandy limestones and dolomites. Several sandstones in this group of rocks are markedly bimodal. The predominant grain size is about 80 microns and the other mode is made up of clear, well-rounded quartz grains varying from about 450 to 800 microns. This probably represents a second source area which was contributing clastics at this time. Above this is a 157-foot section with sandstones similar to those below but with several medium-bedded, bluish gray, hackley-weathering sandy dolomites containing abundant relict pellets. A few thin spicular lime mudstones are also present. The next unit is 173 feet thick, only the bottom half of which is well exposed. The upper half forms the saddle between Rib Hill proper and a low




TEXT-FIGURE 7.—Isopach map of Riepetown Formation.

ridge to the south. This unit contains several sandy very fine-crystalline dolomites which contain relict pellets and clots of dark lime mud. A few bimodal sandstones like those below also contain scattered oolites and pellets and have a dark dolomitic matrix. The top unit of the Riepetown is 60 feet thick and is composed of interbedded sandstones, limestones, and dolomites. One prominent dolomite is cross-bedded and contains laminations of fine quartz sand with scattered coarse quartz grains, dolomitized skeletal fragments, dark pellets, and pelletoid grains. The overlying Pequop Formation is thick-bedded to massive and contains the coral *Durhamina.*

*Moorman Ranch Section.*—The writer's Riepetown section in this area begins at the top of the Riepe Spring Limestone near the creek bottom in Section 7, T. 17 N., R. 59 E. The traverse trends southeastward up the eastern side of the valley to near the top of ridge which is formed by the overlying Pequop Formation. A section measured earlier and trending due east from the Riepe Spring outcrop was abandoned because of complexities caused by faulting.

The thickness of this measured section of the Riepetown is 2,065 feet. This is considerably more than some earlier writers such as Steele (1960, p. 103) who assigned about 1,200 feet to the Riepetown and Stevens (1965, p. 147) who included 870 feet. The writer's top of the Riepetown is apparently much higher in the section than that of Steele. The faulted area discussed by Stevens (1965, p. 147) as a possible explanation for the discrepancy between his and Steele's measured thicknesses is considerably north of the writer's section. No faulting is evident along this more southerly traverse. The writer's measured thickness agrees more closely with that of Brill (1963, p. 324) who shows about 1,900 feet of "Rib Hill Sandstone" (Riepetown) in his columnar section at Moorman Ranch.

The Riepetown Formation may be divided conveniently into an upper and a lower member at Moorman Ranch. The lower member is about 1,200 feet thick and is predominantly sandstone. The upper member is about 865 feet thick and is composed of interbedded sandstone and sandy limestones.

The basel beds of the Riepetown include argillaceous, sandy wackestones with very small spicules which are similar to the basal rocks in the Riepetown at Rib Hill. The sandstones are immature, poorly sorted, very fine-grained to fine-grained, thin-bedded, brownish yellow, brownish orange, and tan, with a lime mud matrix containing about 10-20 percent argillaceous materials. The sandy rocks are relatively soft and weather to slopes of subdued relief which are broken by the thin- to medium-bedded limestones. The limestones include a few crinoidal grainstones with scattered fusulinids and textularids but most are argillaceous sandy lime mudstones and wackestones. The top of the lower member is marked by a 200-foot section of orange-brown, thin-bedded to thick-bedded argillaceous, sandy wackestones, and spicular mudstones overlying a thin-bedded quartzitic to calcareous sandstone about 80 feet thick .

The upper member has a basal unit 536 feet thick made up of medium light-brown, weathering to light-brown, medium-bedded to massive, cherty lime mudstones, wackestones, and crinoid grainstones which also contain scattered fusulinids and bryozoans. Overlying this is a unit 320 feet thick which is mostly thin-bedded, yellow-brown, fine-grained sandstone with a few silty and sandy wackestones. *Schwagerina youngquisti* occurs near the top of this section and dates it as Late Wolfcampian.

The upper member of the Riepetown is overlain by massive limestones of the Pequop Formation containing *Durhamina* which marks the base of this formation. The contact is sharp and conformable.

*Butte Mountain Section*.—At this locality north of 30-mile Ranch, the Riepetown is 680 feet thick. The lower 364 feet which rest on the Riepe Spring Limestone is tan to yellow to gray, weathering to orange-tan and reddish gray sandstones, siltstones, and lime mudstones. A few scattered crinoids, fusulinids, and bryozoans were noted in outcrop. Small spicules occur in thin section in some of the mudstones. Overlying this is a 230-foot section of calcareous sandstones, sandy dolomites, and pelleted mudstones. The dolomites contain coarse, well-rounded quartz grains and are identical to those found at Rib Hill. The upper 50 feet contains highly burrowed and pelleted lime mud. The top of the Riepetown is made up of 90 feet of light grayish brown, weathering to reddish-gray, sandy mudstones, wackestones, and calcareous dolomite. These beds are thin- to thick-bedded and contain moderate amounts of crinoids, fusulinids, bryozoans, and a few gastropods on outcrop. In thin section, the principal particulate grains are ophthalmidid fragments. The overlying beds of the Pequop Formation are thick-bedded to massive grainstones, packstones, and wackestones which contain *Durhamina*. With this good stratigraphic marker as a guide it is relatively easy to correlate these rocks with similar sections at Rib Hill and Moorman Ranch.

*Cherry Creek Mountains Section*.—The Riepetown at this locality is 670 feet thick about one mile south of McDermitt Creek near the east front of the mountains. The formation is underlain by massive crinoidal grainstones of the Riepe Spring. The contact is sharp and conformable. The lower sandstones are very fine grained, reddish brown and reddish tan, thin- to medium-bedded, argillaceous, calcareous, and poorly sorted. Zircon, tourmaline, mica, and dolomite are common accessory minerals. The sandstones are interbedded with dark-gray, bluish gray, and black, weathering to medium-gray, thin- to medium-bedded wackestones, packstones, and grainstones. The crinoid facies with accessory fusulinids, textularids, ophthalmidids, and bryozoans is common in the lower 295 feet. Sandy lime mudstones are also numerous. The overlying 193 feet is much like the previous unit but scattered brachiopods are present on outcrop. Several thin fusulinid-rich wackestones are also present. The top 182 feet of the Riepetown is thin- to medium- to thick-bedded, medium to dark gray with scattered bryozoans and brachiopods. A prominent limestone with fusulinids occurs 82 feet from the top of the formation. In thin section, some of these limestones show good current orientation of brachiopod and bryozoan fragments. The top of the formation is drawn at the base of a 100-foot-thick, massive, cherty, crinoid limestone unit of the Pequop Formation. *Durhamina* is present about 200 feet above the top of this limestone and another bed with this coral occurs 220 feet higher in the section. Neither occurrence is very prominent and a diligent search must be made to locate these organisms.

*Dolly Varden Section*.—As previously discussed the writer correlates a sandy unit 200 feet thick within the Ferguson Mountain Formation at this locality, with the Riepetown Formation. The base of this sandy unit occurs about 330 feet above the base of the Ferguson Mountain Formation. It overlies massive crinoidal grainstones which are Medial Wolfcampian in age. The sandstones and siltstones are thin-to medium-bedded, reddish tan and medium-gray, weathering to brownish red and bluish gray. Some are calcareous and some are quartzitic. Most are organic rich and argillaceous. A thin crinoidal limestone contains the Medial Wolfcampain fusulinid *Schwagerina wellsensis*. Another sandy section 150 feet thick and separated from the lower one by about 190 feet of limestones may also be closely related to the Riepetown. This unit contains sandstones and siltstones similar to the lower tongue but has interbedded with them many sandy and partly silicified medium- to thick-bedded crinoidal grainstones. These sandstone tongues represent approximately the deepest penetration of the Riepetown sands into the Ferguson Mountain depocenter.

*Brush Creek Section.*—A total of 1,320 feet of interbedded, medium grayish-brown, thin- to medium-bedded sandstones, siltstones, and sandy lime mudstones were assigned to the Riepetown at this locality. The formation overlies the Riepe Spring Limestone and underlies the Pequop Formation. The lower 517 feet is predominantly medium-brown, thin-bedded, very argillaceous, very fine-grained sandstones. These beds are organic rich and contain a molluscan and brachiopod fauna. This section gives way upward to a dark-gray silty, cherty, argillaceous lime mudstone about 80 feet thick. Thin sections of this unit show very aboundant, short, spicule-like particles which give the rock an oriented fabric. A well-developed sandy packstone at the top of this unit contains mostly echinoderm fragments and a few broken brachiopods. Overlying this is a 319-foot section much like the basal 517-foot section except that it is darker, more organic, and less fossiliferous. The overlying 400 feet contains more limestone than below, including several fusulinid packstones. The contact with the overlying Pequop Formation is gradational and an unquestionable contact is difficult to draw. The top of the Riepetown was placed where the limestones become thick-bedded to massive and are the dominant lithology.

Text-figure 7 is an isopach map of the Riepetown Formation. The configuration of this depositional pattern suggests that the Riepetown sedimentation was controlled principally by the Antler orogenic belt to the west. The depositional axis of the Riepetown parallels this tectonic feature and probably reflects a rapidly subsiding trough in front of it. The prominent swing to the southeast in the southern part of the map area appears to result from the bulge of the Southern Nevada Highland in this area.

Pequop Formation

*General Statement.*—Steele (1960, p. 106) gave the name Pequop Formation to a heretofore unnamed limestone sequence he dated as lower Leonardian to lower Guadalupean in age. He first proposed the name in an abstract the previous year. He gave as the type section a location in Section 3, T. 33 N., R. 65 E., Elko County, Nevada. He described the section as composed of purplish gray, platy and irregularly bedded, silty limestones and fusulinid coquinas, 1,570 feet thick. Robinson (1961, p. 105) pointed out that the type locality was probably incorrectly located and designated a reference locality for the Pequop in Sections 34 and 35, T. 34 N., R. 65 E.

In the Moorman Ranch area Steele (1960, p. 106) divided the Pequop Formation into three members. He named these the Lower and Upper Moorman Ranch Members separated by the Summit Springs Evaporite Member. The lower and upper members are well exposed at this locality but the Summit Springs Member is not. The type locality for this member is the Standard of

California - Continental Oil Company Summit Springs Unit No. 1 well in Section 30, T. 20 N., R. 60 E., White Pine County, Nevada. The lower of two evaporite sections in this well, from 4400' to 5400', was dated as middle Leonardian (Steele, 1959, p. 135) and designated as the type section. At Moorman Ranch this member may be represented by a thin section of dolomites, and siltstones as suggested by Steele (1959, p. 135), and Bissell (1964, p. 607). Good exposures which can be assigned to this member with surety are rare. The best representation is probably that at Gold Hill.

*Type Area Section.*—Robinson measured a total of 3,087 feet of Pequop Formation at the reference section and was able to assign 1,105 feet to Early Leonardian, 522 feet to Medial Leonardian, and 1,460 feet to Late Leonardian. He did not attempt to carry Steele's member names into the Pequop Mountains because the Early, Medial, and Late Leonardian Subdivisions were not mappable. Steele's Upper and Lower Moorman Ranch Members and Middle Summit Springs Member had been set up in the Moorman Ranch area in the southern Butte Mountains. The formation name has been applied to Leonardian rocks at many other localities in eastern Nevada and western Utah (Bissell, 1964a).

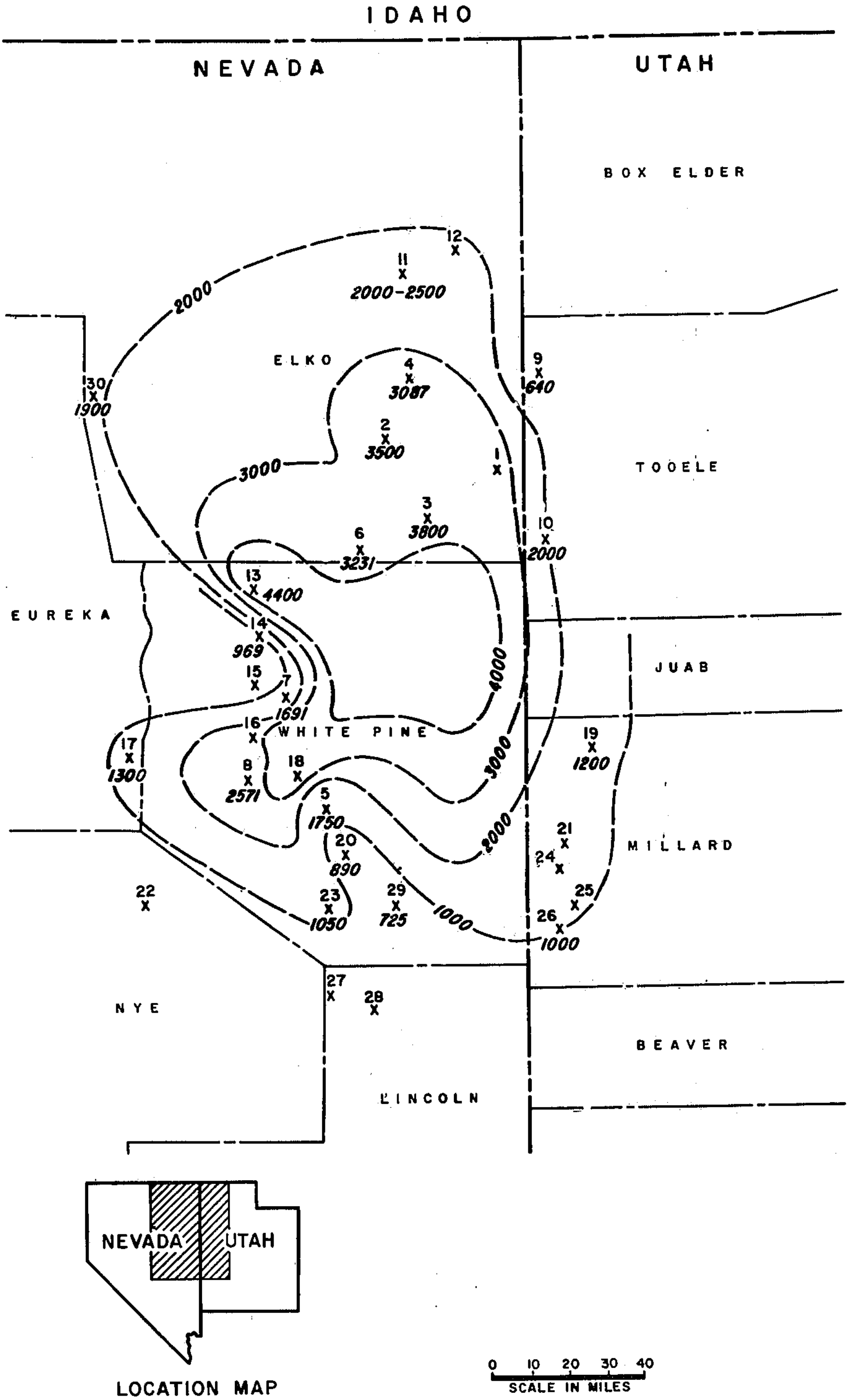
The Pequop Formation at its type locality is decidedly unlike the Pequop Section visited by the writer at other exposures. For this reason the choice of this locality as the type section is unfortunate. Most of the rock types occurring here also occur elsewhere but not in the same relative proportions.

A factor analysis was run on 180 samples from fairly regularly spaced intervals in the section. The variables which were logged in these samples and their respective abundance are as follows:

| | | | |
|---|---|---|---|
| Lime mud | 36% | Undiff. foraminifera | 3% |
| Crinoids | 13% | Fusulinds | 3% |
| Undiff. molluscs | 8% | Algal (?) pellets | 2% |
| Detrital quartz | 7% | Ooliths | 2% |
| Pelletoid grains | 6% | Undiff. bryozoans | 2% |
| Undiff. echinoderm | 5% | Undiff. corals | 1% |
| Dasyclad algae | 5% | Encrusting algae | 1% |
| Brachiopods | 4% | Pellets | 1% |

Ostracods, *Tubiphytes,* and undifferentiated skeletal fragments occur in amounts less than one percent. Nine factors were extracted which explained 82 percent of the logged data. The main factors extracted were dominated respectively by lime mud, crinoids, detrital quartz, ooliths, molluscs, brachiopods, undifferentiated echinoderms, undifferentiated foraminifera (mainly ophthalmidids), and dasyclad algae. Those having the most samples assigned to them were the lime mud, pelletoid, mollusc, crinoid, and detrital quartz facies. Dasyclad algae and ophthalmidids occurred in many samples but these variables usually were placed in the lime mud facies except where they occurred in abundance. Fusulinids, although very prominent in outcrop, were placed in the undifferentiated foraminifera and undifferentiated echinoderm-brachiopod factors most often.

Although Robinson did not attempt to map members of the Pequop as is often done elsewhere, he did split the formation into three divisions on the basis of fusulinids as noted above. With detailed study of the rocks in thin section it is relatively easy to divide the formation into an upper and lower




TEXT-FIGURE 8.—Isopach map of Pequop Formation.

member on a lithological basis. The lower part of the section is dominated by the crinoidal, detrital quartz, and undifferentiated echinoderm-brachiopod facies. In the upper part of the section, the molluscan, ophthalmidid, and dasyclad algal facies become most important. The lime mud facies is present everywhere but is most numerous in the upper part of the section also.

The change in dominant rock type begins where the molluscan fragments appear in a very muddy rock about 1,010 feet above the base of the formation and about 90 feet below Robinson's faunal boundary between the lower and medial Pequop. Sandy lime mudstone reappears immediately above the molluscan facies but 90 feet above, the ophthalmidid and pelleted mud facies become most important. About 1,200 feet above the base of the formation the crinoidal facies reappears briefly but changes upwards into the ophthalmidid and pelleted mud facies and, at 1,300 feet above the base, into the dasyclad facies. A sandy oolite facies overlies these dasyclad wackestones. Above this is an interbedded sequence of the molluscan, pelleted mud, ophthalmidid, and dasyclad facies with a few scattered oolites. The section remains in these shallow water facies for several hundred feet more. These facies are also present on both sides of the fault that Robinson mapped 1,692 feet above the base of the Pequop. The writer agrees with Robinson that there is no important stratigraphic displacement at this fault. The mollusc, dasyclad and ophthalmidid facies continue to be most abundant above this fault despite the occasional occurrence of the crinoid and fusulinid facies.

