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LOWER PERMIAN STRATIGRAPHY OF EAST-CENTRAL NEVADA AND ADJACENT UTAH

by

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LOWER PERMIAN STRATIGRAPHY OF EAST-CENTRAL NEVADA AND ADJACENT UTAH

by Patrick James Barosh

Abstract

The Permian section near Ely, Nevada, consists of, in ascending order: Riepe Spring Limestone, a bluff-forming limestone with abundant corals, and Reipetown Sandstone, a buff to red very coarse-grained siltstone with minor carbonates, both formations of Steele (1960); Arcturus Formation, divisible into a Lower Member composed of alternating medium-bedded limestone and buff siltstone, and an Upper Member composed of alternating thin-bedded limestone and buff to red siltstone and gypsum; and Kaibab Limestone, a massive bioclastic limestone. The Wolfcamp-Leonard boundary occurs within the Arcturus Formation.

West of Ely the Riepe Spring Limestone and Reipetown Sandstone thin and change into thin-bedded cherty limestone. These beds, plus the basal part of the Arcturus Formation, form the Carbon Ridge Formation at Dry Mountain and Eureka. At Dry Mountain minor clastic chert occurs in the Arcturus Formation, and beyond to the west clastic chert replaces most of the limestone to form the conglomeratic Garden Valley Formation. The cherty limestone at the base of the Garden Valley is apparently equivalent to the upper part of the Carbon Ridge Formation at Carbon Ridge.

Eastward in Utah the Riepe Spring Limestone is recognizable in the Confusion Range, but is almost unrecognizable in the Needle Range. The dolomite content in the Reipetown Sandstone gradually increases to 25 per cent of the formation in the Confusion and Needle ranges. The Arcturus Formation thins and undergoes moderate lithologic changes. It is equivalent to the rocks above a horizon 300 feet below Bed A of the Arcturus Formation as mapped in the Confusion Range by Hose and Repenning (1959, 1963).

LOWER PERMIAN STRATIGRAPHY OF EAST-CENTRAL NEVADA AND ADJACENT UTAH

INTRODUCTION

This study, which encompasses an area in east-central Nevada and westernmost Utah centered around Ely, Nevada, extends westward to the southern Sulphur Spring Range and eastward into the Confusion and Needle Ranges. The region is one of structurally complex north-south trending ranges separated by wide alluvial-filled valleys (plates I & III).

The purpose of the study is twofold: first, to describe in detail the Permian sediments in the central Egan Range and second, to trace and work out the facies changes of the main Permian stratigraphic units below the Kaibab Limestone between Ely and Eureka and the Confusion Range.

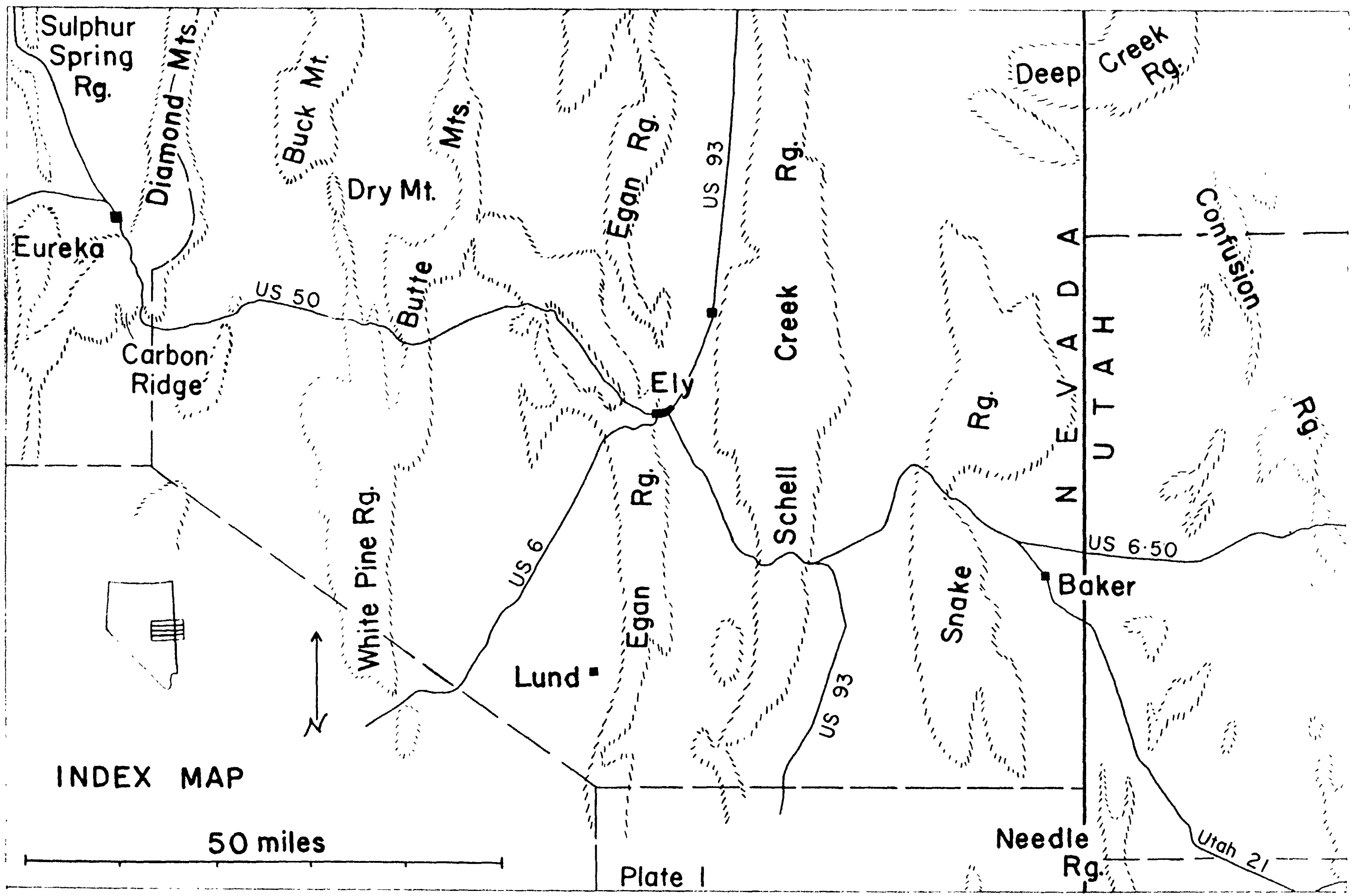
The studied interval includes all the Permian section beneath the Kaibab, except where the Kaibab was included near Ely. The Kaibab and younger Permian rocks were not studied because these rocks have a very restricted occurrence in this region and are not involved with problems of correlation across the area. They have been well studied in the Confusion Range which is their principal area of outcrop.

Field work was carried on during three summers, 1961 through 1963. Familiarization with the Paleozoic section was gained while mapping in the central Egan Range in 1961. Detailed work on the Permian rocks of the Egan Range was carried out in 1962 and in 1963, in addition to mapping, the changes in the Permian section to the west and east were studied. A total of five months was spent mapping Permian rocks in the Egan Range.