Immediately below the fault at 2,318 feet above the base of the formation the pelleted mud and ophthalmidid facies are present. Above the fault the fusulinid and crinoid facies are present for a short distance but give way to the molluscan facies about 50 feet above the fault. There is no clear petrologic evidence for a large stratigraphic displacement at this fault because it appears that the fault cuts the Pequop in a variable part of the section. All the facies noted heretofore, with the exception of the oolites, are present in rhythmic sequences from the fault to the top of the section. The Pequop is overlain, apparently conformably, by tan and yellow-brown silts and sands of the Loray Formation.

*Rishel Peak Section.*—The Pequop Formation at Rishel Peak, Tooele County, Utah, is only partially exposed. The upper part of the section plunges westward beneath Recent alluvium at an angle of about 50°. The lower contact with the Ferguson Mountain Formation is not well defined as noted in the description of this formation at this locality. About 640 feet of Pequop Formation is exposed and consists of 47 percent wackestone, 23 percent mudstone, 17 percent grainstone, 7 percent packstone, and 5 percent sandstone. The rocks are mostly varying shades of gray, thick-bedded to massive, sandy, dense, and recrystallized. Fusulinids, crinoids, echinoid spines, and bryozoans are abundant on outcrop. A few thick beds are mottled with *Leioclema,* and some with brown-weathering beds of chert. Several small faults identified by red weathering brecciated zones intersect the Pequop on this traverse. They appear to be minor in displacement.

No clear-cut lithological zonation of the Pequop is evident at this locality. Much of the particular content is so extensively recrystallized that identification even as to phyla is very difficult. Most of the mud has undergone micrite enlargement to the extent that it is now best described as microsparite. This is the only section visited by the writer where obliteration of original structures and textures has progressed to this extent without dolomitization. The rather thin Pequop sections at Rishel Peak, and other nearby localities in the Silver Island Mountains and the Leppy Range, probably are due to the influence of the Northeast Nevada High.

*Section at Ferguson Mountain.*—Only a thin and incomplete Pequop section is exposed at this locality. The base of the formation crops out near the top of the north peak and the lower beds form the westward-dipping backslope of the mountain. Berge (1960, p. 28) assigned 681.5 feet to this formation and Slade (1961, p. 60) placed 888 feet of Leonardian strata in the Pequop. The upper part of the section is faulted out.

The writer sampled only the limestones in the basal part of the formation and found these composed of 56 percent wackestones, 27 percent grainstones, and 17 percent packstones. As noted earlier a well-developed *Durhamina* biostrome marks the base of the formation. Fusulinids, crinoids, and bryozoans are the most abundant fossils. Ophthalmidids and textularids are also important. A sandy lime mud in varying amounts forms the matrix for these rocks.

*Gold Hill Section.*—Hodgkinson (1961, p. 176) measured about 2,000 feet of Pequop Formation at this locality. He assigned 850 feet to the Lower Moorman Ranch Member, 250 feet to the Summit Springs Member, and 900 feet to the Upper Moorman Ranch Member. The tripartite division may be made easily here because the 250-foot member is mostly gypsum (alabaster) with thin interbeds of sandstone and dolomite.

The base of the formation rests conformably on the Ferguson Mountain Formation and is marked by a well-developed *Durhamina* bed. The lower 500 feet is composed of massive to thick-bedded, medium-light-brown, weathering to light brownish gray, packstones, grainstones, and wackestones. The lime mud, crinoidal, and fusulinid facies are most abundant. These lower limestones grade upward into a thin- to medium-bedded section with a similar faunal suite but which is cherty and dolomitic. The dolomite appears to be secondary. Isolated dolomite rhombs, selectively dolomitized fossil fragments and vugs filled with sparry dolomite are scattered in a lime mud matrix. This unit is overlain by the evaporitic middle member.

The Upper Member above the evaporitic section is characterized by dolomite, dolomitic sandstone, and sandy dolomite. The dolomite is microcrystalline and most of the original rock textures remain. Dolomitized pellets and ooliths are the principal particulate components. These dolomites are interpreted as very early diagenetic in origin. The ooliths are very well developed and abundant especially near the top of the member. The middle and upper members of the Pequop at Gold Hill demonstrate the classical association of ooliths and evaporites very well.

*Dolly Varden Section.*—About 2,380 feet of Pequop Formation is exposed at the writer's traverse in the Dolly Varden Mountains. The section is well exposed in the southeastern part of T. 28 N., R. 66 E., Elko County, Nevada. A summary of the rock types shows the section is composed of 50 percent dolomite, 33 percent sandstone, 10 percent wackestone, 6 percent mudstone, and 17 percent grainstone. The lime mud, detrital quartz, and dolomite are the dominant facies.

The lower 400 feet of the Pequop is composed predominantly of brownish-gray, medium- to thick-bedded sandy lime mudstones, wackestones and calcareous sandstones. Fusulinids, brachiopods, crinoids, and a few bryozoans are present in outcrop. A *Durhamina* bed marks the base of the section which rests conformably on the Ferguson Mountain Formation. This basal section grades upward into a long series of thin- to medium-bedded, light gray-weathering dolomites and dolomitic sandstones. No fossils were noted in this section which is about 1,200 feet thick. Under the microscope the dolomites are microcrystalline and appear to be dolomitized lime mud of very early diagenetic origin. Only ghosts of pellets were noted in this section. Overlying this is a 250-foot section of medium- to thick-bedded, grayish-brown and bluish gray-weathering, cherty packstones, and a few grainstones. These rocks are principally the crinoid, brachiopod, and fusulinid facies. A few beds of syringoporoid corals are present in a silty, dark grayish-brown lime mud matrix. The fusulinids are mostly of the genus *Parafusulina* and suggest a Medial Leonardian age. This section is overlain by 530 feet of sandstones and dolomites much like the dolomitic unit below. Again no fossils were noted but the top beds are good dolomitized oolites like those in the top of the Pequop at Gold Hill. The section is terminated by a fault at this point, but it is believed that most of the Pequop is present and that the upper missing beds below the Loray Formation are probably dolomites and sandstones. Bissell (1964a, p. 611) reported a section of 3,815 feet of Pequop in the Dolly Varden Mountains. It is likely that some of the beds that Bissell placed in the lower Pequop have been included in the Ferguson Mountain Formation by the writer. Also it is quite likely that Bissell's section includes some beds above the fault that limits the top of the writer's section.

*Brush Creek Section*.—A total of about 3,500 feet of section was included in the Pequop Formation at this locality in the Southern Pequop Mountains. The lower contact was placed at the base of a sequence of medium- to thick-bedded, fusulinid-rich limestones which overlie the thin- to medium-bedded, calcareous sandstones of the Riepetown Formation. The upper contact is gradational with the overlying Loray Formation, but was placed at the top of a cherty, medium- to thick-bedded, pelleted mudstone which underlies a sandy and dolomitic thin- to medium-bedded, yellowish-tan unit assigned to the Loray.

The Pequop is composed of 62 percent wackestones, 11 pecent grainstones, 13 percent sandstones and siltstones, 6 percent packstones, 4 percent mudstones, and 3 percent dolomites. The lime mud, detrital quartz, dolomite, fusulinid, crinoid, and oolite facies are the most important rock types. The section can easily be divided into a lower and upper member. The lower 900 feet is made up of sandy lime muds, calcareous sandstones and the fusulinid, and crinoidal facies. The remainder of the section is an alternating sequence of the oolite, ophthalmidid, dolomite, algal pellet, and sandy lime mud facies. The oolites are usually dolomitized and the dolomites are very sandy. A few thin fusulinid-rich sandy wackestones are also present. The sequence appears to be cyclical with at least rythmic oolites appearing periodically, overlain by sandy lime mud, ophthalmidids, and algal pellets. All these facies suggest relatively shallow water deposition. The total sequence is much like the type Pequop section 15 miles to the north, but the molluscan and dasyclad facies found in the upper part of the type section were not found in the Brush Creek section. The rocks are also not as dark and organic rich as those in the type section.

*Cherry Creek Mountains Section.*—A total of 3,231 feet of Pequop Formation was measured in the Cherry Creek Mountains near McDermitt Canyon. The traverse trends generally west along the north side of the canyon and also the north side of the Corral Canyon tributary.

The section can be divided into four units on the basis of lithologic differences. The lower 702 feet is predominantly limestone, the overlying 1,550 feet is mostly dolomite, sandy dolomite, and sandstone. Above this is a 229-foot limestone unit. The top of the Pequop is mostly dolomite, sandy dolomite, and sandstone and is 750 feet thick.

A summary of the section shows the Pequop is 53 percent dolomite, 16 percent packstone, 15 percent wackestone, 10 percent sandstone and siltstone, 5 percent mudstone, and 1 percent grainstone. The base of the formation is placed at the top of a thin-bedded sandy section of the Riepetown Formation. The basal Pequop limestones are thick-bedded to massive- medium-gray, weathering to light-gray, cherty and heavily veined with calcite. Crinoid ossicles are prominent in outcrop. In thin section the basal 100 feet is seen to be the crinoid facies modified with substantial amounts of bryozoans and fusulinids and about 10 percent quartz sand. Overlying this is about 70 feet of thin-bedded, medium-brown, cherty, fine-grained crinoidal wackestone, overlain by about 20 feet of coarse crinoidal grainstone. Above this is 115 feet of dark-gray, fine-grained, medium-bedded, sandy wackestone which weathers light-gray and medium-brown. The rock contains echinoderm fragments and fusulinids and a few pieces of *Durhamina* were found near the top of this unit. Thus *Durhamina* occurs about 300 feet above the base of the Pequop drawn on a lithologic basis at this locality. The fossil is scarce in outcrop, but thin sections cut from limestones in this unit contain distinctive septal fragments of corals. The next 200 feet is a sandy medium-gray to medium-brown, medium- to thick-bedded sequence of packstones and wackestones which contain crinoids, fusulinids, bryozoans, and echinoid spines. Overlying this are 124 feet of dark-gray to grayish-brown, fine-grained sandy dolomitic mudstone. This is succeeded by a 55-foot-thick unit of sandy crinoidal facies with thick beds of dolomitic mudstone at the base and top. The upper one of these mudstones has unusually large crinoid stems in abundance. This is the top of the lower unit.

The lowermost bed of the 1,550 foot dolomitic unit is a dolomitized oolite. This denotes a distinctive change from the skeletal limestone deposition of the underlying basal unit. The ooliths are well preserved despite the conversion to microcrystalline dolomite. The cement is slightly coarser crystalline. The remainder of this sequence is made up of alternating beds of sandstone, sandy dolomite, dolomitized oolite, and a few bryozoan - and echinoderm - rich wackestones. The basal part of the overlying 229 feet of limestones contains some unusual bryozoan biostromes (plate 1). These beds are one to three feet thick and are composed almost entirely of stalked bryozoan pieces up to about two inches in length set in a silty lime mud matrix. Several of these biostromes are present in a 40-foot-gross section of massive to thick-bedded limestones. No encrusting algae or other binding organisms were present in the thin sections examined by the writer. The biostromes are very distinctive and are also present in Cottonwood Canyon, about ten miles to the northwest, near the north end of the range. The remainder of this 225-foot section is mostly thick-bedded to massive, sandy crinoidal-and bryozoan-rich wackestones. The upper 750 feet of the Pequop is dominated by dolomite, sandy and silty dolomite, sandstone, dolomitized oolite, pelletal muds, and a few wackestones with abundant algal-coated grains. The top of the Pequop was picked at the base of some vari-colored molluscan-rich mudstones assigned to the Loray Formation.

*Central Butte Mountains Section.*—The writer assigns 1,691 feet of strata to the Pequop Formation on the east side of the Central Butte Mountains, about five miles north of the 30-mile ranch. The basal contact with the underlying Riepetown Formation was picked at the base of a prominent limestone sequence about 110 feet thick and containing *Durhamina* midway in the unit. Pequop, at this locality, consists of 52 percent dolomite, 17 percent packstone, 17 percent wackestone, 8 percent mudstone, 5 percent sandstone and siltstone, and 1 percent grainstone. The dolomites are calcareous and most appear to be dolomitized lime mud. Almost all the rocks are sandy, and detrital quartz makes up 10 percent of the total rock volume. The opthalmidid, algal pellet, sandstone, and lime mud facies are important in addition to the dolomite. Echinoids, crinoids, corals (*Durhamina*), and brachiopods are important in the lower 314 feet and this part of the section may be treated as a lower member. The remainder of the Pequop is dominated by carbonate mud, detrital quartz, and nonskeletal grains with molluscs near the top and may be lumped together as an upper unit. The entire Pequop Formation here is regarded as very shallow water deposition.

The upper contact with the overlying Loray Formation is gradational and was arbitrarily chosen where the somber dolomite and lime muds and sandstones of the upper Pequop beds are succeeded by the brighter-colored muds of the Loray.

*Moorman Ranch Section.*—The Pequop Formation at this locality has been divided into three members as discussed earlier. The fact that there is, to the writer's knowledge, no exposed gypsum or anhydrite equivalent to the Summit Springs Member here, makes the stratigraphy difficult to fit into its proper perspective. However, about two miles north of Highway 50 on the east side of the broad valley separating the Lower and Upper Members, there are some reddish dolomites and sandstones which may represent the Summit Springs.

The writer places the lower boundary of the Pequop at the base of a thick limestone sequence overlying the sandstones and thin limestones of the Riepetown formation. *Durhamina* occurs at the base of this limestone section and the Riepetown-Pequop sequence can be correlated with more easily understood section at Rib Hill using this fossil as a stratigraphic marker.

The Pequop Formation section measured by the writer begins near the top of the ridge east of a north-south trending valley about two miles west of the ranch headquarters. The traverse steps southward across Highway 50 at the west side of the broad strike valley which separates the lower part of the Pequop Formation from that part studied by Knight (1956). It then continues around the south flank of a small southward-plunging anticline and returns to the highway near the base of Knight's section from where it continues to the highest exposed beds on the mountain north of the high ridge near the highway.

The Pequop is 36 percent packstone, 27 percent grainstone, 27 percent wackestone, 8 percent sandstone, and 2 percent mudstone at this locality.

The distribution of the constituents logged in this section is a follows:

| | | | |
|---|---|---|---|
| Lime mud | 31% | Bryozoans | 3% |
| Ooliths | 12% | Pellets | 2% |
| Crinoids and echinoids | 12% | Encrusting algae | 2% |
| Detrital quartz | 10% | Lumps | 2% |
| Pelletoid grains | 7% | Dasyclad algae | 1% |
| Fusulinids | 6% | Undiff. skeletal | 1% |
| Undiff. Foraminifera | 6% | | |

Ostracods, corals, and molluscs make up the remaining two percent. The composition of this section differs from that of the type Pequop most in that it has fewer molluscs and dasyclad algae, and has more ooliths and foraminifers.

Factor analysis was run on 115 samples distributed throughout the Pequop section. The first six factors extracted were dominated respectively by lime mud, detrital quartz, crinoids, undifferentiated formanifers (mostly opthalmidids), fusulinids, and ooliths. These are the most abundant facies in the Pequop section.

The greater part of the Pequop limestones are medium- to thick-bedded to massive, light grayish brown to light-brown on fresh fracture and weather to light-gray and light yellowish gray. The erosional profile is one of thick- to massive ledges formed by the limestones, separated in several places by softer, yellowish sandstones. The exposures are excellent.

Crinoids and fusulinids are the most noticeable fossils on outcrop in the lower 423 feet of the Pequop. The crinoid, ophthalmidid, fusulinid, quartz sand, and oolite facies are the most abundant rock type in this interval. Overlying this is about 90 feet of section in which the lime mud facies is dominant. Small amounts of crinoids, fusulinids, and other Foraminifera are the principal particulate components of these rocks. The succeeding 128 feet has good examples of the lime mud, fusulinid, opthalmidid, quartz sand, and oolite facies in a cyclical sequence. The remaining 321 feet which extends to the top of the Lower Pequop has numerous examples of the lime and facies present and the ophthalmidid and fusulinid facies are also important. A prominent oolite caps this sequence which totals 962 feet. Cyclic patterns in the Pequop Formation in this area have been noted by Bissell (1964b).

The Summit Springs Evaporite Member is obscure in this area. It has been assumed by several workers at Moorman Ranch that the broad north-south trending strike valley between the Upper and Lower Members is the result of solution and collapse of the soluble Evaporite Member. While this explanation probably would not account for all of the topographic relief formed by the valley, it could account for part of the relief and graben-type faulting is possibly responsible for the remainder. The valley is largely covered by alluvium, but about two miles north of Highway 50 on the east side of the valley, there is a 600-foot section of the dolomite, sandstone, siltstone, and limestone which appears to belong to the Summit Springs. The dolomites are probably very early diagenetic in origin and resemble those associated with evaporites at Gold Hill. The few fossils noted were pelecypods and gastropods which normally are associated with a shallow, muddy, often restricted environment.

Upper Moorman Ranch Member exposed immediately north of Highway 50 has a much higher sand content than the lower member. A prominent yellowish brown medium- to fine-grained sandstone about 20 feet thick occurs about 130 feet above the base of the section and another occurs 584 feet above the base. Most of the limestones are sandy and many contain abundant, very rounded quartz grains in the medium- and coarse-size grades. These sands have undoubtedly gone through several cycles of erosion and deposition.

The lower 479 feet of this section is very fossiliferous. Crinoids, fusulinids, bryozoans, and brachiopods are common. The sedimentation is rhythmic and sequences of sandstone followed by crinoidal grainstone or packstone and capped by fusulinid wackestone are common. The crinoidal and quartz sand facies are most abundant in this interval.

In the overlying 530 feet the crinoid facies is much less in evidence although scattered crinoids are present in other rock types. The lime mud, quartz sand, fusulinid, ophthalmidid, and oolite facies are most abundant. A few unusual rocks composed of algal-coated lumps and pelleted grains in a sparry calcite cement were noted in this section.