Six sections were measured in the Egan Range, two in the Butte Mountains and one at Dry Mountain. Much time was consumed in working out the structure in the area in which the sections were measured. Moreover, many other localities were visited and studied in varying detail, for example, Tyrone Gap in the southern Sulphur Spring Range, Carbon Ridge, Buck Mountain, several localities in the Butte Mountains, White Pine Range, Connors Pass area in the Schell Creek Range, northern Needle Range and several localities in the Confusion Range.

PREVIOUS WORK

A large number of papers have discussed the Permian stratigraphy of this part of the eastern Great Basin. The Permian rocks of the area around Eureka (Nolan et al 1956, Dott 1955, DeJoia 1952, and Riva 1957) and those of the Confusion Range (Hose and Repenning 1959) are well studied. In addition, brief descriptions of Permian rocks at various localities within the region appear in numerous theses and short articles. A number of papers deal with the Permian stratigraphy of the central Egan Range, but no work has been reported in a very detailed manner, although some detailed paleontologic work has been done.


Sulphur Spring Rg.
Diamond Mts.
Buck Mt.
Dry Mt.
Butte Mts.
Egan Rg.
US 93
Schell Creek Rg.
Deep Creek Rg.
Confusion Rg.
Eureka
US 50
Carbon Ridge
Ely
Snake Rg.
NEVADA
UTAH
US 6·50
Baker
White Pine Rg.
US 6
Egan Rg.
Lund
US 93
INDEX MAP
50 miles
Needle Rg.
Utah 21
Plate I

Dott's (1955) excellent regional study of the Pennsylvanian and basal Permian stratigraphy extends into the western part of the area studied here. Some recently published articles, which discuss the regional Permian stragigraphy of this region, are either so erroneous or so very inadequate that they are not mentioned.

Significant papers are mentioned under the units they describe.

ACKNOWLEDGEMENTS

This study was part of the U.S. Geological Survey's investigations of the Ely, Nevada, area. I wish to thank R. K. Hose for his tour of the Confusion Range and use of his measured sections and E. L. Yochelson, Mackenzie Gordon, Jr., and R. C. Douglass for fossil identification and age determination. I also wish to thank Don Fiero, Tom Heidrick, and William Raymond for their aid in measuring sections, and Dixie Lee Brewer for typing the manuscript.

STRATIGRAPHY

The Permian sediments of east-central Nevada and adjacent Utah disclose many facies changes. In places, significant changes take place between exposures in adjacent ranges, which generally are separated by valleys eight to twelve miles wide. Whereas most of the facies changes concerned with here take place in an east-west direction, changes, which need to be taken into account when comparing sections of different latitudes, also occur in a north-south direction. Most ranges are complex structurally and in most places it is very difficult to get a complete and accurate section in a single range. Facies changes and structural complexities account for the great differences in described lithology, thickness and much of the terminology that has been used in the region.

Due to lithologic changes, the well described Permian sections, in different districts within the region, do not correlate readily. Near Ely the Permian section consists of, in ascending order: the Riepe Spring Limestone, a bluff-forming limestone with abundant corals; the Reipetown Sandstone, a buff (used to include colors near 10 YR 7/4 on the rock-color chart) to red siltstone with minor carbonates; the Arcturus Formation, consisting of a Lower Member of alternating medium-bedded limestone and buff siltstone and an Upper Member of alternating thin-bedded limestone and buff to red siltstone with some gypsum; and the Kaibab Limestone, a massive bioclastic limestone.

Near Eureka the Permian rocks are named the Carbon Ridge Formation, composed of thin-bedded cherty silty limestone, whereas northwest of Eureka, in the southern Sulphur Spring Range, the

Permian Garden Valley Formation is characterized by chert conglomerate.

In the Confusion Range basal Permian rock is a limestone or dolomite unit, that in places cannot be distinguished from the Ely Limestone of Pennsylvanian age, hence is mapped with it. The basal Permian is overlain by interstratified siltstones, sandstones, carbonates and some gypsum which is mapped as the Arcturus Formation, above which lie the Kaibab and higher Permian Formations.

Happily, the above terminology represents all significant facies of the Permian rocks in the region, so that the existing terminology needs only slight modification.

All lateral lithologic changes within the Permian rocks appear perfectly normal and no evidence of telescoping of facies by thrusting was seen.

The distribution of Permian rocks varies greatly in adjacent regions. Little Permian sediment crops out south of the region under study between White Pine County and southern Nevada, no Permian is exposed east of the Confusion and Needle Ranges until the Star Range is reached, the thick Permian to the north, except for the Carlin area, has yet to be adequately studied and described, and minor Permian is exposed immediately to the west.

HISTORY OF PENNSYLVANIAN-PERMIAN STRATIGRAPHIC TERMINOLOGY IN THE ELY AREA

Lawson (1906, p. 292-5 & unpub. map) was the first to publish on the stratigraphy of the area. He mapped a strip along the mineralized belt of the Robinson (Ely) district extending from Lane City, at the northeast corner, to about 5,000 feet west of Pilot Knob, at the northwest corner, in which he divided the Pennsylvanian-Permian rocks, in ascending order, into the Ely, Arcturus and Ruth limestones. Lawson mapped together the rocks here designated Reipetown Sandstone and Arcturus Formation as the Arcturus Limestone, but did not extend his mapping far enough to the southwest to include Kaibab rocks in the formation. Lawson's Ely and Ruth limestones are equivalent. The name Ruth Limestone was used for the overturned beds on Rib Hill that mistakenly were thought to overly the Arcturus. Except where complicated by faulting, his Arcturus-Ely or Ruth contacts are drawn along what presently is mapped as the Reipetown-Riepe Spring contact.

Spencer (1917, p. 26-8 & plate II) in mapping the Robinson mining district used considerably different boundaries. He recognized the equivalency of the Ely and Ruth limestones of Lawson, but drew the Arcturus-Ely contact much higher than Lawson, placing it at what is presently mapped as the contact between the Upper and Lower members of the Arcturus Formation. Thus the Ely Limestone as mapped by Spencer included the present Ely Limestone, Riepe Spring Limestone, Reipetown Sandstone and the Lower Member of the Arcturus Formation. The Arcturus Limestone as mapped was equivalent to the Upper Member of the Arcturus and the Kaibab.

Spencer, as did Lawson, considered the formations of Pennsylvanian age; the Permian was then considered part of the Carboniferous System by the U. S. Geological Survey, with Girty (in Spencer 1917, p. 28) noting the similarity of the fauna of Spencer's Arcturus with that of the Kaibab of Arizona.

Blanchard (in Pennebaker 1932, p. 164, unpub. map & in Bauer et al 1960) raised the lower boundary of the Arcturus even higher, restricting the Arcturus to the present Kaibab Limestone. The top of the Ely Limestone was lowered to where Lawson had placed it, thus naming between the two a new formation, the Rib Hill Formation, which was exactly equivalent to Lawson's Arcturus Limestone. Blanchard divided the Rib Hill into three members: the Lower Rib Hill Sandstone, the Rib Hill Limestone, and the Upper Rib Hill Sandstone. These members are equivalent, respectively, to the Reipetown, the Lower Member and the Upper Member of the Arcturus. Thus Blanchard recognized all of the major lithogic divisions in the Pennsylvanian-Permian stratigraphy. The terminology only has varied since.

Langeheim et al (1960, p. 154) lowered the Rib Hill-Arcturus contact to the top of the Lower Rib Hill Sandstone Member of Blanchard. They recognized that the Pennsylvanian-Permian boundary fell within the upper part of the Ely Limestone and also noted that the name Rib Hill was preoccupied by the Precambrian Rib Hill Quartzite in Wisconsin. Steele (1959b) proposed a radically different terminology, but quickly abandoned it and proposed (1960, p. 100, 102-3) only the following modifications: that the Kaibab Formation be separated from the top of the Arcturus, the term Rib

Plate II

Stratigraphic Terminology Used In The Ely Area For Permian Rocks

	Lawson 1906	Spencer 1917	Blanchard 1932	Langenheim et al 1960	Steele 1960	Wilson and Langenheim 1962	This Paper 1964
Tert	Rhyolitic lavas and tuffs	Rhyolite and tuff	Volcanics	Sheep Pass Fm	covered	Tert. sediments	Tert. rocks
Lower Permian: Leonard	not mapped	Arcturus Ls	Arcturus Ls	Arcturus Ls	Kalbab Fm	"Kaibab" Ls	Kaibab Ls
	Arcturus Ls		Rib Hill Fm: Upper Rib Hill Ss		Arcturus Fm	Upper Arcturus Fm	Arcturus Fm: Upper Mb
?		Ely Ls	Rib Hill Fm: Rib Hill Ls			Lower Arcturus Fm	Arcturus Fm: Lower Mb
Lower Permian: Wolfcamp			Rib Hill Fm: Lower Rib Hill Ss	"Rib Hill" Ss	Riepetown Ss	Riepetown Ss	Reipetown Ss
	Ely Ls / Ruth Ls		Ely Ls	Ely Ls	Riepe Spring Ls South Ridge Ss	Ely Ls	Riepe Spring Ls: U. Mb., Coralline Mb., L Mb
M. Penn.					Ely Ls		Ely Ls

Hill be abandoned because of preoccupation and that Reipetown Sandstone be substituted, and that the upper, Permian part, of the Ely Limestone be broken off as a separate formation, the Riepe Spring Limestone. He also designated a new formation which later was abandoned (in Wilson and Langenheim 1962, p. 498), the South Ridge Sandstone, between the Riepe Spring and Ely, which arose from a misconception concerning a fault block of Reipetown Sandstone. Similar stratigraphic changes had been previously proposed in unpublished theses (Ehring 1957, Barr 1957).

The stratigraphic terminology has thus been in most cases developed by people who have mapped in the area and the terminology reflects practical mappable lithologic units. This paper, with only minor changes, follows for the Ely area the terminology as presented by Steele (1960) and Wilson and Langenheim (1962).

REGIONAL UNCONFORMITY

An unconformity which lies at the base of the Permian rocks of this region, extends over much of eastern Nevada and western Utah, making an excellent stratigraphic base for this study. The regional character of this unconformity was first recognized and studied in northeastern Nevada and adjacent Utah by Dott (1955, p. 2283) and later over a slightly wider region by Steele (1959b, p. 52-4; 1960, p. 98). Throughout most of the region under study Lower Permian rocks rest disconformably on the Middle Pennsylvanian limestones of the Ely with Upper Pennsylvanian and possibly very lowest Permian rocks missing. To the west, however, apparently greater uplift caused pre-Permian erosion to cut even deeper into the underlying rocks. The upper half of the Ely Limestone is present in the northern, but is missing in the central part of the Diamond Mountains (Dott 1955, p. 2270; Riva 1957, p. 13), whereas south of Eureka the entire Ely Limestone wedges out beneath the unconformity so that the Mississippian Diamond Peak Formation underlies the Permian. Locally even the Diamond Peak is missing and the older Mississippian Chainman Shale underlies the Permian (Nolan et al 1956, p. 65). At the south end of the Sulphur Spring Range, to the west, Permian sediments rest with angular unconformity on contorted cherts of the Ordovician Vinini Formation. Dott (1955, figs. 11 & 19) illustrates these relationships and depicts a similar situation near Carlin.

On Radar Ridge, northwest of Ely, this regional unconformity is well exposed in many places. Whereas no relief is seen at the unconformity, it is overlain by a thin chert breccia, the variations in the thickness of which imply deposition on a surface of some relief. The breccia is fairly uniform in thickness, with a three foot maximum variation, along the southern part of the ridge, but along the north end of the ridge the breccia thickens northward 11 feet in 1.65 miles and then 10 feet over the next 0.6 mile, beyond which to the north it thins again. No evidence was seen, anywhere in the region, of weathering just below the unconformity. The breccia averages about one half to three feet in thickness. Based on the chert content of the Ely Limestone below, it would not take a great thickness of weathered limestone to supply this thickness of chert. Because of the angularity of chert fragments, the minor relief, the absence of evidence of weathering of the underlying limestone, and some evidence indicating marine deposition of the breccia (see p. 16), it is concluded that the unconformity was mainly either a submarine product or at least a surface smoothed under marine conditions. The unconformity seems to represent a period dominantly of nondeposition for the greater part of the region, during which bottom currents redistributed the chert fragments left from the erosion to the west of the Ely and Diamond Peak formations and very slight erosion to the east from the top of the Ely.

Dott (1955, p. 2281-2 & fig. 18) shows that whereas Wolfcamp sediments overlie the unconformity in the region under study; to the north in Elko County and adjacent Utah, Upper Pennsylvanian rocks rest on the unconformity. Moreover, in northwest Arizona, northwest Nevada and in the Toquima Range, about 50 miles southwest of Eureka, Upper Pennsylvanian deposits overlap older Pennsylvanian and pre-Pennsylvanian rocks. In addition, to the south, Upper from northern Lincoln County (Kellogg 1960, p. 193; Tschanz and Pampeyan 1961). Thus east-central Nevada and adjacent Utah appear to have been slightly positive. Dott (1955, p. 2289-90)

> "...concludes that Upper Pennsylvanian strata were never deposited over most of the positive area because: (1) there are no scattered Upper Pennsylvanian remnants known in this large region, (2) such rocks in adjacent areas contain more clastics than older ones and possess cross-stratification which suggest derivation from an area being eroded in eastern Nevada and west-central Utah, and (3) distribution of Upper Pennsylvanian, lowest Wolfcampian and higher Wolfcampian deposits indicate gradual centripetal transgressive overlap of the area beginning in Late Pennsylvanian time".

On the other hand, Douglass (1962, 1963b & in Playford 1961) reports Upper Pennsylvanian rocks beneath the unconformity in the Egan Range east of Lund that seemingly bridge the reported unconformity between Middle Pennsylvanian and Permian. If so, these are the only Upper Pennsylvanian rocks known below the unconformity.