Upper Moorman Ranch Member as interpreted here totals 1,009 feet and is capped by oolite at the top of the exposed section. This is probably an incomplete section in the upper part because no Loray-like rock types were noted near the top of the exposure.

*Rib Hill-Murray Summit Section.*—The Pequop Formation at this location southwest of Ely is about 1,750 feet thick. The section can be divided into a lower unit about 230 feet thick and an upper unit about 1,520 feet thick on the basis of differing lithologies. The lower part forms a prominent ridge on the south side of Rib Hill and consists of medium-bedded to massive, sandy wackestones. A few calcareous sandstones, siltstones, sandy dolomites, and packstones are also found in thin beds. *Durhamina* occurs near the base of this section.

Composition of the Pequop is 66 percent wackestone, 13 percent mudstone, 10 percent sandstone and siltstone, 6 percent dolomite, and 5 percent grainstone. In the lower part the lime mud, detrital quartz, and dolomite are the most abundant facies. A few beds of the undifferentiated skeletal facies are also present. These facies are modified by scattered pieces of echinoderms, brachiopods, bryozoans, and dasyclad algae. In the upper 1,520 feet of the Pequop the lime mud facies accounts for about 70 percent of the rock types present. The detrital quartz, dolomite, and ophthalmidid facies make up most of the remainder. Molluscs, dasyclad algae, algal pellets, pellets, and lumps are the principal modifiers in the lime mud facies. Burrowing is common throughout and much of the section is argillaceous.

The top of the formation is picked at a color change from the grays and browns of the Pequop into the yellows and reds of the overlying Loray Formation.

*Correlations.*—Pequop Formation can be correlated as a stratigraphic unit throughout the area of investigation. The lower boundary is rather sharp where underlain by the Riepetown and is usually marked by the presence of *Durhamina* within 100 to 200 feet of a good lithologic boundary. In areas where the Pequop Formation is underlain by the Ferguson Mountain Formation a few sandy beds appear immediately below the boundary and *Durhamina* is usually present also. A study of the fusulinids will also help locate the contact as explained earlier.

The division of the Pequop Formation into units or informal members on a lithologic basis and the correlation of these units throughout the area is much more difficult. In general, the section can be divided into a lower limestone member, a middle dolomite, sandstone and evaporite member and an upper limestone, dolomite, and sandstone member. In areas where the middle member is evaporite, this subdivision is easily made. The Gold Hill section is really the only surface section like this. In several areas, such as Brush Creek and Rib Hill, a two-fold subdivision is more evident. At Dolly Varden and Cherry Creek a four-fold division is possible because a prominent limestone unit divides the normally dolomitic and sandy upper member into two parts.

Text-figure 8 is an isopach map of the Pequop Formation. A northeast-southwest orientation of the depositional axis is evident. The overall distribution pattern is much like that of the Riepe Spring Limestone except for the northeast part where the Pequop is recognized and the Riepe Spring is not. Another prominent exception is in the Rib Hill-Coke Ovens area where the southeast-trending isopachous thick in the Riepe Spring is replaced by a northwest-trending thin in the Pequop.

## PETROLOGY AND PETROGRAPHY

### Laboratory Methods

Laboratory work consisted principally of the examination of thin sections using the petrographic microscope. Approximately 1,300 thin sections were prepared from hand samples collected during the course of the field work. Acetate peels were used to study those rocks exhibiting a coarse fabric.

Because of the large number of thin sections prepared for this study, it was decided to use plastic spray rather than cover glasses to cover the slides. This method is much faster and proved satisfactory. Alizarin red stain was used on the slides from interbedded dolomite and limestone sequences. On slides from pure limestone sections it was not used to permit better contrast in photography. Plastic spray permits the use of acid directly on the slide to check grains of questionable mineralogy. To check the reaction to dilute HCl of any part of the slide, it is only necessary to scrape the plastic spray from a speficied area with a razor blade, apply acid, and observe the reaction through a microscope. An ordinary binocular microscope with several inches of working distance was used for this to prevent possible damage to the objective lens by the acid. With a little practice one can distinguish aphanic limestones from dolomites in which the extremely small grain size makes this determination difficult with the microscope alone. The estimation of quartz silt content is facilitated also since these grains will remain and in polarized light will stand in sharp contrast in the dark area where the calcite has been removed by the acid. Another useful technique is to check individual grains, replaced fossils, or vugs filled with secondary minerals by piercing the plastic covering the grain with a needle. A drop of acid then can be applied to the exposed grain and the reaction observed. The remainder of the slide is protected by the plastic. The plastic spray can be removed with Xylol and replaced by a cover glass if necessary on those slides selected for photography. Good quality photos are obtained through the plastic spray also.

The rock chips sliced from the slide by the thin section machine were saved for study under incident light, and for insoluble residue studies. These residues were used chiefly as a check on the clay content, particularly in the darker-colored rocks.

### Carbonate Classification

In recent years many new classifications of carbonate rocks have been added to the older ones of Grabau (1904), Black (1938), and Pettijohn (1949). In a study like the present paper in which the determination of the depositional environment is an important objective a classification using descriptive terms, but with genetic implications is most suitable. Also, in order to use the digital computer for analysis and retrieval, the division into rock types should be on a quantitative basis. For these reasons, the writer has adopted the classification proposed by Dunham (1962) for use in this study (Text-figure 4). All classes except one are used as defined by Dunham. The grainstone class is slightly modified to include limestone with up to 10 percent mud instead of restricting this class to rocks which are free of all mud. In most areas of modern carbonate deposition that the writer has visited, some mud is present in the sediments even though agitation is pronounced. The mud is probably formed at the depositional site by abrasion of particles or the decomposition of some organisms and the release of aragonite needles as suggested by Lowenstam (1955). Some of this mud is readily trapped in sheltered interstices within the framework formed by the grains and eventually becomes part of the lithified rock. The writer believes that these rocks containing up to 10 percent mud are better grouped with the mud-free grainstones of Dunham than with the packstones which may contain up to 50 percent or more mud.

*Mudstone.*—These are carbonate rocks containing less than 10 percent grains. No specific carbonate mineralogic composition is implied and thus modifying terms such as lime or dolomite may be used without ambiguity. The grain content is commonly used as a modifier, resulting in good descritpive terms that have genetic implications such as pelleted mudstone, birdseye mudstone, etc. In context, when discussing only carbonate and not clay rocks, these terms can be shortened to pelleted mud, birdseye mud, etc., without confusion.

*Wackestone.*—These carbonate rocks are mud supported but contain more than 10 percent grains. The name is cumbersome and has much against it as Dunham so states. It does, however, call to mind a mixture of mud and grains, as similar terminology has been used in some sandstone classifications, e.g., Gilbert (1954), to describe rocks composed of grains and clay. This terminology has not received wide acceptance among sandstone workers, however. Wackestone, as a single word name for this class of rocks, does have utility.

*Packstone.*—This name is applied to carbonate rocks which are grain supported but have considerable mud content. The amount of mud present varies greatly but generally ranges from 10 percent up to about 50 percent. The maximum amount of mud a rock may contain and still have grain support depends on the shape and packing of the grains. Generally speaking, those having large irregularly shaped grains such as platy algae can contain mud in excess of 50 percent and still retain a grain supported texture.

*Grainstone.*—As already discussed above, this term is used here for grain supported rocks which may have up to 10 percent mud.

## Logging System

In anticipation of using the digital computer for retrieval and analysis of the petrographic data, a quantitative recording system readily adaptable for keypunching onto IBM cards was used. For convenience for keypunching, a vertically ruled form with 80 columns corresponding to the 80 spaces on an IBM card was used to record the data. No size designation was recorded for skeletal particles because the size of these variables is dependent upon that of the original particles as well as the normal physical, chemical, and biological processes operative upon them. The writer regards the size of these skeletal variables as of little importance. All constituents smaller than 16 microns were recorded as mud regardless of their supposed composition. Although it is not ordinarily possible to recognize fragments of the various taxa approaching 16 microns, it usually is possible to separate the grains in the size classes immediately larger than 16 microns into skeletal, nonskeletal, and crystalline categories.

During the field work the thickness of each individual bed was not recorded except for some special distinctive ones. The stratigraphic section was divided into units of about 40 to 250 feet during the measuring and describing process. The relative position of the collected samples was recorded for each unit. In the petrographic work, a thickness interval was assigned to each sample depending on the thickness of the stratigraphic unit and the number of samples collected from the unit. Thus, each sample is used to represent an interval of the stratigraphic section. For example, if the field unit is 100 feet thick and ten samples were collected, each sample would represent ten feet of the section. In this way, an approximation of the respective amounts of the rock types can be gained from summations performed by the computer. The accuracy of this approximation is dependent upon how closely the sample represents the rocks in the sample interval. A check on this approximation is obtained from field notes where the respective amounts of rock types in interbedded sections were estimated. The volume percent of the constituents in each slide was estimated from traverses made over the slides at low power. Point counting was considered too slow and laborious to be done on the large number of slides used in this study.

## Variables Recorded

A list of the variables recognized and recorded appears below:

*Nonskeletal Grains*
- Pellets
- Pelletoids
- Oolites
- Lumps
- Lithoclasts
- Intraclasts
- Algal pellets

*Skeletal Grains*
- Brachiopods
- Echinoids
- Crinoids
- Undifferentiated echinodermata
- Fenestrate bryozoans
- Ramose bryozoans
- Encrusting bryozoans
- Undifferentiated bryozoans
- Fusulinids
- *Climacammina*
- *Endothyra*
- Ophthalmidids
- Undifferentiated foraminifers
- Calcispheres
- Encrusting algae
- Dasycladacean algae
- *Tubiphytes*

Algal fragments
Ostracods
*Thysanophyllum*
*Syringopora*
*Durhamina*
Undifferentiated corals
Gastropods
Pelecypods
Undifferentiated molluscs
Spicules
Trilobites

*Mud Components*
Lime mud
Dolomite mud
Clay mud
Burrowed mud
Birdseye mud
Stromatolites

*Crystalline Components*
Calcite
Dolomite
Silica (microcrystalline chert)

*Detrital Grains*
Quartz
Mica
Feldspar

## Statistical Methods

*General Statement.*—During the logging process some perspective of the rock types, their constituents and interrelationships, was obtained. All too often, however, the geologist, when confronted with a very large array of data, has difficulty in determining all the meaningful relationships and also needs some objective method of checking the conclusions he has made. The recording of data in digital form makes possible the application of various statistical techniques using the digital computer. Associations and relationships may be obtained which are objective in nature and not based on any *a priori* assumptions. The principle analysis technique employed in this study was factor analysis (Imbrie 1962, 1963). Additional schemes to summarize and retrieve part or all of the estimated 10,000 bits of recorded data were also used.

*Data Summary.*—The classification of each slide according to Dunham's system was made during the microscopic examination. It is not feasible to have the computer designate the class for each sample based on the recorded composition because the division between mud supported and grain supported rocks is not fixed by the mud or grain percentage. Rather this division depends upon other evidence also such as the size and shape of grains, packing, and other criteria of grain support such as floored interstices, embayed contacts and shelter effects (Dunham 1962, p. 113). Therefore, the slides were coded and recorded as to their textural classification on the logging form.

*Factor Analysis.*—This is a part of multivariate analysis dealing with the internal structure of matrices of correlations. Its use in this study was for the purpose of reducing the large number of rock styles to a small number of groups (factors) which explain an acceptable percentage of the total variability. In the ideal case, all the variability would be explained, but in normal practice this is not possible because of errors in interpretation of the slides, recording of variables, and the vagaries of nature. In the several factor analysis performed on groups of samples in this study, the average amount of total information explained was 80 percent.

Factor analysis was developed by workers in the behavioral sciences. Its application to geological problems has been advanced by Imbrie (1962, 1963, 1964). For a more detailed account of the processes the reader is referred to these papers but a brief explanation is offered here.

Two types of factor analysis are commonly used; the R-mode, which explores the relationship between variables and the Q-mode, which denotes the relationship between samples. The Q-mode centroid method using rotated orthogonal factors was used in this study. The questions which it was hoped the anaylsis would answer are:

1. What is the relationship between rock samples? How many natural groups (facies) are necessary to explain most of the information recorded?
2. Which rock samples best represent the designated facies?
3. What variables are important in the various facies?
4. What can be learned about the formational boundaries drawn in this study and by other workers in this area? Are they closely related to lithofacies boundaries or perhaps to time stratigraphic boundaries only?
5. Can factor analysis aid in the recognition and identification of sedimentary cycles?

The analysis program begins with the generation of the data matrix. This is simply an array with the samples listed down the left hand side (columns) and variables arranged across the top (rows). The volume percent of each variable is recorded opposite the appropriate sample. The data matrix is then transformed to reduce the disproportionate effect that abundant variables have in determining the position of the sample vector. This is done by recalculating the percent of each variable in each sample and recording the new value as the percent of the maximum value for that variable found in the data matrix. For example, if a variable constituted 10 percent of a sample and the maximum recorded for that variable in any sample was 50 percent, then the new value for the variable would be $\frac{10}{50}$ or 20 percent.

The data array is an N x n matrix, where N is the number of samples and n is the total number of variables recorded in describing the samples. In this study n was 50 and N was 200, the maximum number of samples which could be run in any one analysis using the IBM 7094 computer. This limitation presents a serious problem in the analysis where large numbers of samples are involved because the factors extracted are dependent upon only a fraction of the total sample population. Several methods were used to combat this problem: (1) Where good formation boundaries were drawn in the field, samples were selected from the same formation in various localities and factored. This gave the representative factors for this formation over a rather broad area. (2) All samples from all formations at one locality were factored. Several samples representative of each factor were then put with a large number of unknowns (the total being 200) and factors extracted from the new matrix. This process was repeated until all samples were factored.

Each sample in the data matrix can be represented by a vector of unit length in n dimensional space, the n in this case being fifty. A necessary part of factor analysis is that each sample must be compared with every other sample. The method of comparison used here was to measure the cosine of the angle between each sample vector and every other sample vector. This becomes the cosine $\Theta$ matrix when the results are arranged in a square. This matrix may be scanned to determine the similarity or dissimilarity of each pair of samples, A value of one for cosine Θ between a pair of samples means they are identical. A value of zero denotes no similarity.

The next step is to generate the factor matrix. Reference centroids or factors through centers of clusters of sample vectors are extracted. After the first centroid is extracted, the second is extracted at right angles to it. This process continues until the number of centroids reaches a preselected figure.

The reference centroids may now be put through an orthogonal rotation procedure. This has the effect of simplifying the results by maximizing the loadings of groups of samples on one rotated factor and minimizing the loadings on others. The sample with the highest loading on each rotated factor may then be taken to represent that factor. This gives a real end member for each cluster of samples rather than a theoretical one.

A scoring system (Pitcher, 1966, p. 73) was used to show which variables were most important in the internal composition of each factor.

The most important factors extracted in this analysis are listed below. Many are quite obvious and were recognized and well known during the logging procedure before the factor analysis was run. The analysis helps greatly to confirm these facies, however, and to define their composition and the relative importance of their variables more accurately. The analysis also tends to point out the more obscure factors and to define their composition. The validity of these factors may then be checked by re-examining the samples assigned to them. A computer printout listing the samples in each factor in order of the descending value of their loading on that factor aids greatly in this evaluation.

## Description of Facies

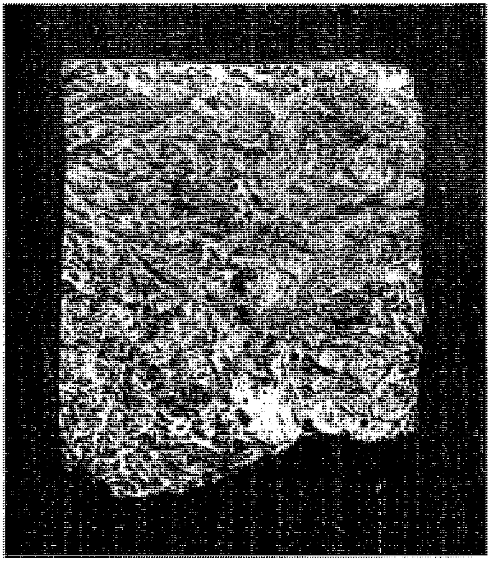
*Crinoid-bryozoan facies.*—This facies (Plate 2, figs. 1 and 2) is widespread in the area, occurring throughout the stratigraphic section studied. It often forms massively bedded ledges which may attain twenty feet in thickness. It is usually medium-gray to gray-brown and has a very coarse texture. Cross-bedding is sometimes present in the finer grained examples.

The rock is a grainstone made up principally of crinoid ossicles and stems. The composition of a sample from this facies selected as an end member in factor analysis is a follows:

Slide 14E, Ferguson Mountain Formation
Dolly Varden Section

| | |
|---|---|
| Crinoids | 86% |
| Lime mud | 05% |
| Sparry calcite | 04% |
| Bryozoa | 02% |
| Foraminifera | 02% |
| Brachiopods | 01% |
| Detrital quarts | Trace |
| Trilobite? | Trace |

The crinoid particles vary in size from about 0.5mm to 7mm in diameter. This variation reflects both the original size of the particles and the amount of breakage, abrasion, and solution suffered by them. The particles are very closely packed with abundant evidence of pressure solution in the form of both



1

10 mm

2

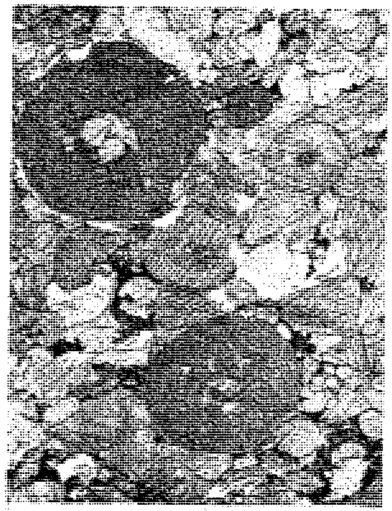
1 mm

EXPLANATION OF PLATE 1

FIG. 1.—Bryozoan biostrome, upper middle Pequop Formation, Cherry Creek Mountains. Abundant, fragmented bryozoans on weathered surface of hand specimen, incident light.