Baars (1962, fig. 4) outlines an area in southern Utah in which a similar unconformity beneath Wolfcamp sediments is flanked by areas in which sedimentation was probably continuous during the latest Pennsylvanian and earliest Permian. This unconformity may be the southeastern continuation of the regional unconformity that developed over the slightly positive area in east-central Nevada and adjacent Utah described by Dott (1955).

PERMIAN FORMATIONS

In the following section, discussion of each of the presently accepted stratigraphic units is given, beginning with the oldest. Each unit is discussed in turn by area, with much more detail presented for the Egan Range than the other localities.

RIEPE SPRING LIMESTONE

The upper, Permian, part of the Ely Limestone was first formally separated as a formation by Steele (1960, p. 102) as the Riepe Spring Limestone, named after Riepe Spring near the type area at the north end of Ward Mountain in the SE 1/4 sec. 7, T. 15 N., R. 63 E. Whereas the formation is valid on a lithologic basis, it is doubtful that it would have been separated from the Ely as a formation had it been of Pennsylvanian age, as both formations are composed of similar colored limestone.

The Riepe Spring Limestone is a bluff-forming limestone containing abundant *Lithostrotion*-like corals and has a thin chert breccia at the base overlain by a thin fusulinid coquina. In the Egan Range, and to the west, a thin-bedded cherty limestone member overlies the coralline limestone. The formation rests disconformably on the cherty limestones of the restricted Ely and not on the nonexistent South Ridge Sandstone (see p.10), also the Riepe Spring is not equal to the top 300 feet of the Ely as described by Spencer (Steele 1960, p. 102) (see plate II). It is conformably overlain by the Reipetown Sandstone.

The type section is faulted and the 410 feet given by Steele (1960) includes considerable repetition. The best exposure of the formation in the central Egan Range is at the south end of Radar Ridge, Section I (plate XI), NE 1/4 SE 1/4 NE 1/4 sec. 2, T. 16 N., R. 61 E., and this should be used as a reference section in preference to the faulted and much more poorly exposed type section. Detailed descriptions of section locations are given in the appendix.

The formation is best exposed and developed in the central Egan Range. It is present also in the Butte Mountains, but it loses its identity as a separate formation west of the Butte Mountains. East of the Egan Range, it is present in the central Schell Creek Range and the Confusion Range. In places in the Confusion Range it is nearly unrecognizable as a separate formation which is also the case to the south where it crops out in the Needle Range.

LITHOLOGY

Egan Range

The Riepe Spring is exposed in a belt 30 miles long through the central Egan Range from the north end of Radar Ridge south to the southern end of Ward Mountain. The Riepe Spring forms a bluff along the west side of Radar Ridge, where the limestone is completely overturned, occurs in many places between Radar Ridge and Ward

Mountain and forms the crest of Ward Mountain and bluffs along the east slope. It crops out farther south, notably just east of Lund, and probably in small patches farther north also.

The formation is divided into three members: a lower member of silty limestone, limy dolomite and fusulinid coquina; a middle coralline limestone member; and an upper thin-bedded cherty limestone member.

Lower Member

A basal chert breccia with a sharp lower contact is found wherever the base of the Riepe Spring Formation is exposed. The breccia most commonly occurs at the base of the Lower Member, but where the Lower Member is absent, it is present at the base of the Coralline Member. The breccia generally has an olive gray or brown color on the weathered surface and is composed of angular to subangular chert fragments in a limestone matrix. The chert fragments are mainly green and medium gray with some dark gray to black. They range from coarse sand size to pebbles three inches in diameter, averaging about 1/4 to 3/4 of an inch in diameter, and are coarsest where thickest. There is some sorting and the size range within individual layers is not too great. The fragments are commonly somewhat tabular in shape and show some orientation parallel to bedding. Besides the chert, rare silicified crinoid stems, bryozoa, and horn corals have been found as clasts, also a thin-shelled unsilicified brachiopod was found which may have been living on the sea floor during deposition. The clasts are embedded in a light gray weathering limestone matrix and in places are not touching. The percentage of matrix varies between layers, but shows an overall increase upwards, locally with a few nearly pure limestone lenses near the top, and grades into the overlying limestone.

The breccia is generally well exposed along the north half of Radar Ridge, where it occurs in a slight saddle topographically above the overturned coralline limestone. Farther south it is in places exposed where the rocks dip steeply, but it is very rarely exposed south of U. S. highway 6, where it is generally buried in talus at the base of the limestone bluff.

At the north end of Radar Ridge, in the center of the N 1/2 SE 1/4 sec. 33, T. 18 N., R. 61 E., the breccia is nearly 25 feet thick, which is the greatest thickness seen anywhere in the region. The breccia thins southward, being 15 feet thick 3,000 feet south, down to five feet 1.15 miles farther south, and continues to gradually thin southward, although it may locally attain five feet in thickness, as at the south end of Radar Ridge (Section I). Wilson and Langenheim (1962, p. 499) mention 29 feet of buff weathering sandstone with scattered chert pebbles at the disconformity southeast of Ward Mountain. Playford (1961) states that near Lund the breccia is rarely more than one foot thick, is absent in places and in others may occur interbedded with limestone through as much as five feet of section.

Overlying the breccia, and generally better exposed, is a fusulinid coquina bed about three feet in thickness, with thinner coquinas a little above. The fusulinids weather medium gray brown and where the fine-grained lime matrix is of a similar color they are difficult to locate, but where the matrix is light gray the fusulinids are strikingly displayed. The fusulinid coquinas are interbedded in the lower part of an olive gray to light gray brown-weathering medium-bedded limestone unit with minor buff silty bands. The unit is 40 feet or less in thickness on Radar Ridge and is generally poorly exposed, except for the fusulinid coquina bed near the base.

On Radar Ridge, a distinctive unfossiliferous dolomitic unit composed of medium-bedded fine-grained limy dolomite that weathers very light yellowish gray forms the top of the Lower Member. This unit is 20 to 30 feet thick and is poorly exposed. It is overlain by the middle coralline limestone member.

The Lower Member thickens southward from Radar Ridge, where, at the south end of Ward Mountain, it is roughly 150 feet thick; here the lower unit has changed to yellow gray weathering thin-bedded limestone and siltstone. The limy dolomite is about 20 feet thick and two additional units are present above it. The lower of these is a brownish gray-weathering unit of dark gray thin platy limestone, shaly silty limestone, and some calcareous siltstone, approximately 50 feet thick, overlain by a unit roughly 30 feet in thickness, of thin platy limestone and some silty limestone containing abundant fusulinids and, at one horizon, abundant small Orbiculoidea.

Farther south, just east of Lund, the Lower Member is 130 feet thick and is composed predominantly of very fine-grained silty limestone which is yellow to yellow gray in color, and medium to thin-bedded. Most beds contain 20 to 50 per cent of lenticular yellow chert with a thin fusulinid coquina at the base (Playford 1961, p. 179-80).