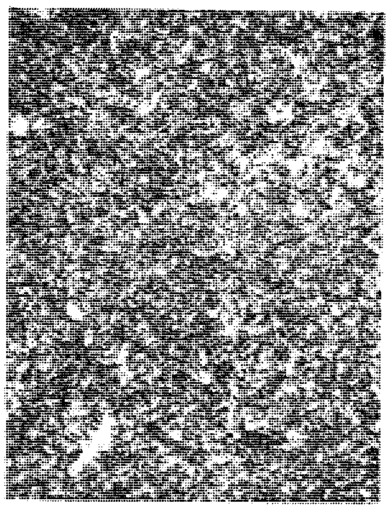
FIG. 2.—Same rock as above in thin section. Bryozoans form weak frame filled with silty lime mud. Slide 27, Pequop Formation, Cherry Creek Mountains section.

1 1 mm



2 1 mm

3 500 μ



4 330 μ

EXPLANATION OF PLATE 2

FIG. 1.—Crinoidal Facies. Well developed crinoid grainstone, showing "welded" fabric. Dark areas are abraded and sometimes crushed bryozoan colonies. Slide 14E, Ferguson Mountain Formation, Dolly Varden section.

FIG. 2.—Crinoidal Facies. Two large crinoid stems with numerous smaller pieces. Dark inter-particle areas are crushed bryozoans. Light areas are secondary voids. Slide 12G, Ferguson Mountain Formation, Dolly Varden section.

FIG. 3.—Lime Mud Facies. Burrowed pelleted mud with a few bryozoan and molluscan fragments. Clear areas (burrows) are filled with sparry calcite. Slide 67D, upper Ferguson Mountain Formation at type locality.

FIG. 4.—Lime Mud Facies. Dark, silty lime mud with a few small skeletal fragments. Slide 13D, Riepe Spring Limestone, Central Butte Mountains section.

straight and embayed contacts between grains. Dark rims probably composed of the residue of solution mark the contact edges. There is only very minor secondary growth of calcite along edges of lesser pressure, however. The grains exhibit the unit extinction characteristic of crinoids and cleavage planes and twinning lamellae are well developed in about 50 percent of the grains. A few pieces contain dark thread-like structures which may be the result of boring algae.

The bryozoans are of both the fenestrate and stony types and occur as scattered bits and pieces of zoaria. The fragments are rather poorly preserved and badly deformed by pressure from the stronger crinoid grains. They vary in size from about 0.1 mm to 0.5 mm and are found in the interstices between the larger crinoid fragments.

The Foraminifera are fusulinids and paleotextularids. The fusulinids are badly fractured and deformed and have a schwagerinid wall structure. Both types are poorly preserved.

The brachiopods occur as fragments showing the characteristic laminate wall structure. Some elongate pieces about 3mm long are deformed and wind around between the crinoids. Some spines are present.

A few fragments displaying the traveling extinction common in arthropods are present in very minor amounts. These are apparently trilobite remains.

The lime mud occurs between the particulate components in isolated parts of the rock. This is highly washed rock but small amounts of mud are trapped despite this. Some is undoubtedly the result of pressolving of the particulate components which leaves behind a dark residue resembling lime mud.

Sparry calcite is present as a pore filler around some of the grains and within small vugs. Some is evidently the result of solution and precipitation near the ends of elongate grains. It fills most of the intra-bryozoan pore space.

Detrital quartz is disseminated throughout the rock and occurs mostly in the lime mud between the carbonate grains. Most is in the very fine sand to coarse silt sizes varying from about 0.1 mm to 0.04 mm. Much of the quartz is in the form of idiomorphic crystals with very small calcite inclusions. These are replacing calcite and are actually authigenic rather than detrital. A few appear to have detrital quartz nuclei.

*Lime Mud Facies.*—Wackestone is the predominant rock type in all sections studied. The lime mud facies is always the first extracted in factor analysis of these rocks and more samples are assigned to this factor than any other. Everything considered, the lime mud-rich rocks placed in this facies vary widely because of the differences in their minor constituents. They also represent several different depositional environments ranging from probable tidal flats to deeper offshore locales. They are all lumped together in the factor analysis because of the overpowering effect of their high lime mud content. The removal of lime mud from the variable table previous to running a factor analysis splits this facies into several subfacies. Examples of this facies are shown on Plates 2 and 3. An end member slide selected by factor analysis for this facies is as follows:

Slide 47A, Pequop Formation
Brush Creek Section

| | |
|---|---|
| Lime mud | 84% |
| Pellets | 10% |

| | |
|---|---|
| Quartz silt | 05% |
| Crinoids | Trace |
| Opthalmidids | Trace |

The lime mud is largely cryptocrystalline but small patches show some micrite enlargement with crystals attaining five to ten microns in diameter. The texture is fairly uniform except for a few probable burrows.

The pellets are dense, featureless, cryptocrystalline mud averaging about 65 microns in diameter. They are rounded to slightly ovate in shape. A few larger pellets of about 400 microns in diameter fill some burrow-like structures.

The quartz silt is evenly distributed through the slide. Most grains show well-developed crystal faces and many are doubly terminated prisms. These contain very small calcite inclusions and are undoubtedly growing and replacing the lime mud.

The crinoids are rare, highly-abraded fragments, identified largely by their unit extinction and microcellular texture. Twinning is prominent. The opthalmidids are small fragments, very dense in transmitted light with tubes about 15 microns in diameter. They are also rare in the slide.

Other slides with a loading on this factor in excess of .800 have compositions as follows:

Slide 12C, Pequop Formation
Cherry Creek Section

| | |
|---|---|
| Lime mud | 75% |
| Quartz sand | 10% |
| Undiff. echinoderm | 10% |
| Bryozoans | 01% |
| Fusulinids | 01% |
| Dolomite euhedra | Trace |
| Clay mud | Trace |

Slide 28A, Pequop Formation
Dolly Varden Section

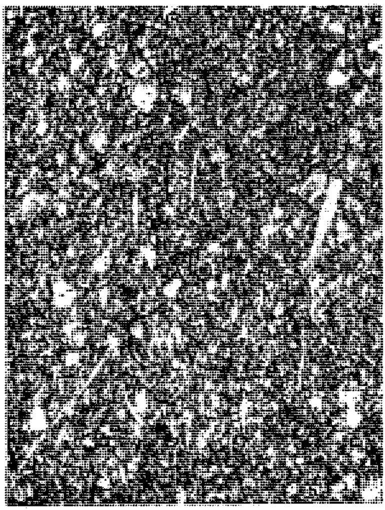
| | |
|---|---|
| Lime mud | 71% |
| Echinoderm | 20% |
| Fusulinids | 05% |
| Brachiopods | 03% |
| Quarts sand | 01% |
| Undiff. Foraminifera | Trace |
| Clay mud | Trace |

Slide 7G, Riepetown Formation
Moorman Ranch Section

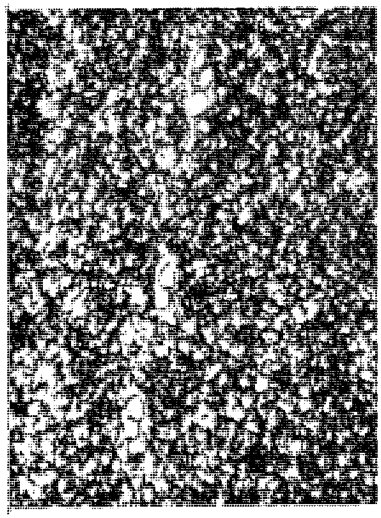
| | |
|---|---|
| Lime mud | 85% |
| Clay mud | 15% |

Slide 15A, Riepetown Formation
Moorman Ranch Section

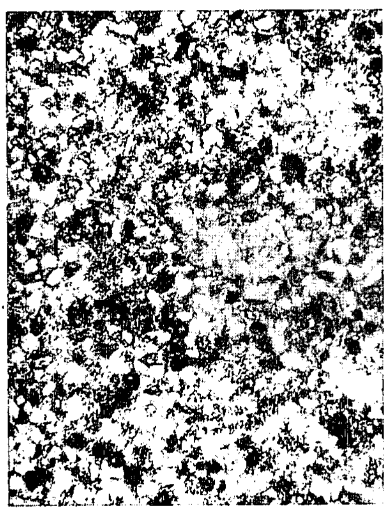
| | |
|---|---|
| Lime mud | 68% |



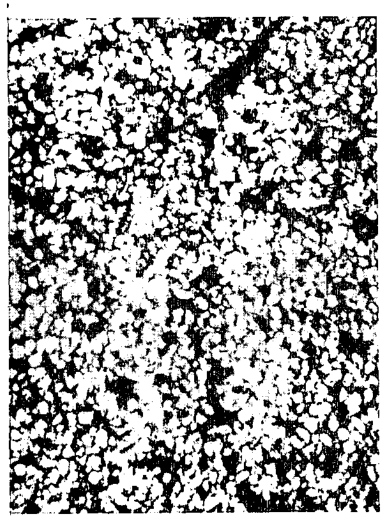
1 — 250 μ



2 — 500 μ



3 — 330 μ



4 — 500 μ

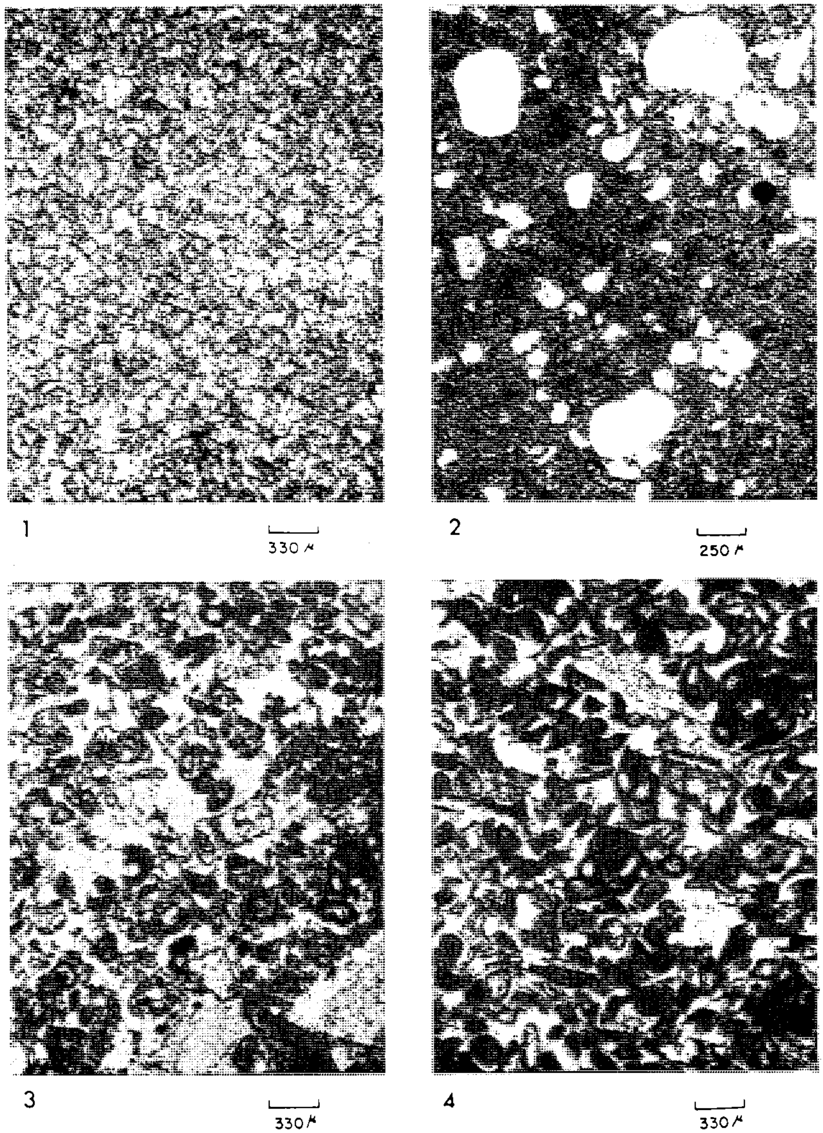
EXPLANATION OF PLATE 3

FIG. 1.—Lime Mud Facies. Dark lime mud with some quartz silt and sponge (?) spicules. Slide 14F, Ferguson Mountain Formation, Dolly Varden section.

FIG. 2.—Lime Mud Facies. Silty lime mud with fenestrate bryozoan colony, slightly dolomitic. Slide 10E, Riepe Spring Limestone, Dolly Varden section.

FIG. 3.—Detrital Quartz Facies. Quartz sand and dark pellets with lime mud matrix. Slide 23J, Pequop Formation, Central Butte Mountains section.

FIG. 4.—Detrital Quartz Facies. Fine-grained quartz, slightly corroded by the lime mud matrix.




EXPLANATION OF PLATE 4

FIG. 1.—Dolomite Facies. This is the coarser of the two common dolomite fabrics. All grains are dolomite. Slide 33, Pequop Formation, Dolly Varden section.

FIG. 2.—Dolomite Facies. Fine crystalline dolomite mud showing bimodal quartz detritus. Slide 19A, Riepetown Formation, Central Butte Mountains section.

FIG. 3.—Ophthalmidid Facies. Dark fragments of ophthalmidid Foraminifera and a few echinoid fragments (lower right) and dark pelletoid grains. Slide 11B, Riepe Spring Limestone, Central Butte Mountains section.

FIG. 4.—Ophthalmidid Facies. Fragments of these tubular Foraminifera in a sparry calcite cement. Slide 50D, lower Ferguson Mountain Formation, type section.

| | |
|---|---|
| Crinoids | 10% |
| Brachiopods | 10% |
| Quartz sand | 10% |
| Bryozoans | 2% |
| Clay mud | Trace |

It can be seen that these slides have some similarity in their minor constituents also. Most of these rocks contain quartz silt or sand in varying amounts and crinoids, spiny brachiopods, and bryozoans are common. The lime mud facies in the Ferguson Mountain, Dolly Varden, Pequop Mountains, and Pyramid Peak sections is generally much darker in color than in the Moorman Ranch and Rib Hill sections in the southern part of the study area. This appears to be largely the result of a higher organic content in the northern sections. The southern sections contain more detrital quartz.

*Detrital Quartz Facies.*—Quartz sandstones and siltstones are wide-spread especially in the Riepetown and Pequop Formations. They are less important in the Ferguson Mountain Formation except in the upper part and also of minor importance in the Riepe Spring Limestone. The quartz rich rocks are usually moderately well sorted, range in size from about three phi to five phi, but usually are immature because of their lime mud or clay mud content. (Plate 3, figs, 3 and 4). They form rounded slopes in contrast to the more resistant limestones. Since this study is primarily concerned with carbonate rocks the directional features and other parameters usually measured for sandstones in the field were not recorded. A typical rock selected as an end member in a factor analysis shows the following composition:

Slide 25A, Pequop Formation
Moorman Ranch Section

| | |
|---|---|
| Detrital quartz | 70% |
| Lime mud | 20% |
| Pelleted grains | 10% |
| Clay mud | Trace |

The quartz is in the coarse silt size range. The grains are angular, of low sphericity, and generally clear without bubble trains and inclusions, except around the edges where interaction with the lime mud has left the edges corroded and indistinct. Extinction is sharp in most grains but some show an undulatory pattern.

The lime mud is cryptocrystalline and fills the pore space between the grains. The pelleted grains are dark, cryptocrystalline mud of about 80 microns in diameter. They are uniformly distributed in the rock. Limonite stain is prominent.

Another slide with a loading of .932 on this factor has the following composition:

Slide 3D, Riepe Spring Limestone
Moorman Ranch Section

| | |
|---|---|
| Quartz silt | 60% |
| Lime mud | 40% |

| | |
|---|---|
| Clay mud | Trace |
| Mica | Trace |

This slide is very similar to 25A except for the relative percentages of the constituents and the small amount of mica. This slide is also stained with limonite, some of which occurs as subspherical clots only a few microns in diameter.

*Dolomite Facies.* Dolomite is prominent in some Riepetown sections and especially abundant in the upper part of some Pequop sections. Usually it is found interbedded with sandstones and siltstones. Most commonly it occurs as thin- to medium bedded, light-gray, hackly weathering beds which are somewhat more resistant than the enclosing sandstones. Most appear to be primary or early diagenetic in origin because of their extremely small grain size (Plate 4, fig. 2), and some, notably at Gold Hill, are closely associated with evaporites. Quartz silt and sand are almost always present in varying amounts and pelletoid grains are common. Because of the rather uniform composition of many of the samples, several usually have a loading of 1.00 on the sample selected to represent this rock type. These may vary in crystal size, texture, and other nonquantitative elements, however. Some examples of this facies are as follows:

Slide 26B, Pequop Formation
Central Butte Mountains Section

| | |
|---|---|
| Dolomite | 88% |
| Calcite | 12% |
| Detrital quartz | Trace |
| Collophane | Trace |

The dolomite is cryptocrystalline except for numerous rhombs up to 60 microns in size. Most of the larger rombs are closely associated with scattered patches of sparry calcite which are being replaced by the dololimte. The quartz occurs as badly corroded grains up to 90 microns. The collophane still retains the shape of the original bone fragments and very small vertebrae. Some fairly distinct pelletoid ghosts remain despite the dolomitization. The rock was probably a pelleted lime mud originally.

Slide 19, Pequop Formation
Central Butte Mountains Section

| | |
|---|---|
| Dolomite | 85% |
| Detrital quartz | 15% |

The dolomite in this rock occurs as an interlocking mass of dolomite crystals with a very uniform size of about 15 microns. The quartz is biomodal with moderately rounded grains averaging 80 microns in diameter most abundant. Very well-rounded grains of about 500 microns are also abundant in the slide.

Slide 2B, Riepetown Formation
Rib Hill Section

| | |
|---|---|
| Dolomite | 90% |

| | |
|---|---|
| Limonite | 10% |
| Calcite | Trace |
| Crinoid | Trace |

This rock is a mosaic of dolomite rhombs averaging 80 microns with only a trace of calcite remaining as scattered crystals usually smaller than 40 microns. The limonite occurs as small (80 microns) grains and probably is altered from pyrite. This is enough to give the rock a slight yellowish color. Another example of this dolomite appears as Plate 4, fig. 1.

*Dasyclad Algae Facies.*—This is a very distinctive rock which comes out well in the factor analysis. It is only moderately abundant but occurs in the Riepe Spring, Riepetown, and Pequop Formations.

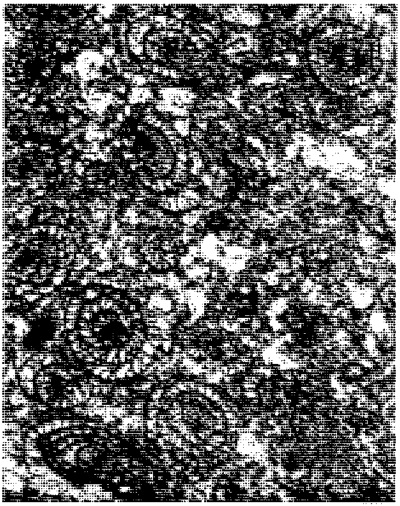
Slide 1B, Riepetown Formation
Rib Hill Section

| | |
|---|---|
| Dasyclad algae | 70% |
| Algae "pellets" | 10% |
| Fusulinids | 10% |
| Ophthalmidids | 10% |
| Endothyrids | Trace |
| Ostracods | Trace |
| Crinoids | Trace |
| Phylloid algae | Trace |
| Quartz | Trace |

This is a well-washed rock with about 20 percent pore space filled with sparry calcite. The allochems are very dense calcite, however, which gives a dark overall appearance to the slide. The dasyclad algae resemble *Epimastopora* in this sample but *Mizzia* is a common alga in other samples belonging to this facies. The algal "pellets" are dark, featureless subspherical grains which are inferred to be algal in origin because of their very dense appearance in transmitted light, apparently because of their algal coating. They average about 200 microns in diameter. The fusulinids are the staffellid type showing their characteristically poor state of preservation. The ophthalmidids are highly fragmented for the most part and no generic determination is attempted.

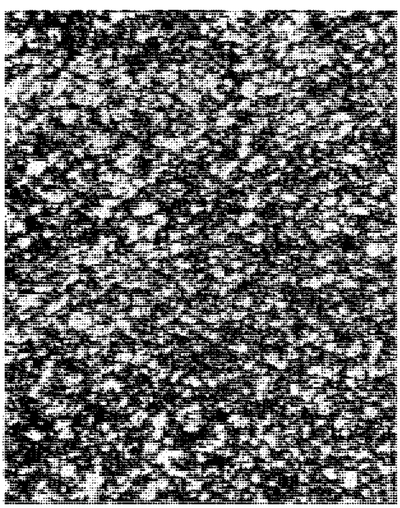
Other examples of this facies are not well washed and have varying amounts of mud. The algal "pellets" are usually more abundant in this type and may be well oriented.

*Fusulinid Facies.*—Fusulinids are the dominant skeletal constituent in many of the limestones and are especially abundant in the Ferguson Mountain Formation and in the Pequop Formation in several areas. Locally they form fusulinid packstones and a few grainstones were noted. Most commonly they occur with lesser proportions of crinoids, bryozoans, and other Foraminifera such as *Cribostomum* and *Climacammina* set in a lime mud matrix. Usually this faices is a dark to medium gray, thin-bedded to platy limestone which may also be slightly silty or sandy (Plate 5). In the Moorman Ranch area the facies is lighter colored and individual beds may attain five to ten feet in thickness. One sample selected an end member for this facies has the following composition:

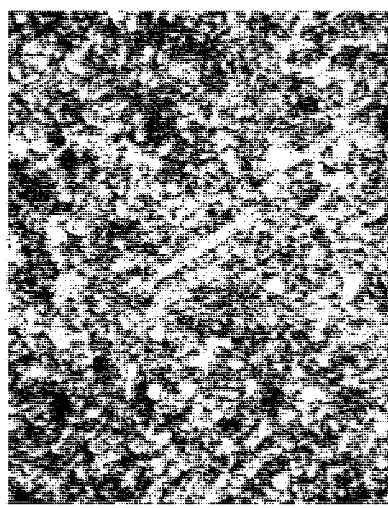


1 — 1 mm

2 — 1 mm



3 — 330 μ



4 — 330 μ

EXPLANATION OF PLATE 5

FIG. 1.—Fusulinid Facies. Schwagerinid fusulines and some crinoid fragments set in a lime mud matrix. Slide 10A, Upper Pequop Formation, Moorman Ranch section.

FIG. 2.—Fusulinid Facies. Fusulines, crinoid fragments, (large light areas) and *Tubiphytes* (dark, upper left) in lime and matrix. Slide 5K, upper Pequop Formation, Moorman Ranch section.

FIG. 3.—Undifferentiated Skeletal Facies. Small skeletal fragments in a dark mud matrix. Slide 11E, Riepe Spring Limestone, Central Butte Mountains section.

FIG. 4.—Undifferentiated Skeletal Facies. Sand-sized skeletal particles and a few brachiopod spines in dark lime mud matrix.

Slide 10A, Upper Pequop Formation
Moorman Ranch Section

| | |
|---|---|
| Fusulinids | 50% |
| Echinoderms | 12% |
| Other Foraminifera | 2% |
| Brachiopods | 1% |
| Lime mud | 35% |
| Quartz silt | Trace |

This facies is very common in the Ferguson Mountain Formation. The distinctive feature there is that about half the fusulinids by volume are a large schwagerinid type and the other half are tiny *Schubertella* sp. which are extremely abundant in the lime mud matrix. Another noteworthy characteristic of this facies is that much of the lime matrix is made up of fine silt-sized calcite grains, probably of skeletal origins. This distinguishes this rock type from other fusulinid rich rocks where the lime mud matrix is wholly micritic.

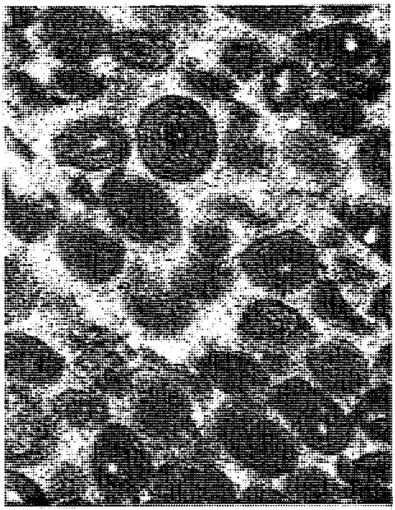
*Undifferentiated Skeletal Facies.*—In this group of rocks fall those samples in which the small size of the skeletal fragments make identification of the particulate content very hazardous or impossible (Plate 5). The skeletal fragments are invariably found in a lime mud matrix. An example of this facies is as follows:

Slide 24A, Pequop Formation
Rib Hill Section

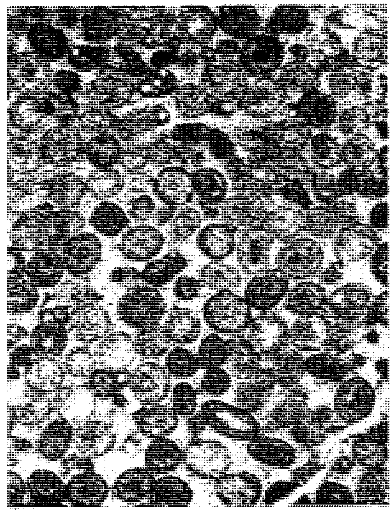
| | |
|---|---|
| Undiff. skeletal | 50% |
| Echinoderms | 5% |
| Quartz sand | 1% |
| Bryozoans | Trace |
| Brachiopods | Trace |
| Ostracods | Trace |
| Lime mud | 44% |

This facies is not widespread because it usually is possible to differentiate the various skeletal particles into their respective phyla.

*Oolite Facies.*— Oolite is rather common in the sections studied although it is not easily noted in the field without careful hand lens examination. This is because the ooliths are generally intact rather than leached and thus the facies does not display the distinctive oomoldic porosity commonly found in this type of rock. The facies is especially difficult to find in the field when dolomitized or simply recrystallized. The ooliths are seen only in a thin section under this condition (Plate 6). The facies is found principally in the Pequop Formation especially in the upper part where it is often found associated with dolomite and sandstone. At Moorman Ranch several beds are in limestone sections and at Gold Hill it is found in association with evaporites. In this latter location all of the samples of this facies were dolomitized. One prominent oolite at Ferguson Mountain occurs high in the Ferguson Mountain Formation where it appears to herald the beginning of the regression at the end of Wolfcamp time. A typical example of this facies is as follows:



1 250 $\mu$



2 500 $\mu$

3 250 $\mu$

4 330 $\mu$

EXPLANATION OF PLATE 6

FIG. 1.—Oolite Facies. Normal ooliths, dolomitized, in a dolomite cement. Upper Pequop Formation, Gold Hill section.

FIG. 2.—Oolite Facies. Mostly superficial ooliths and a few Foraminifera set in a sparry cement. Slide 21C, base of Pequop Formation, Moorman Ranch section.

FIG. 3.—Oolite Facies. Normal and superficial ooliths in a fine crystalline calcite cement. Slide 21B, base of Pequop Formation, Moorman Ranch section.

FIG. 4.—Oolite Facies. Collapsed ooliths in fine crystalline calcite cement. Slide 22C, base of Pequop Formation, Moorman Ranch section.

Slide 25B, Pequop Formation
Moorman Ranch Section

| | |
|---|---|
| Ooliths | 98% |
| Quartz sand | 2% |
| Ostracods | Trace |

This is a poorly sorted oolite but has about 20 percent porosity filled by very fine crystalline calcite. The ooliths vary in size from about 0.1mm to 0.45mm in diameter. Many of the smaller ones have a quartz grain nucleus which almost fills the entire grain. These grains represent an incipient stage of oolitization. Many of the larger grains, in contrast, have a quartz grain nucleus but are multiringed or exhibit one thick ring and are in an advanced stage of oolitization.

The rock contains all three of the types of ooliths described by Carozzi (1960, p. 238). He classified these grains as : (1) pseudoolites for those having no coating or concentric layer, (2) superficial oolites for those having one concentric layer, and (3) normal oolites for those which have at least two concentric layers. In this paper the term oolith is adopted for the individual grain and oolite is used for the rock term to avoid confusion and ambiguity.

The ooliths were probably originally aragonite but have undergone conversion to calcite. This apparently is a result of a recrystallization process rather than solution of the original aragonitic oolith followed by infilling of the mold with calcite. The evidence for the recrystallization is that the ooliths and the pore filler are now an anhedral mosiac of calcite crystals giving the rock a zenotopic (Friedman, 1965) fabric. The average crystal size is somewhat smaller in the ooliths (12 microns) than in the cement (30 microns). The crystallinity of the ooliths is masked and almost obscured by the dense and dark appearance of the grain in transmitted light. This is believed to be an original property of the grain, perhaps due to contained organic matter, and is further evidence that the grains have not been leached. A few grains do appear to be collapsed ooliths but they are not important quantitatively.

About 10 percent of the ooliths have a distinct nucleus which is quartz in most instances. Echinoderm fragments are common as the nucleus also. All normal ooliths are of the concentric ring type. No radial ooliths are present.

Slide 12, Upper Pequop Formation
Gold Hill Section

| | |
|---|---|
| Ooliths | 85% |
| Quartz sand | 15% |
| Calcite | Trace |

This is a typical oolite from the upper Pequop Formation at Gold Hill. The ooliths are dolomitized to a microcrystalline zenotopic dolomite. The inter-oolith porosity is filled with anhedral dolomite crystals averaging about 30 microns in diameter. The quartz is poorly sorted varying from about 30 to 300 microns and is unevenly distributed in the slide. The calcite occurs as scattered aggregates of anhedral crystals apparently formed by dedolomitization of both the dolomite ooliths and cement. All three types of ooliths are present but pseudooliths make up about 70 percent of the total.

*Algal Pellet Facies.*—This is a very distinctive rock type although it is not as widespread as most of the others. A good example occurs in the Riepe Spring Limestone about 85 feet above the base in the Moorman Ranch section (Plate 7). Here in outcrop the rock is a thick-bedded, medium gray-brown, dense micritic limestone which weathers to a medium light-brown color. A few silicified crinoid ossicles, echinoid spines, and plates are visible on the weathered surface. In thin section the rock appears as follows:

Slide 3A, Riepe Spring Limestone
Moorman Ranch Section

| | |
|---|---|
| Algal pellets | 94% |
| Echinoid fragments | 4% |
| Undiff. forams | 2% |
| Endothyrids | Trace |
| *Staffella* (?) | Trace |
| Ostracods | Trace |
| Ooliths | Trace |

The algal pellets are variable in size and shape but all show a characteristic dark, dense appearance in transmitted light. They vary in size from small ovate grains about 60 microns in diameter to large irregularly shaped grains about 1mm in diameter. These larger grains show some indistinct aggregate structure and may be composed of many small pellets which may have accreted in a manner similar to that of the grapestones on the Bahama Platform.

*Ophthalmidid Facies.*—Ophthalmidid Foraminifera are abundant and widespread in the sections studied, and when they dominate the rock, they form a distinctive facies. These Foraminifera are usually fragmented but often occur relatively undisturbed in very muddy rocks. The best development, however, occurs when the organisms are set in a sparry cement (Plate 4). A typical example of this is as follows:

Slide 50D, Ferguson Mountain Formation
Ferguson Mountain Section

| | |
|---|---|
| Ophthalmidid Foraminifera | 65% |
| Pellets and pelletoids | 20% |
| Echinoderms | 5% |
| Encrusting algae | 5% |
| Lime mud | 3% |
| Lumps | 2% |
| Fusulinids | 1% |

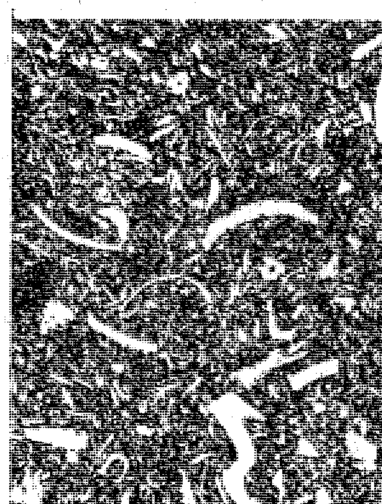
Other organisms commonly associated with this facies are dasyclad algae, molluscs, and various other Foraminifera.

*Molluscan Facies.*—This rock type is abundant in the upper Pequop, especially where this formation grades into the overlying Loray Formation. The molluscs are almost always leached and replaced by coarse crystalline calcite. The molluscs may be highly broken or relatively intact (Plate 7), but in either case

1 500 $\mu$

2 330 $\mu$

3 1 mm



4 1 mm

EXPLANATION OF PLATE 7

FIG. 1.—Algal (?) Pellet Facies. Elongate, oriented, dark grains with light areas filled by sparry calcite. A few forams and echinoderm fragments are also present. Slide 2E, Riepe Spring Limestone, Moorman Ranch section.

FIG. 2.—Algal (?) Pellet Facies. Same slide as above at higher magnification. Intergranular areas, now sparry calcite, may have been some kind of mucilaginous envelopes around grains at time of deposition.

FIG. 3.—Molluscan Facies. Complete gastropod with original shell material. Note large dark pellets within the shell cavity. Slide 54, Ferguson Mountain Formation, type section.

FIG. 4.—Molluscan Facies. Fragments of molluscs, mostly pelecypods, in a dark lime mud matrix. Slide 76C, Pequop Formation, Pequop Mountains section.

1 — 1 mm

2 — 1 mm

3 — 2 mm

4 — 500 μ

EXPLANATION OF PLATE 8

FIG. 1.—Dasyclad Algae Facies. One large oblique section of *Mizzia* (?) and several other fragments in a dark lime mud matrix. Slide 77D, Pequop Formation. Pequop Mountains section.

FIG. 2.—Dasyclad Algae Facies. Numerous thalli of dasycladacean algae in a dark mud matrix. Slide 77D-2, Pequop Formation, Pequop Mountains section.

FIG. 3.—Intraclast Facies. Large intraclasts of dark lime mud, pelletoid grains, and one mollusc in a sparry calcite cement. Slide 22B, Pequop Formation, Moorman Ranch section.

FIG. 4.—Intraclast Facies. Dark, large, intraclasts, pelletoid grains, and ophthalmidid fragments in sparry calcite cement. Slide 50, Ferguson Mountain Formation, type locality.

they are set in a lime mud matrix which often dominates the rock and causes this facies to be grouped with the lime mud facies by factor analysis. A typical example is as follows:

Slide 76C, Pequop Formation
Pequop Mountains Section

| | |
|---|---|
| Mollusks | 35% |
| Brachiopods | 10% |
| Echinoderms | 3% |
| Quartz silt | 2% |
| Lime mud | 50% |

*Intraclast Facies.*—A rather uncommon rock, this facies occurs in sequences with other shallow water rock types (Plate 8). The intraclasts are disrupted, often abraded pieces of lime mud which usually contain very small skeletal fragments. Larger intraclasts which may approach 4mm in diameter may contain crushed fusulinids or other organisms of similar size. Intraclasts do not commonly make up the bulk of this rock, but they are so distinctive that the facies is best denoted by this particle. An example is as follows:

Slide 22B, Pequop Formation
Moorman Ranch Section

| | |
|---|---|
| Intraclasts | 30% |
| Pellets and pelletoids | 25% |
| Undiff. Foraminifera | 25% |
| Mollusks | 5% |
| Fusulinids | 5% |
| Lime mud | 10% |

The Foraminifera are mostly ophthalmidids and a sparry calcite cement binds the rock together.

*Summary.*—Although there are many other rock types in the sections studied, the above facies are most important and give the best clues to the environmental setting. Brachiopods often form a distinctive rock type and bryozoans occasionally do also. Usually, however, these organisms are grouped in the facies characterized by crinoids.