Coralline Member

Above the Lower Member is a sequence of resistant coral-bearing limestones that typifies the formation and is what Steele (1960) described at the type section. The limestone is medium brownish gray and weathers yellowish medium to yellowish light gray, fine to medium-grained, forms medium to thick beds and contains only very minor chert. The limestone is characterized by very abundant <u>Lithostrotion</u>-like corals which form as much as 25 per cent of the thicker beds. Some one foot layers are composed almost entirely of corals. Steele (1959b, p. 231-2) considered the corals to form 40 per cent of two-thirds of the member and about 25 to 30 per cent of the remaining third, at Rib Hill, but only 10 per cent at the type section (1960, p. 102), in which the corals are just as plentiful. The coral heads are eight inches to over three feet in diameter and in places overturned. Locally the corals are partially or completely recrystallized and may be hard to distinguish; generally only the partially silicified tops of the heads are seen. Some completely recrystallized corals show up as lighter areas in the limestone. <u>Syringopora</u> colonies are fairly common also.

A characteristic of the beds in this member is the knobby bedding surfaces, on which occur a series of low mounds and depressions, each in the order of 10 to 18 inches in diameter, with a total relief of one to three inches. This might be due to differential compaction around coral heads rather than the preservation of bottom features.

The member has a sharp lower contact, but grades into the Upper Member.

The Coralline Member forms bluffs or prominent outcrops. Talus below the bluffs covers the units above or below, depending on whether the limestone is right side up or overturned.

The member is 209 feet thick at the south end of Radar Ridge (Section I), 228 feet at Rib Hill (Steele 1959b, p. 231-2), somewhat less at the type section, 150 to 130 feet near Ward Mountain (Wilson and Langenheim 1962, p. 499) and 120 feet two miles east of Lund (Playford 1961, p. 179). The member thins northward along Radar Ridge (plate XIII).

Upper Member

A sequence of thin-bedded cherty limestone, some silty limestone and calcareous siltstone, that weathers yellowish gray to light olive gray, overlies the coralline limestone. Most of the chert is in thin lenses and bands that weather yellow gray to dark brown, but there is also considerable partial silicification that commonly weathers buff and at first glance resembles siltstone. The member is conformable above with the red and orange buff weathering siltstones of the basal Reipetown Sandstone. In many places the unit is

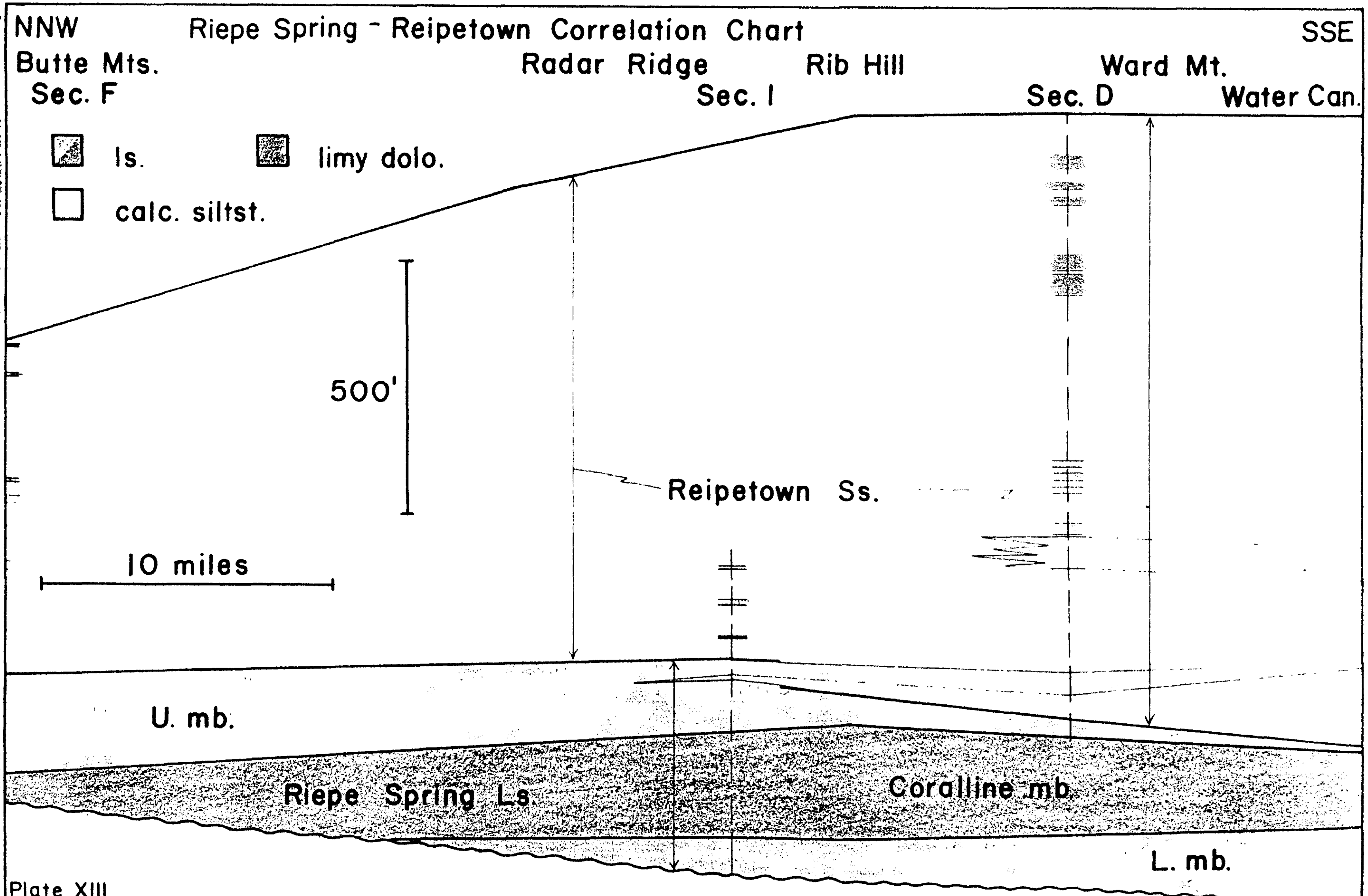

NNW
Riepe Spring - Reipetown Correlation Chart
SSE
Butte Mts.
Sec. F
Radar Ridge
Sec. I
Rib Hill
Ward Mt.
Sec. D
Water Can.
ls.
limy dolo.
calc. siltst.
500'
10 miles
Reipetown Ss.
U. mb.
Riepe Spring Ls.
Coralline mb.
L. mb.

Plate XIII

quite fossiliferous, containing abundant fusulinids and common brachiopods, whereas in other areas fossils are not too common. Along the north end of Radar Ridge the member also contains crinoidal limestones and has a well developed zone of fasciculate corals close to the top (see Section E, plate VI). This coral zone is very similar in appearance to the "Corwenia" zone in the Lower Member of the Arcturus Formation with which it may be confused.

The unit was long ago recognized by some of the mining geologists in the area as the "contact cherts" (Blanchard in Bauer et al 1960, p. 226), but the Upper Member is often masked by talus and the poor exposure probably explains why it was overlooked by Steele (1960, p. 102).