## Depositional Environments

### General Statement

Interpretation of the depositional environments of the Wolfcampian and Leonardian rocks in the area of study is complicated by the fact that there is no starting point in the conventional or stereotyped method of environmental analysis. Specifically, there are no reef tracts, deep-water basins, red beds-carbonates transition zones, shelf edges, or other obvious wide ranging trends which can provide a reference point of unquestioned origin. Similarly, the oolite trends are difficult to map in the field because most are dolomitized and are very obscure without thin sections for study. The isolated mountain ranges with the broad intervening valleys floored by alluvium do not lend themselves to this type of facies mapping in the field.

An approach to the problem has been to construct isopach, lithofacies, and constituent distribution maps using the ten control sections studied. The facies and constituent distribution maps were constructed by using the computer to calculate the positions of the various end members within the facies triangle. In all cases where the combined total of the end members did not equal 100 percent originally, they were recomputed to equal this amount. The lithofacies end members were selected on the basis that their distribution could be interpreted using modern ideas of Recent carbonate sedimentation. To be effective these end members must be abundant in the sediments so that they make up a significant portion of the variable distribution and appear in varying amounts in several sections. The constituents such as lime mud, dolomite mud, detrital quartz, and oolite fit these requirements best. These are widespread and their distribution and relationships to each other are relatively well known from Recent sediment studies. These variables were very likely subject to the same physical processes in Permian time as they are today. This, however, can be said with less certainty about the fossil variables. For this reason the use of these parameters as end members is diminished in this study. Some of the more abundant groups have been used where the writer has gained a concept of their relationships to each other by their association with various other parameters such as rock textures, lithologic associations, their abundance in certain parts of the section, and their postulated habitat in other studies.

Facies distribution maps were constructed for sediments representing the entire Wolfcampian and the entire Leonardian rather than trying to split them into smaller units. To demonstrate the major environmental distributions it is not necessary to subdivide further. The subdivision could probably be made using fusulinids as the basis for doing so, but in several cases, these subdivisions would represent time boundaries only without significant changes in the depositional patterns. The Wolfcampian-Leonardian boundary, however, can be traced throughout the area and represents a very real chronostratigraphic event. A widespread change in sedimentation can be demonstrated in several areas at this time. This is probably best represented at Ferguson Mountain where an oolite appears in beds dated at Late Wolfcampian by Slade (1961). This oolite is succeeded by lime mud with a fauna consisting of dasyclad algae and ophthalmidids which is interpreted to be of very shallow water origin. Thus, this sequence represents a withdrawal of the sea during very Late Wolfcampian and Early Leonardian time. This withdrawal occurs throughout the area and is probably epeiric in nature and possibly related to reported glaciation in the Southern Hemisphere. It serves as a valid time marker and is used to split the Lower Permian into two major parts for this study.

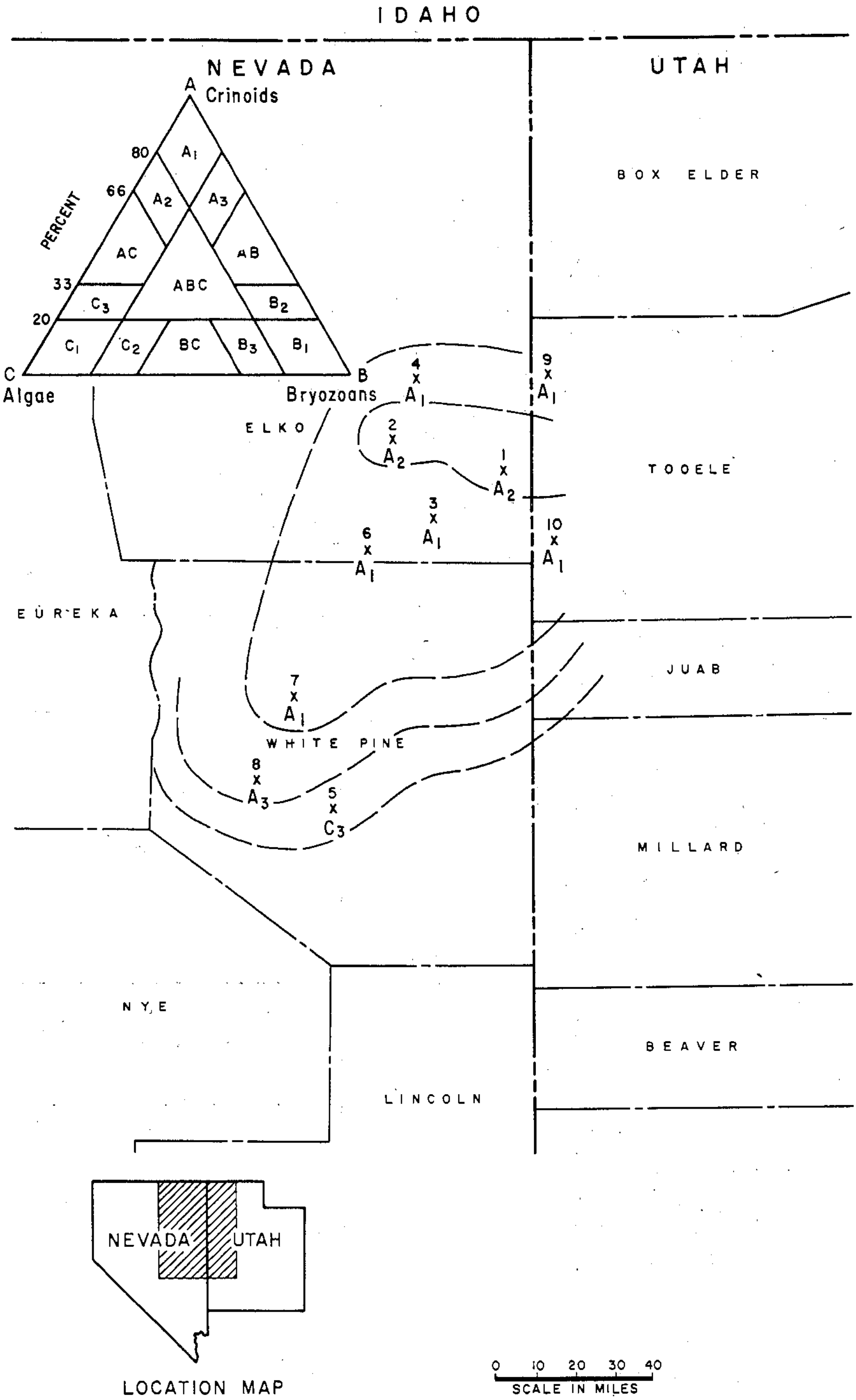
Wolfcampian Series

An ideal starting point for an analysis of this rock unit is at Ferguson Mountain. Sedimentation is seemingly unbroken from Pennsylvanian to Permian time and this represents an incomplete withdrawal of the sea during the post-Desmoinesian regional uplift. This then is the most negative portion of the study area during Early Wolfcampian time. Fusulinids and echinoderms (principally crinoids) are abundant in these Early Wolfcampian rocks and are closely associated with each other. Fusulinids have been interpreted to inhabit relatively deeper water by Elias (1937, 1964) which is in agreement with the interpretation given here. However, at no time does a deep basin appear in the study area which can be likened to some of the deep "starved basins" of the West Texas Pennsylvanian and Permian where the water may have been in excess of 1,000 feet deep. The fusulinids and crinods, while denoting relatively deeper water in the study area, probably inhabited water which was less than 100 feet deep.

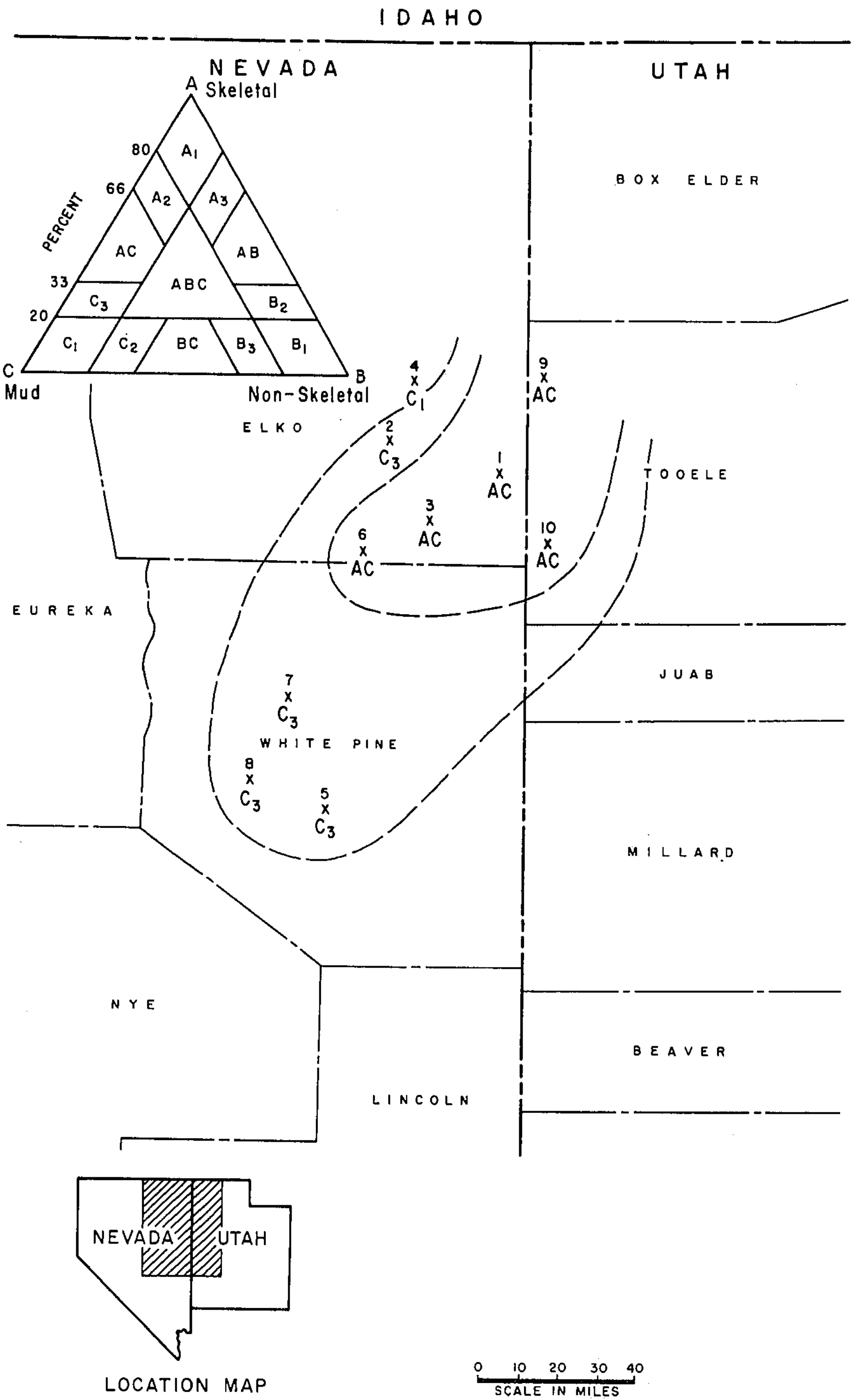
By Medial Wolfcampian time the sea had spread outward from the Ferguson Mountain depocenter onto the more shallow surrounding shelf-like areas. As this transgression occurred the Riepe Spring Limestone was deposited on these shallow shelves while sedimentation continued relatively unchanged in the Ferguson Basin. The lower Riepe Spring is characterized by ophthalmidid Foraminifera dasyclad algae and pelleted muds. Todd (1957) reports the presence of ophthalmidids in waters less than 38 feet deep at Saipan, Mariana Islands. Rigby (personal communication, 1963) reported abundant dasycladacean algae in a very shallow water environment in the back-reef area of the West Texas Guadalupian. These forms are usually found in a dark, dense, often pelleted mud in the Wolfcampian. These shallow facies are rare in the lower two-thirds of the Ferguson Mountain Formation but do appear in abundance in the upper part as noted earlier. This mud indicates a low energy environment and, coupled with the shallow water fauna, suggests a very shallow shelf probably protected from the more open high energy environment by crinoid banks. The upper part of the Riepe Spring Limestone is characterized in many areas by the crinoid facies which may reach 50 feet or more in thickness. This is a result of continued deepening of the sea which allowed this facies to spread laterally from the more central areas of the basin and invade the heretofore more shallower areas occupied by the ophthalmidid and dasyclad facies. The crinoidal facies spread out of the Ferguson depocenter and reached as far south as the Moorman Ranch and Central Butte Mountain areas at this time. Scattered occurrences of crinoids in Lower Riepe Spring Limestone in some areas are unimportant when compared to this later event. Text-fig. 9 is a map showing the relative importance and distribution of crinoids, bryozoans, and algae in Wolfcampian sediments. Bryozoans are interpreted to occupy chiefly environments intermediate between the crinoids and algae. The differentiation between the Ferguson Mountain and Brush Creek section and those sections immediately surrounding them is due to the presence of algae in the top part of the Wolfcampian in these two sections. These sections are dominated by crinoids throughout the bulk of the column and the overall distribution pattern shows that the central part of the basin was more favorable for the growth of these organisms and the shallow southern part was more favorable for algae, especially in the Rib Hill area.

Text-fig. 10 shows the distribution of skeletal grains, nonskeletal grains and mud during Wolfcampian time. Again the pattern shows a central area where skeletal constituents were important and a surrounding area where lime mud is the dominant constituent. Nonskeletal grains are shown to be less than 20 percent of the total.

In Medial Wolfcampian time moderate uplift of the entire area probably accompanied by some tectonic activity in the Antler-Sonoma Belt permitted quartz sands of the Riepetown to be spread over the relatively shallow shelves. This terrigenous material was transported into the margins of the Ferguson Mountain depocenter but did not substantially contribute to the Ferguson Mountain depocenter as discrete sands because this area remained as the most negative portion of the basin. Periodic cessation of a supply of sand or a slight deepening of the sea allowed thin limestones, principally the crinoidal facies to spread over




TEXT-FIGURE 9.—Distribution of crinoids, bryozoans, and algae in Wolfcampian rocks.




TEXT-FIGURE 10.—Distribution of skeletal grains, non-skeletal grains and lime mud in Wolfcampian rocks.

the area. In the Rib Hill area thin muds accumulated which became dolomitized in this very shallow area. The bimodality of some of the sands at Rib Hill and the Central Butte Mountains probably reflects the addition of small amounts of sand, possibly reworked from an older mature sandstone. This supplied the large rounded grains which formed the coarser mode in the distribution. Marine currents were probably the transporting agent for most of the sands. These sands were probably moved across the shallow shelves more easily than the lime mud which accumulated on them during times when a supply of sand was unavailable.

Text-fig. 11 portrays the relative importance of skeletal material, quartz sand, and lime mud in Wolfcampian rocks. This shows that the skeletal material and deeper muds are concentrated in the center of the basin and diminish outward toward the margins. Sands are most important around the inside margins of the basin. The shallow lime muds are dominant around the outside margins.

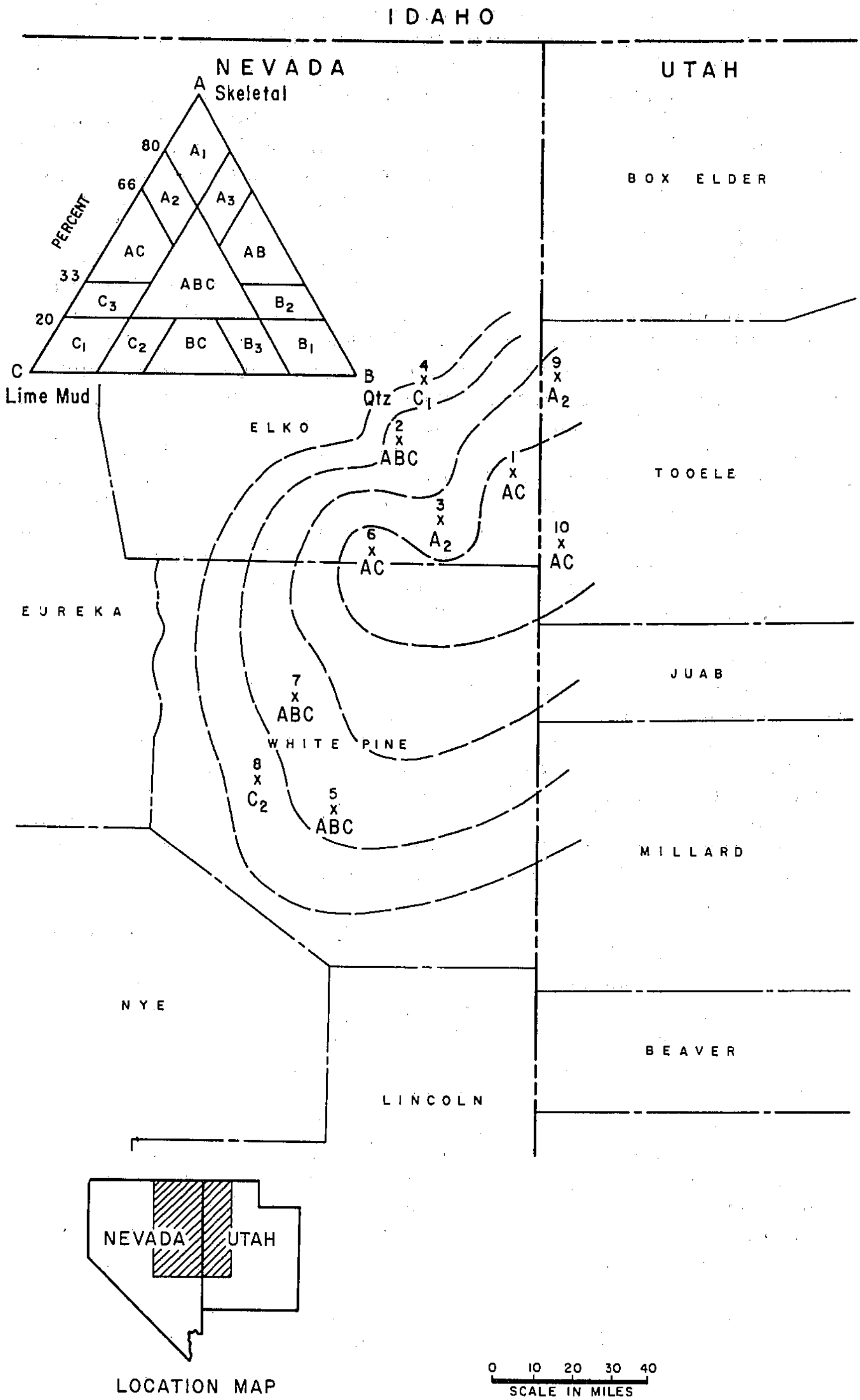
Text-fig. 12 shows the distribution of dolomite, detrital quartz, and lime mud in these rocks. In this diagram lime mud is shown to be important in the central portion of the basin where wackestones are abundant. Detrital quartz increases around the margin outside of the Ferguson depocenter and reflects the importance of the Riepetown Formation. Dolomite is relatively unimportant in this diagram and it is difficult to determine definitely where it fits in the distribution. It occurs in significant amounts only wthin the Riepetown Formation at Rib Hill. Here it results from the dolomitization of lime muds which remained as mudstones in other locations. Some primary dolomites probably formed in the more restricted environments.