The Upper Member thins southward; at Radar Ridge (Sections E & I) it is about 150 feet thick, in the Robinson (Ely) mining district, 58 feet (Blanchard in Bauer et al 1960, p. 226), at the northern part of Ward Mountain (Section D), 37 feet, near the south end, 16 feet (D. R. Shawe, unpub. section 1960), and farther south near Lund it is not mentioned by Playford (1961). Part of the thinning can be explained by the fact that it interfingers with siltstones of the Reipetown. At North Ward Peak (Section D) the limestone 47 feet above the base of the Reipetown is probably a southward-extending tongue of the Upper Member of the Riepe Spring Limestone.

The formation as a whole thins southward also; at the south end of Radar Ridge (Section I) it is 434 feet thick, at the south end of Ward Mountain, SW 1/4 SW 1/4 sec. 4, T. 13 N., R. 63 E., 311 feet (from D. R. Shawe, unpub. section 1960) and east of Lund it is 250

The Riepe Spring is probably present in small patches in the northern Egan Range, but Woodward (1962) thought that only the upper 57 feet of his Ely Limestone, in a faulted section 18 miles north of Ely, might possibly be correlative to the Riepe Spring, and at the north end of the range, Fritz (1960) found no fossils in the top of the Ely and considered it all of Pennsylvanian age.

Central Butte Mountains

The Riepe Spring Formation is exposed for a short distance along the east side of the central Butte Mountains (Section F, plate VIII) where the Lower Member is absent. The Coralline Member is 61 feet thick, including two feet of chert breccia at the base, and the Upper Member 194 feet, for a total of 255 feet. In the Coralline Member, badly recrystallized Lithostrotion-like corals are only visible at one horizon in the section, however, on the ridge to the north the corals are more abundant and one bed near the top contains abundant specimens of the gastropod Omphalotrochus. The Coralline Member differs lithologically from that in the Egan Range in that a band of silty limestone is present near the top and the member is slightly to moderately cherty in places. The Upper Member consists principally of crinoidal limestone and some silty limestone, with many cherty layers, conformable beneath the buff weathering calcareous siltstone of the Reipetown.

Southern Butte Mountains and Moorman Ridge

On the west side of the range, west of Moorman ranch, the lower part of the Riepe Spring,is well exposed just north of U. S. highway 50, on the west edge of sec. 7, T. 17 N., R. 59 E. and the northeast corner of sec. 12, T. 17 N., R. 58 E. As it was to the north, the

Lower Member is absent. The basal chert breccia, 26 inches thick, is present at the base of the Coralline Member, which is much better developed and contains abundant corals. Easton (1961) measured 100 feet of coralline limestone at or near here. The Upper Member is absent, apparently due to faulting in the small valley to the east of the coralline limestone, although a narrow band could be present, but covered below the first-exposed siltstones of the Reipetown.

Farther south, on Moorman Ridge, sec. 19, T. 16 N., R. 59 E., the Riepe Spring is changed. The Lower Member is composed of an estimated 90 feet of medium gray, medium gray weathering cherty limestone in four inch to one foot beds with the chert occurring as carmel to buff weathering lenses and nodules. The base is covered, but a band of chert breccia float is present about 30 feet stratigraphically below making the total thickness of the member about 120 feet. A few buff weathering silty zones are present and, especially near the top, some crinoidal limestone beds.

The Coralline Member is about 70 feet thick and the Upper Member is approximately 25 feet thick, consisting of cherty limestone similar to that near the base. A thin fusulinid coquina is present a few feet below the top, and at the top, bordering the poorly exposed buff and reddish weathering siltstones to the east, is a bed containing large, nearly spherical Pseudoschwagerina.

The change in the Riepe Spring southward from the central Butte Mountains is similar to that in the Egan Range in that the Lower Member thickens and the Upper Member thins to the south.

White Pine Range

In the Corduroy Mountains on the east flank of the central White Pine Range, at the west edge of sec. 23, T. 13 N., R. 58 E., is a small outcrop that may be the basal part of the Lower Member. This outcrop is shown as the westernmost Arcturus, with the 60° east dip, on Misch and Hazzard's map (in Misch 1960, plate 3). The rest of the Arcturus shown in this area appears to be Ely Limestone. The block consists of light gray weathering medium-bedded limestone alternating with silty intervals. A thick limestone bed at the east edge contains scattered subrounded chert pebbles and may represent the base of the Riepe Spring Limestone. One silty interval contains a very abundant and varied brachiopod fauna which discloses an age consistent with the assignment.

Dry Mountain and Western Areas

At Dry Mountain the 44 foot thick limestone unit at the base of Section H is similar to the coralline limestone and might possibly represent a western extension of the member, although no corals could be found. The limestone unit is underlain by cherty limestone typical of the Ely. There is nothing resembling the coralline limestone at Carbon Ridge nor described from the northern Pancake Range (Rich 1956).

The Upper Member has presumably thickened at Dry Mountain and Carbon Ridge, but it cannot be separated from similar cherty limestones that have replaced the siltstones in the Reipetown. Thus, west of the Butte Mountains the Riepe Spring does not exist as a formation and the Riepe Spring-Reipetown interval becomes the Carbon Ridge Formation. Steele's recognition of the Riepe Spring at Carbon

Ridge was done apparently on the basis of similar fusulinids (1960, p. 102).

Schell Creek Range

The Riepe Spring crops out at many places in the central Schell Creek Range and most of the formation is well exposed in localities near Connors Pass. Two miles southeast of the pass the Upper Member is absent and an estimated 150 feet of the Coralline Member is present, but the base of the formation was not exposed. Harold Drewes (oral communication) found fusulinid coquinas and light gray-weathering dolomite in the Permian part of the unrestricted Ely, in the Connors Pass quadrangle, which may correspond to similar units in the Lower Member in the Egan Range. He also reported one to three feet of chert breccia exposed in the northwest corner of the quadrangle.

An unusual development occurs in the Riepe Spring on the east side of Connors Pass and is exposed along the old roadcuts below the present U. S. highway 6-50-93 in SE 1/4 SW 1/4 sec. 25 and northeast corner sec. 35, T. 14 N., R. 65 E. Here the limestone is essentially a cemented sedimentary rubble. Medium to dark gray limestone, weathering lighter, forms irregular one to two foot beds that are very fossiliferous with Lithostrotion-like corals, and other fossils. This rubbly limestone might very well represent a reef talus, but the possibility that it represents the filling of a sinkhole developed below a post-Middle Cretaceous erosion surface cannot be ruled out at present.

Confusion Range

"The Ely Limestone of the Confusion Range ... contains Permian strata in the upper 100-350 feet" (Hose and Repenning 1959, p. 2171).

In places, mainly due to dolomitization, the Permian part could not be separated for mapping purposes from the Pennsylvanian part and for this reason, the Permian part of the Ely was not differentiated as a separate formation (R. K. Hose, oral communication), although it was mapped where possible (Hose and Repenning 1963). Earlier workers (Kraetsch and Jones 1951; Campbell 1951) had also recognized the Permian age of the top of the Ely and saw no lithologic reason for separation.

The Riepe Spring was seen one mile south of Indian Pass where it is very similar to the formation in the Egan Range at Radar Ridge, except that the Upper Member is missing. The Lower Member consists of one foot of chert breccia with a high percentage of yellow gray weathering limestone matrix overlain by the limestone unit containing the fusulinid coquina, but the dolomitic unit is absent. The Coralline Member is the same.

Hose and Repenning (1959, p. 2174) report

> "The Permian part of the Ely Limestone thins northward from about 350 feet 3 1/2 miles southwest of Skunk Spring to 190 feet 2 miles north of Indian Pass and to about 100 feet 9 miles north of Indian Pass. Criteria for mapping the Permian part of the Ely Limestone differ from place to place. Northward from the vicinity of Indian Pass the Permian has a basal breccia 0.5-3.0 feet thick, little or no chert, and is massive dolomite in part. Chert is present 3 1/2 miles southwest of Skunk Spring as it is at other places. However, in areas south of Cowboy Pass the breccia appears to be absent or lenticular. Fusulinids were collected from several beds 200-350 feet below the top of the Ely...." "These fusulinids range through the lower 150 feet of the Permian part of the Ely 3 1/2 miles southwest of Skunk Spring, and are confined to the lower 20 feet, 2 miles south of Indian Pass. Nine miles north of Indian Pass, no fusulinids were found in the Permian part of the Ely."

The fusulinids are probably restricted to the Lower Member and thus it appears that the Lower Member thickens southward through the range.

Needle Range

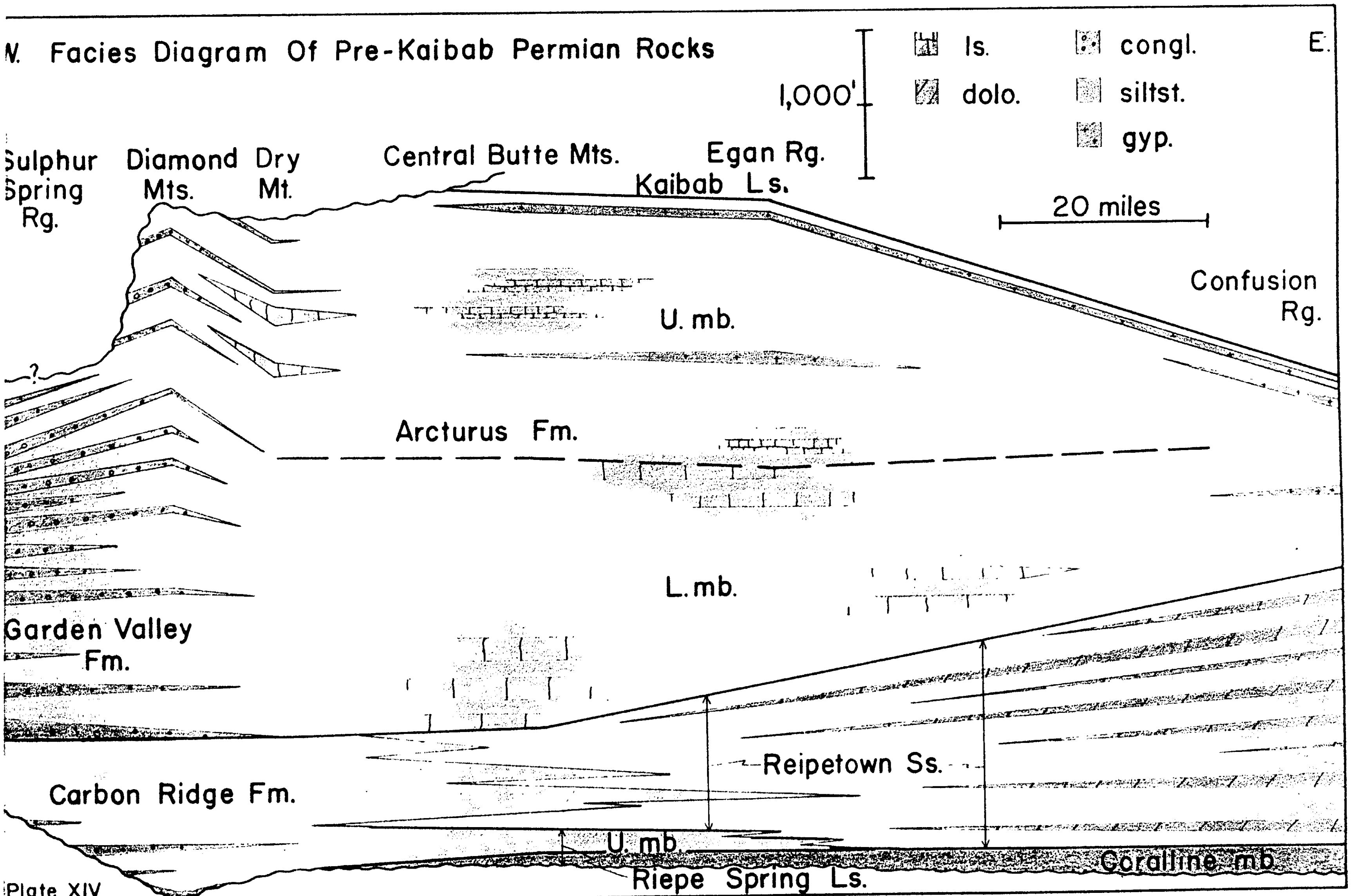
At the north end of the Needle Range, 50 miles south of the Confusion Range, the Riepe Spring Limestone is nearly unrecognizable. Below the limy dolomites that are present there at the base of the Reipetown is a medium to thick-bedded dark to medium gray medium gray weathering noncherty limestone resembling the Coralline Member. At one locality it contains Lithostrotion-like corals in the top foot and is roughly 20 feet thick, overlying cherty limestones. A quarter of a mile to the north a similar 50 foot thick limestone, with no visible corals, overlies a poorly exposed 20 foot unit of moderately cherty, light gray weathering limy dolomite, which in turn, overlies a thick unit of thin to thick-bedded fusulinid bearing cherty limestone and minor dolomitic beds of probable Permian age, but similar to the Pennsylvanian limestones of the Ely. At the possible base of the Permian Limestone is a 10 foot bed of limestone conglomerate with clasts, mainly two to four inches in diameter, set in a lime matrix. Below are cherty limestones typical of the Ely Limestone. Gould (1959, p. 11) considered the upper 600 feet of the unrestricted Ely to be of Permian age in this area. Apparently the Riepe Spring is represented almost entirely by the Lower Member which cannot be readily distinguished from the Ely.

SUMMARY OF FACIES CHANGES

Except in the Needle Range and at Dry Mountain the basal chert breccia was seen everywhere. It is best developed at the north end of Radar Ridge. The overlying fusulinid coquina and dolomite units of the Lower Member of the Riepe Spring pinch out westward between the Egan Range and the Butte Mountains. Eastward, the fusulinid coquina seems to be continuous, but the dolomite, although it may be present in the Needle Range, ends before reaching the Confusion Range. The Lower Member, as a whole, appears to pinch out to the north along a near east-west line extending from the northern Confusion Range westward, following approximately the position of U. S. highway 50 north of Radar Ridge to the southern Butte Mountains. The lithology of the Lower Member, where thickened, is variable from place to place and may be very similar to the underlying Pennsylvanian Ely Limestone.