Leonardian Series

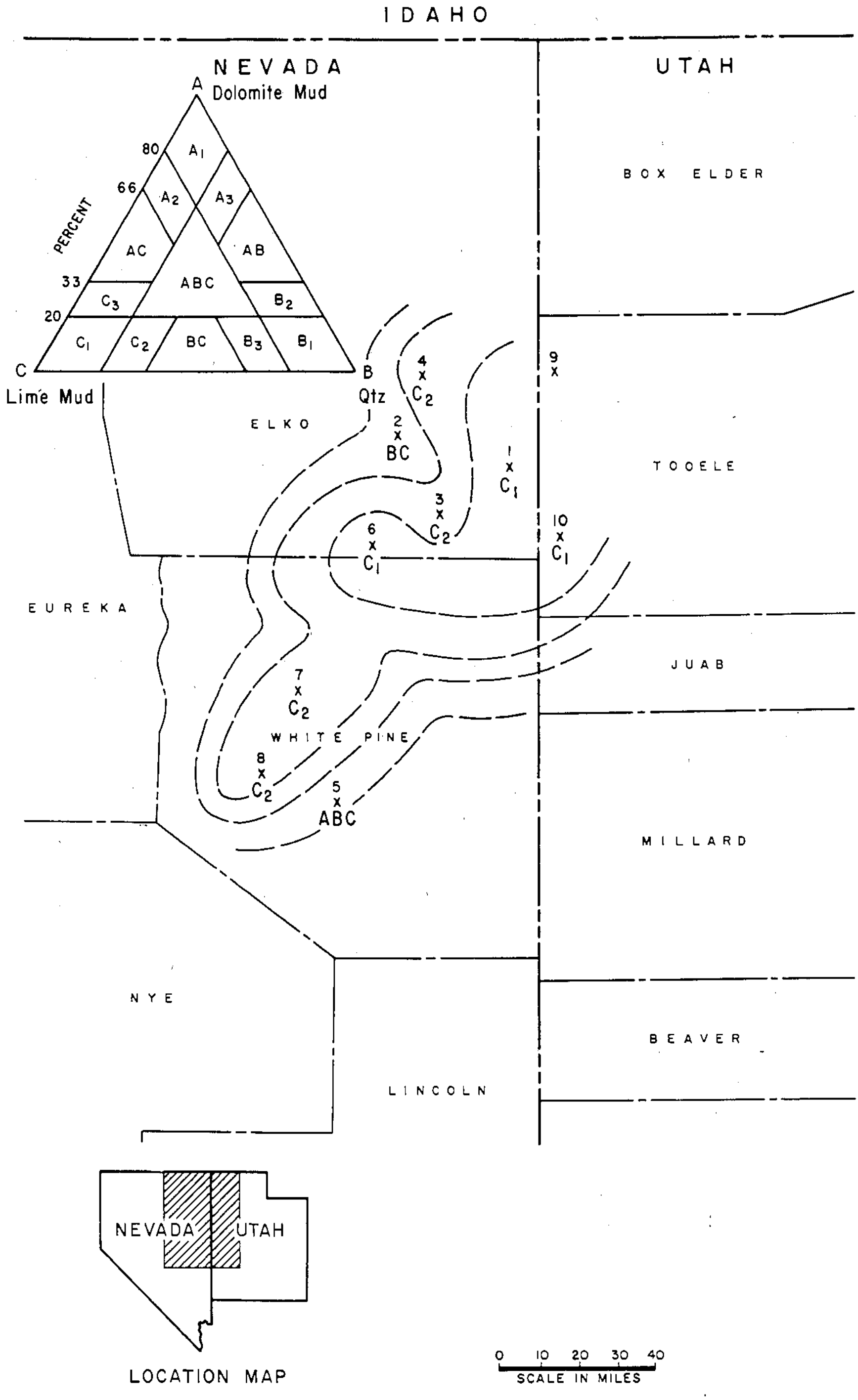
At the beginning of Leonardian time sands spread over much of the Arcturus Basin including the Ferguson Mountain area which had received little sand until Late Wolfcampian time. Shortly thereafter, however, the supply of sand being fed into the basin diminished and thick carbonates, chiefly the crinoidal facies, developed widely. It was during this time that *Durhamina* was established over most of the basin and is now known to comprise an excellent time-stratigraphic marker. Stevens (1967, p. 424) places the most prolific development of *Durhamina cordillerensis* (Easton) in the very latest Wolfcampian.

The general configuration of the basin which was established during the previous epoch, perished during Leonardian time. During this latter epoch, however, tectonic conditions were more unstable and several small local basins and sags developed which received various types of carbonates, clastics, and evaporites. The principal difference between the sediments of the Wolfcampian and Leonardian is the abundance of dolomite, evaporite, and oolite deposited in the Leonardian. These are all very shallow water sediments and emphasize the shallow nature of the sea during Leonardian time.

Text-fig. 13 shows the distribution of skeletal material, nonskeletal grains and mud in Leonardian-age rocks. The general distribution of these parameters is the same as in the Wolfcampian section. The skeletal material is abundant in the central part of the basin and decreases outward where the mud becomes more important. Considerable mud is present along the central axis also where it occurs chiefly in wackestones and packstones as the matrix material. In this area water depth was too great and wave energy too low to bring about a thorough washing of these rocks. Some of the skeletal rocks




TEXT-FIGURE 11.—Distribution of skeletal grains, detrital quartz and lime mud in Wolfcampian rocks.




TEXT-FIGURE 12.—Distribution of dolomite mud, detrital quartz, and lime mud in Wolfcampian rocks.

which accumulated on relatively shallow banks and swells within the central part of the basin were washed free of mud. These grainstones are principally the crinoidal facies.

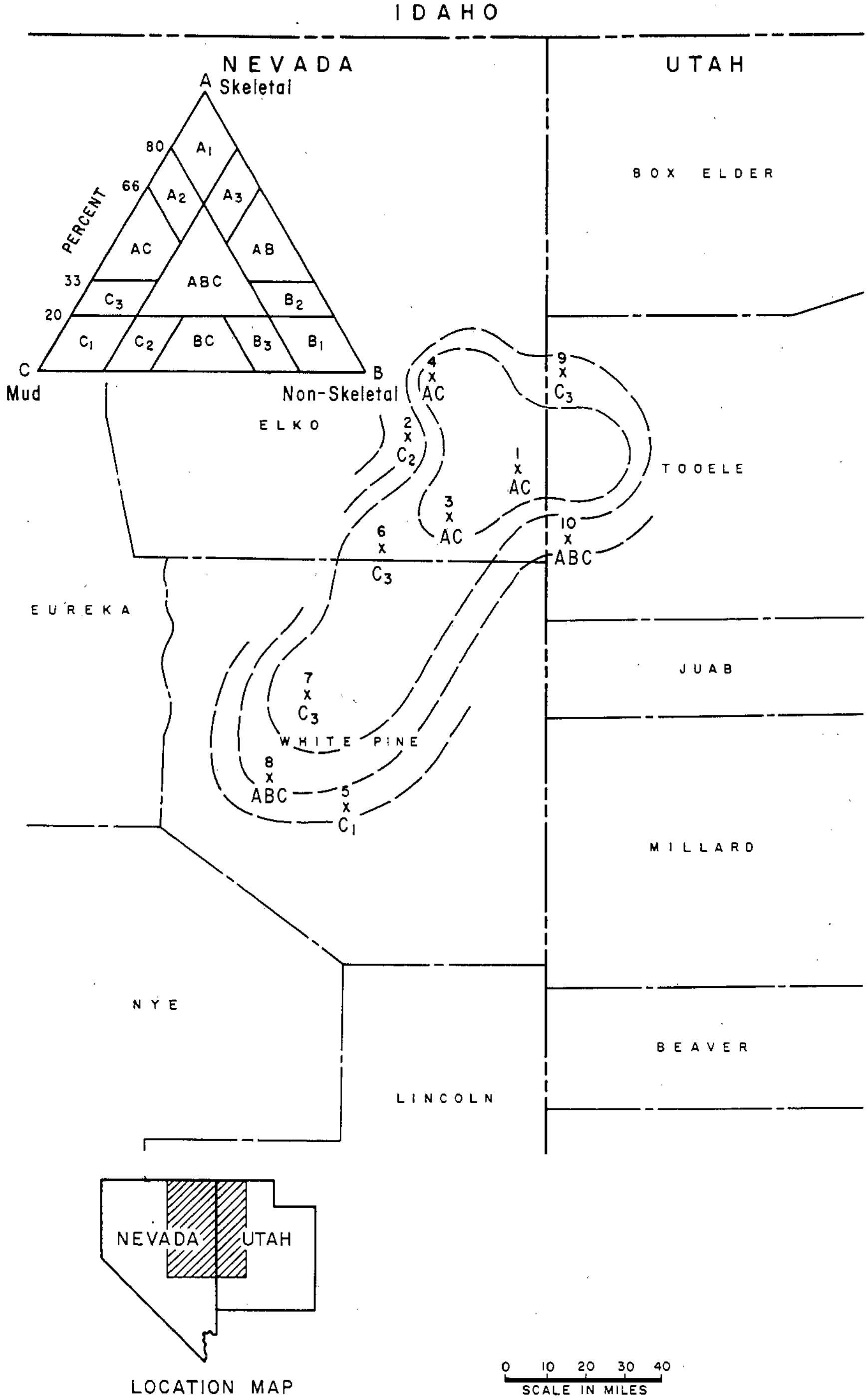
A notable difference between the Wolfcampian and Leonardian maps of these variable distributions is the indicated band around the inner margins of the basin in the map of the Leonardian series. This band contains approximately equal amounts of skeletal, nonskeletal material, and mud. The nonskeletal material is composed chielfly of ooliths, oolite being a common rock type in the Pequop Formation. The distribution of the oolites is the best key to relative water depth in this area during Leonardian time. This distribution also demonstrates by analogy that the relative depths postulated for the facies distributions in the Wolfcampian are in accordance with those in the Leonardian. But probably of most importance is that the oolites give the best and most positive indication of the absolute depth of water in this area during their formation. Ooliths forming today in such areas as the Bahama Platform and the Persian Gulf are in very shallow water, commonly less than ten feet deep. Many of the oolite bars are exposed at low tide. Oolites in the Pequop Formation formed where the ideal combination of water depth and wave action existed. This was commonly around the inner margin of the trough but was not restricted to this area only because some oolite is found in all the ten Pequop sections studied by the writer except the Ferguson Mountain and Pyramid Peak sections, both of which are incomplete.

Oolites also give a good indication of the water depth of several other facies with which they are closely associated. Among these are the dasyclad algae, dolomite and sandy dolomite, ophthalmidids, molluscans, and evaporites. All these occur within a few stratigraphic feet of oolite and interbeds of oolites and these facies are common. A few lime muds are closely associated with oolites also but mostly this facies has been dolomitized. The skeletal facies in the middle of the trough were deposited in deeper water but it is believed this water was relatively shallow also. No deep-water lime muds or clay were found by the writer.

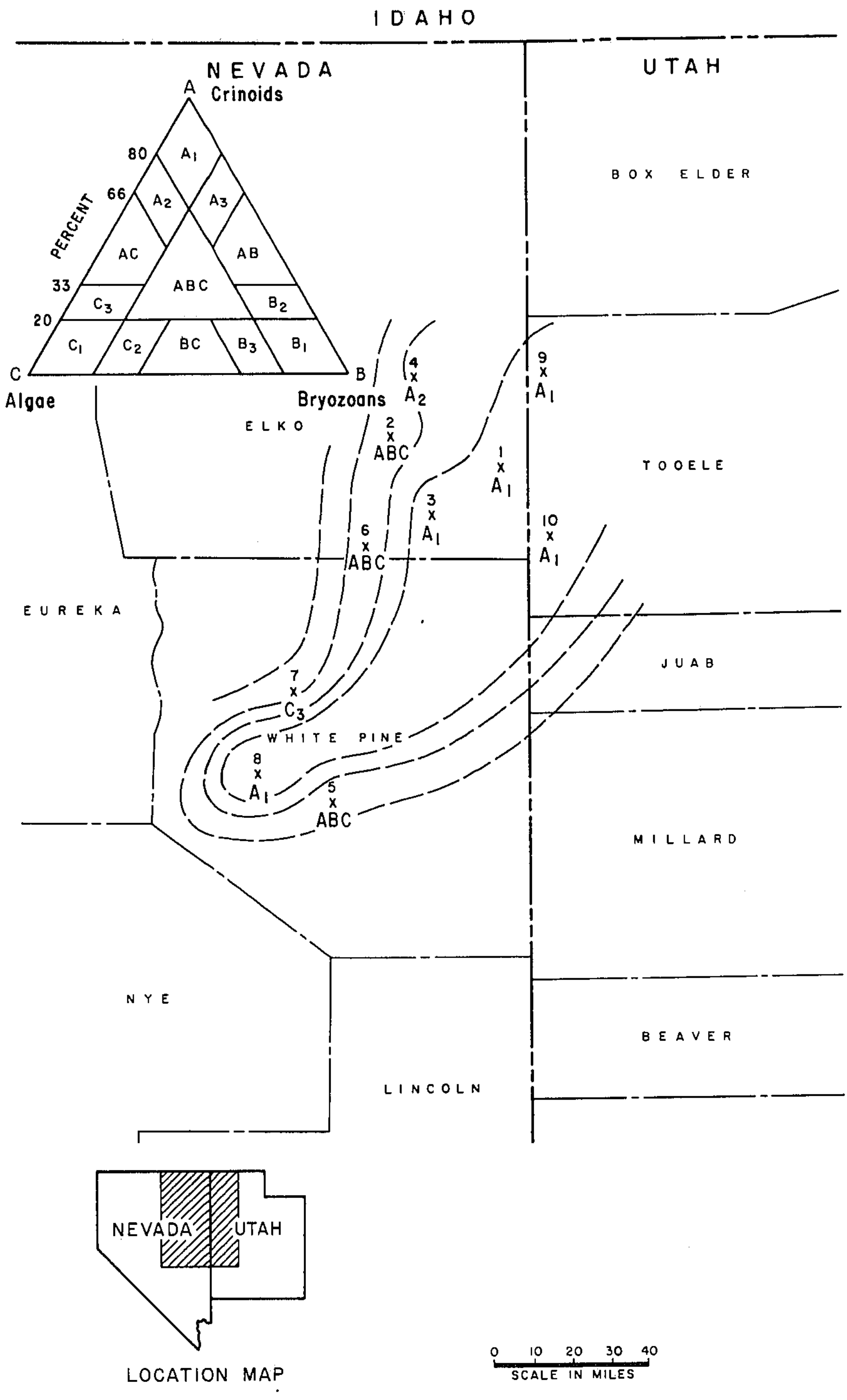
Lime muds around the outside margin of the basin are herein interpreted to be very shallow, low-energy deposits. These deposits are best exhibited by the Upper Pequop especially at Rib Hill. At this locality the sequence grades upward through algal and molluscan wackestones into the Loray Formation which has considerable evidence of shallow deposition such as clay mud, a molluscan fauna, abundant evidence of oxidation as shown by the reds and yellows present, and collapse breccias. One oolite was found at Rib Hill about midway in the Pequop but for the most part the energy present was too low for oolite formation at this locality. Much of the Pequop represented by these mudstones and wackestones is interpreted to be mudflat or mudbank in origin.

Text-fig. 14, showing the distribution of crinoids, bryozoans, and algae, presents a pattern very similar to the Wolfcampian map of these variables. Again the crinoids dominate the central part of the basin and algae, the outside margin. The bryozoan influence is seen to fall intermediate between these two.

Text-fig. 15 is a lithofacies map showing the distribution of dolomite mud, detrital quartz, and lime mud in Leonardian rocks. Here the dolomite is concentrated in the center of the basin with the quartz and lime mud around the margins. The diagram clearly shows the association of dolomite and evaporite because the known occurrences of evaporite in the Pequop Formation are in




TEXT-FIGURE 13.—Distribution of skeletal grains, non-skeletal grains and lime mud in Leonardian rocks.




TEXT-FIGURE 14.—Distribution of crinoids, bryozoans and algae in Leonardian rocks.

the subsurface at the Continental Oil Company—Standard of California well near the Butte Mountain section (control point number 7) and exposed on the surface at Gold Hill (control point number 10). This diagram probably gives the best estimation of the distribution of this evaporite (Summit Springs), and it is here interpreted to occur perhaps discontinuously along an axis connecting these points. Similar associations of evaporites and dolomites are known from other areas. An example would be the Desmoinesian of the Paradox Basin.

This figure likely represents conditions of sedimentation in Medial Leonardian during the period of regression which lowered sea level markedly and produced the restrictive conditions necessary for evaporitic sedimentation. It also reflects in part the sedimentatry environments during Late Leonardian where dolomites and sands are important in most of the sections near the center of the diagram.

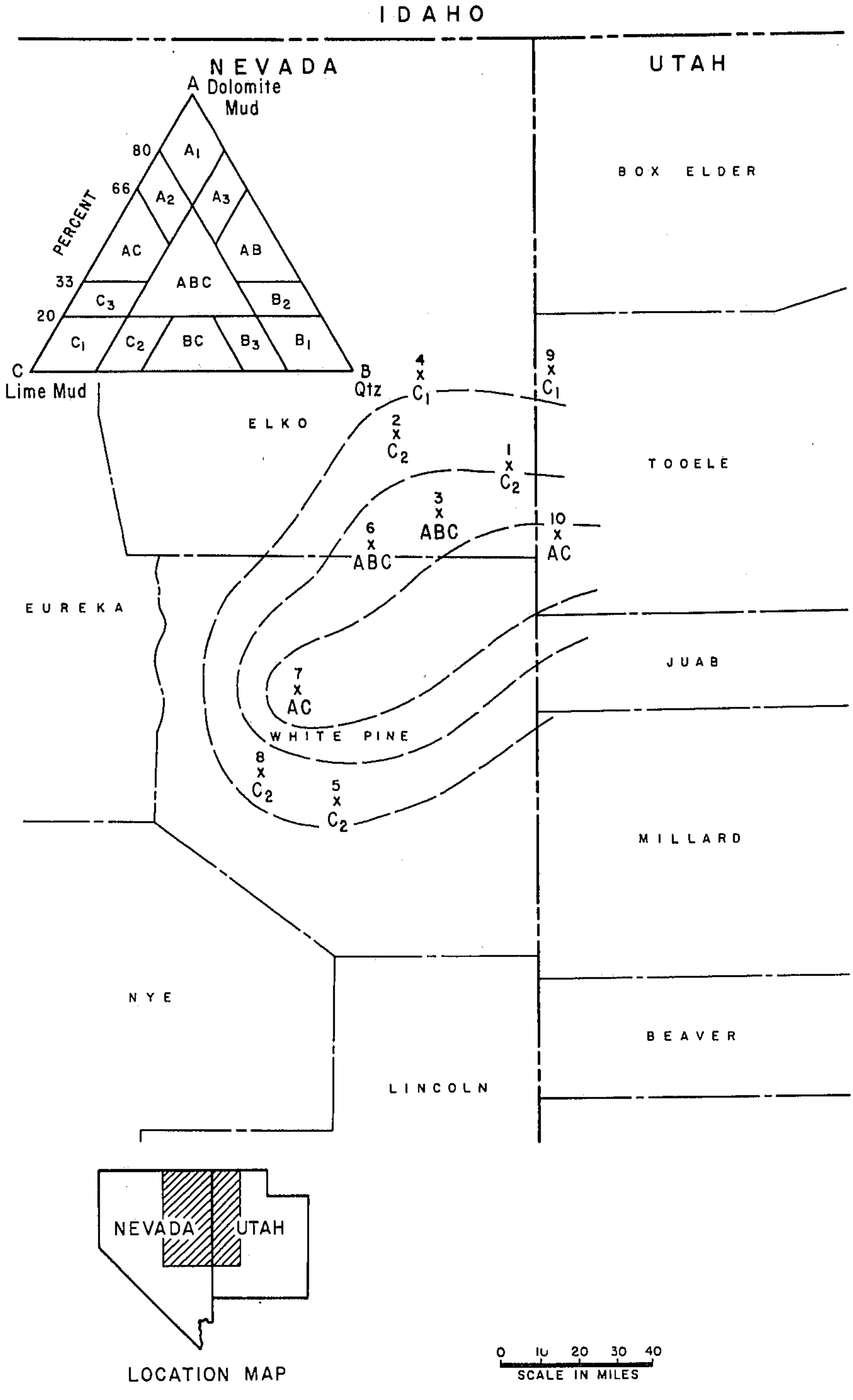
Text-fig. 16 shows the distribution of skeletal material, detrital quartz, and lime mud in the Leonardian section. This diagram is similar to the one for these variables in the Wolfcampian.

Most writers would agree that these Wolfcampian and Leonardian sediments were deposited in an area several hundred miles west of any well established, marine-nonmarine transition area denoting the shoreline in Utah. Despite this, the evidence is abundantly clear that these sediments are for the most part very shallow water in origin. Mudflats, mudmounds, and oolite bars, often awash, account for much of the rock sequence. Shallow crinoidal banks were also important. When sand was introduced into the area, the shallow water depths permitted marine currents to sweep it into all but the deepest and most protected areas. During major periods of regression evaporites accumulated in small restricted areas.

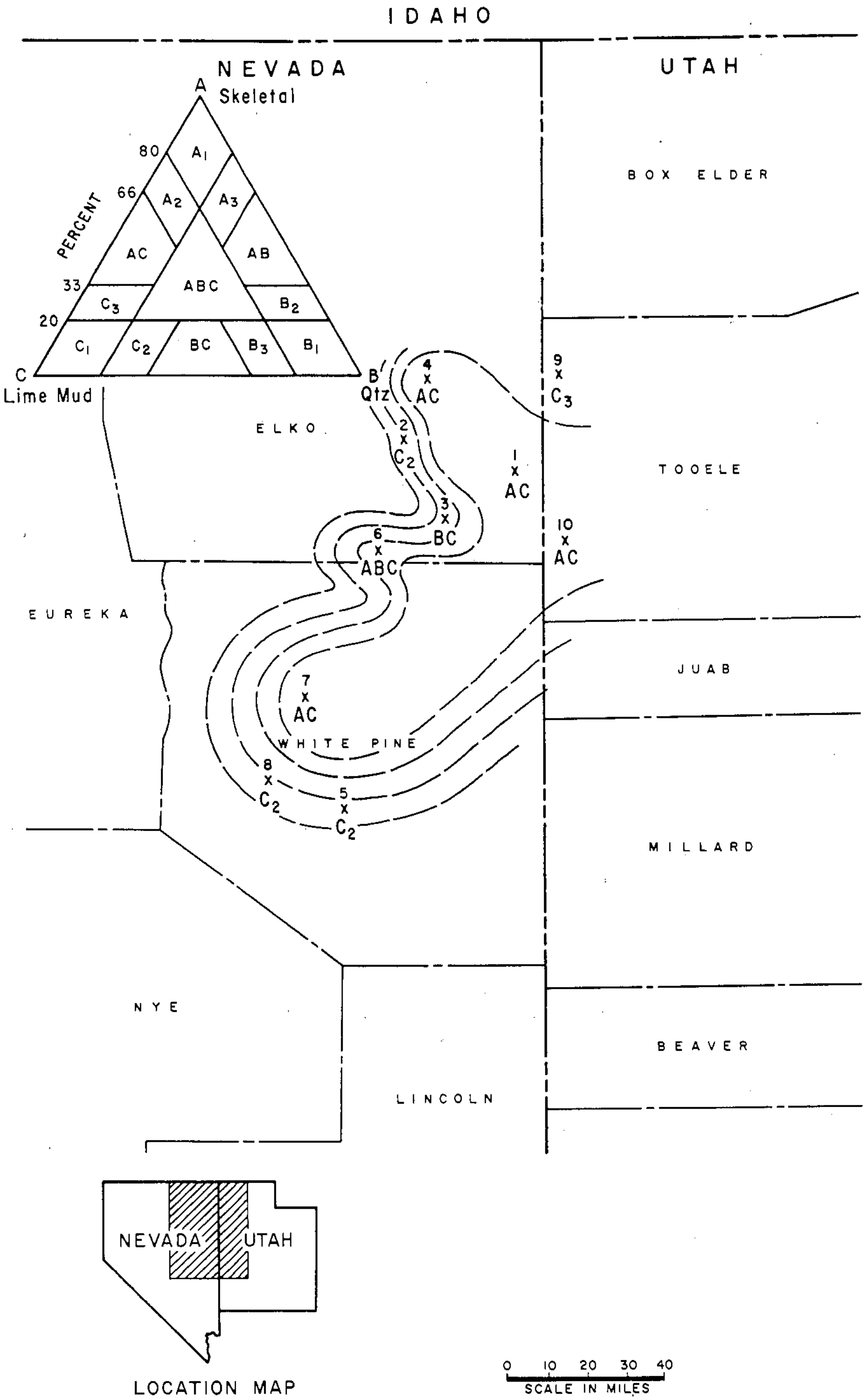
The configuration of the lithofacies maps outlines an elongate basin which remained fairly constant in geographic position within the miogeosyncline during Wolfcampian and Leonardian time. Local shifting of the principal depocenters occurred but did not destroy the basic depositional pattern.

## Diagenesis

Although the problem of diagenesis in these carbonates was not of primary concern in this study, the following conclusions appear to be justified as a result of the petrographic investigation. In general, it can be said the Wolfcampian and Leonardian rocks in the study area experienced low to moderate diagenetic changes only, except for dolomitization which is abundant. Where the carbonates are still limestone, most of them remain at a diagenetic level they probably assumed relatively early in their history. This is despite the post-depositional folding and faulting typical of Great Basin tectonics to which these rocks have been subjected. The postulated moderate level of diagenesis is based on the fact that the grain size of the lime muds has undergone very little enlargement in most of the rocks examined. Details of wall structure in most fossils are very well preserved. The notable exception is the Rishel Peak section where the lime muds have undergone some grain enlargement and the detail of many of the fossils is poor. This, however, is epigenesis, probably due to hydrothermal alteration brought on by fluids moving along the several faults which transect the measured section. Some areas of Gold Hill have also been altered epigenetically, probably by several dikes which have intruded these rocks.




TEXT-FIGURE 15.—Distribution of dolomite mud, detrital quartz, and lime mud in Leonardian rocks.




TEXT-FIGURE 16.—Distribution of skeletal grains, detrital quartz and lime mud in Leonardian rocks.

Grain Cementation

This process is of moderate importance only in the rocks studied. The reason for this is that carbonates with primary intergranular porosity are not numerous except for the crinoidal and oolite facies. The majority of the rocks, with the exception of these two facies, are mud filled and thus no porosity exists into which carbonate cement can be introduced. The crinoidal facies is not commonly grain cemented and will be discussed later. The oolite facies is usually dolomitized and the original cemented fabric has been altered.

Drusy Infill

Larger pore spaces, which may be filled with drusy calcite or dolomite, are commonly confined to intra-fossil cavities or fractures. Large vugs are rare and other possible voids such as burrows or borings are filled with mud. As a consequence of this, the drusy mosaics which are found are usually formed by relatively small crystals of less than 200 microns. The gradation of crystal size from smaller ones on the wall of the void to larger ones in the center is not great because of the small pore spaces being filled. Normally, drusy mosaics are found within corals, fusulinids, and molluscs.

Pressure Solution

This phenomenon is common where grains are in contact with each other. Crinoid facies exhibit this type of diagenesis in excellent detail. Crinoid ossicles are pressolved to the point where intergranular porosity is almost completely destroyed (Plate 9). The resultant rock is a mosaic of poorly sorted crinoid remains which show abundant cleavage planes and fit together very tightly. The individual grain contacts are long and straight, gently curved, or show penetration of one grain by another. Fusulinids or bryozoans in this fabric are invariably broken or crushed.

Unlike the crinoidal rocks described by Bathurst (1958, p. 21) and Murray (1960, Figure 6) which show syntaxial overgrowths, these crinoidal grainstones show very little evidence of rim cementation. They are welded together by pressure solution which has allowed the grains to become interlocked. Calcite put into solution at the points of contact where the pressure was greatest has evidently been removed from the rock rather than be deposited in areas of lower pressure. It is possible that the mobilized calcite was deposited within the porous ossicles as these are now optically a single nonporous crystal, the original porosity of the grains having been filled by calcite.

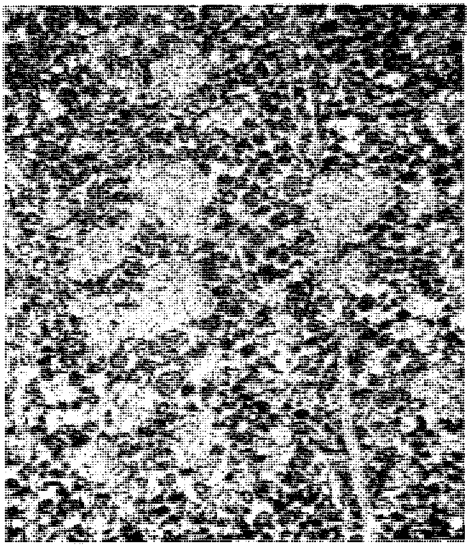
Dolomitization

Dolomitization has been extensive in Leonardian-age rocks especially in the middle and upper parts of the Pequop Formation. As noted in the section on environments, this diagenetic process has operated chiefly on carbonate muds and oolites in close association with evaporites.

There are two main grain sizes in these dolomites. The smaller varies from about three to ten microns and is characteristic of dolomitized oolite or oopelletoid rocks. In these the original grains are well preserved. Coarser grain size averages about 60 microns. This rock is not as abundant as the former but is present in several sections. In most of these the texture, matrix, and particulate content of the original rock has been altered to the extent that they are no longer recognizable. Resultant rock is a mosaic of interlocking equant grains with rounded or curving boundaries. A few small rhombs are also present.

1

500 μ



2

500 μ

EXPLANATION OF PLATE 9

FIG. 1.—Diagenetically altered crinoid facies. Crinoid ossicles exhibit strong cleavage and pressure solution resulting in a "welded" fabric without rim cement.

FIG. 2.—Incipient dedolomitization. The rock is an oopelletoid dolomite which is inverting to calcite as demonstrated by the light patches composed of mosaics of calcite crystals varying from about 50 microns to 200 microns in diameter. Slide 23-32, Upper Pequop Formation, Gold Hill section.


1


2

EXPLANATION OF PLATE 10

FIG. 1.—Crinoid stem in cross-section. Light areas have been replaced by microcrystalline chert. Remainder of stem, central canal filled with lime mud, and lime mud matrix have remained unaffected. Slide 13G, Ferguson Mountain Formation, Dolly Varden section.

FIG. 2.—Dark crinoid fragment showing intra-particle light areas of incipient silicification. Slide 5J, Upper Pequop Formaton, Moorman Ranch section.

Dedolomitization

This process is apparent in many dolomites throughout the stratigraphic section. It is probably of post-uplift origin in many instances because the outer, more weathered surface of some of the dolomites has been affected more than the fresh surfaces.

Many fresh, unweathered rocks show dedolomitization also. An example is shown in Plate 9, a sandy oopelletoid dolomite from the upper Pequop at Gold Hill. The light colored, blotchy areas and the thin fractures are calcite, the crystals averaging about 80 microns in diameter. Calcite evidently has replaced the dolomite, rather than filling pre-existing vugs. The usual criteria of drusy infilling are absent. In addition, the calcite patches commonly contain quartz grains that have remained unaffected by the process. Dolomite crystal size varies from about three to 10 microns and original carbonate (aragonite?) was probably syngenetically dolomitized to this grain size. At some later date a microfracture system developed which allowed calcium rich waters to penetrate the rock and initiate the dedolomitization process.

Silicification

Chert is abundant in many of the sections. It commonly occurs as thin lenses, blebs, and nodules of black to brown varieties. "Case-hardening" is also abundant on many of the weathered surfaces.

In thin section many of the rocks show evidences of incipient silicification. Commonly, this process is very selective, operating on some grains to the exclusion of others; the silica is microcrystalline and has a yellow to orange color. Delicate patterns may be traced in some of the larger grains. Crinoid stems are very susceptible to selective silicification. Ordinarily the outer margins and the central canal will be attached first; however, in many instances the invasion of silica has progressed in irregular lacy networks among the cells of stems. Ordinarily the silicification pattern cannot be seen in plain light except as a vague yellowish mass but is readily observed using crossed nicols, (Plate 10).

Grain Enlargement

This process of recrystallization with increase in grain size is widespread but only on a moderate scale. The lime muds for the most part remain at the grain size they assumed very early in their history. This varies from about three to ten microns, the same size range as that of most of the dolomites.

## CONCLUSIONS

During Wolfcampian and Leonardian time the Arcturus Basin was an area of rapid subsidence within the more slowly subsiding miogeosyncline. Carbonate and clastic sedimentation kept pace with this subsidence, however, and the water depth remained very shallow. The configuration of the basin was strongly controlled by the Antler orogenic belt on the west and north; eastward from the basin axis the sedimentary pattern was controlled by the Western Utah Highland. The basin was probably connected to the Oquirrh Basin through one or more accessways. The two basins were separate entities and received markedly different sediments as pointed out by Bissell (1967).

The basin first received Early Wolfcampian sediments in the Ferguson depocenter. Subsidence and sedimentation continued here and by Medial Wolfcampian the remainder of the basin was flooded. The Ferguson depocenter continued to be the most negative portion until early Late Wolfcampian at which time the entire basin subsided rather evenly and sediment distribution was more uniform.

There is excellent evidence that both local tectonics and widespread epeiric changes played important parts in controlling sedimentation. The regional withdrawal at the end of Wolfcampian time is reflected by the presence of very shallow water sediments of this age throughout the basin. Another withdrawal of less magnitude occurred about Medial Leonardian time and was followed by periodic area-wide fluctuation of sea level throughout the remainder of the Leonardian. The Pequop Mountain section, where only 250 feet of Wolfcampian sediments, conglomeratic in part, are overlain by 3,087 feet of Pequop Formation, is an example of local tectonic control of sedimentation.

The relative ease with which stratigraphic units representing short spans of time can be traced for long distances demonstrates that transgressions and regressions occurred rapidly and affected most of the area of study. This is characteristic of a shallow basin where small changes in sea level can bring about changes in sedimentation over broad areas. Text-fig. 17 shows the writer's correlations of Wolfcampian-lower Leonardian rocks in the Cherry Creek Mountains-Ferguson Mountain area. Text-fig. 18 is a stratigraphic cross section showing correlation in the Rib Hill-Moorman Ranch area. Lithologic units can be traced for many miles in both figures. The writer's concept of the sedimentation in the area differs, therefore, from that of Stevens (1965) who stated that widespread application of most formation names to sections throughout the area was unrealistic and who preferred to apply the lithosome concept instead.

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