From the Egan Range, west of Ely, the Coralline Member thins to the north-northwest, to the south and to the west, where it apparently pinches out beneath Newark Valley. Eastward, the member maintains its thickness as far as the southern Confusion Range. In Utah, the Coralline Member thins northward in the Confusion Range, south from the Confusion Range and has not been recognized east of this area.

The Upper Member tongues in beneath Steptoe Valley west of Connors Pass and thickens northwestward. It also thickens rapidly northward through the Egan Range and westward from the Egan Range to Moorman Ridge (plate XIII).


W.
Facies Diagram Of Pre-Kaibab Permian Rocks
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Diamond Mts.
Dry Mt.
Central Butte Mts.
Egan Rg.
Kaibab Ls.
Confusion Rg.
U. mb.
Arcturus Fm.
L. mb.
Garden Valley Fm.
Carbon Ridge Fm.
Reipetown Ss.
U. mb.
Riepe Spring Ls.
Coralline mb.
Plate XIV

West of the Butte Mountains, where the Coralline Member pinches out, the Upper Member forms the lower part of the Carbon Ridge Formation (plate XIV). Southward, nearer the latitude of Eureka, probably both the Lower and Upper members of the Riepe Spring merge to form the lower part of the Carbon Ridge.

PALEONTOLOGY

The discussions of the paleontology of this and the following formations refer to the Egan Range, unless stated otherwise.

The most characteristic fossils are the abundant Lithostrotion-like corals. These occur in and are diagnostic of the coralline limestone. They were designated Thysanophyllum princeps by Easton (1960, p. 576-9). Later McCutcheon and Wilson (1961) named a new genus, Ptolemaia ftatateeta, but the name Ptolemaia was afterwards found to be preoccupied and they (1963) replaced it with Kleopatrina. Wilson and Langenheim (1962, p. 502) assigned the corals at Ward Mountain to several genera: Eastonoides elyensis, Lithostrotionella brokawi, Ptolemaia ftatateeta, Sciophyllum mulleri, and Thysanophyllum princeps, however, it is stated that the fossils

> "...are strikingly similar in gross morphology (and) their differences ... could readily be ascribed to intraspecific variation."

In other words the corals might all be the same specie. The corals are best observed in the vicinity of the type section. The corals collected by Easton (1960, U. S. C. localities 332, 345 & 360) east of Connors Pass are almost certainly from the Coralline Member and not from the Arcturus as this is the only prominent limestone in the collection area and no Lithostrotion-like corals were seen in the Arcturus to the south. Easton lists Thysanophyllum princeps, *Lithostrotionella dilatata*, *Lonsdaleia illipahensis*, and *Diphyphyllum connorsensis* from these collections.

Syringopora, designated *Syringopora mccutcheonae* by Wilson and Langenheim (1962, p. 515-6), is common in the Coralline Member, in places in growth position on top of a *Lithostrotion*-like coral. Wilson and Langenheim (1962, p. 503-4 & 515) also list *Stereostylus* sp., *Diphyphyllum connorsensis* Easton and probably *Cladochonus shawi* from the coralline limestone at Ward Mountain. Moreover they list (p. 500) several fusulinids: *Triticites* aff. *T. cellamagnus*, *Schwagerina elkoensis*, *S.* aff. *S. verveilli*, *Pseudoschwagerina uddeni* and *Parafusulina* sp.

Omphalotrochus occurs sporadically in the Coralline Member, but is most common at the top, along Ward Mountain, in association with *Pseudoschwagerina*. Fusulinids are rare in the coralline limestone, except at the top.

The Lower Member contains abundant fusulinids, and scattered horn corals, brachiopods and bryozoans. Corals collected from it are *Caninia hanseni* and *Diphyphyllum connorsensis* (Playford 1961).

The Upper Member contains variable amounts of fusulinids, scattered brachiopods and bryozoans and, along the north end of Radar Ridge, fasciculate corals near the top.

M. Gordon, Jr. and E. L. Yochelson (written communication) remark

> "The Riepe Spring Limestone has a fairly distinctive (brachiopod) fauna including large semireticulate productid brachiopods and a narrow *Neospirifer* that may be referable to *N. texanus* (Meek)."

Fossil determinations presented in this paper on the sections and tables, for this and other formations, are from several sources within the U.S. Geological Survey, unless otherwise noted. Ellis L. Yochelson and Mackenzie Gordon, Jr. identified the mollusks and brachiopods, except for a few brachiopods from Section H identified by R. E. Grant. Fusulinid identifications were made by Raymond D. Douglass. Fossil names listed on Sections G and I and many on F and H are field identifications of the author as are the listings of general types of fossils on the other sections.

Fossil distribution in the members of the Riepe Spring is shown on table 1.

AGE

The Riepe Spring Limestone is assigned to latest Pennsylvanian and Early Permian based on studies of the brachiopod and gastropod fauna by E. L. Yochelson and M. Gordon Jr. (written communication). R. C. Douglass (in Playford 1961) concurs with the above assignment from fusulinid identifications; placing most of the formation in the Wolfcamp, but with the basal fusulinid coquina latest Pennsylvanian or earliest Permian. More recently Schwagerina sp. have been identified from the basal coquina on Radar Ridge and this discovery apparently requires that the entire formation be assigned to the Wolfcamp. However, the base of the formation may be slightly older to the south if the Upper Pennsylvanian rocks at the south end of the Egan Range lie above the regional unconformity (see p. 33 and p. 36).

The Wolfcamp age assignment is in aggrement with Steele (1960, p. 102), Wilson and Langenheim (1962, p. 498) and Easton (1961).

Also Henbest (in Hose and Repenning 1959, p. 2174) considered the Riepe Spring equivalent in the Confusion Range "to represent but a limited part of the Wolfcamp-Hueco time interval."

CORRELATION

The Coralline Member of the Riepe Spring pinches out to the west. Apparently it tongues out also east of the Needle Range as the member has not been recognized in the Star Range. The member thins both to the north and south from the center of the region under study and may therefore have no lithologic correlatives far to the north or south. Steele (1959b, p. 62-3, 81 & 94), however, mentions massive coralline limestone in the Wolfcamp part of his Ferguson Springs Formation at the type locality in southern Elko County, He describes Syringopora and Lithostrotion whitneyi as common in the upper 250 feet, with individual Lithostrotion heads ranging from six inches to eight feet in diameter. This could be a northern continuation of the Coralline Member. If it is, the member thickens again to the north.

In northern Lincoln County there are a few small outcrops of Upper Pennsylvanian and basal Permian rocks. At the south end of the Egan Range, 517 feet of Upper Pennsylvanian yellow and light brown weathering fine grained calcareous sandstone with interbeds of limestone, overlying the Ely, were dated as probably Virgil, based on Triticites related to T. cullomensis and T. pygmaeus; an unconformity at the base may be necessary to explain the apparent lack of rocks of Missouri age (Kellogg 1960, p. 193). If these rocks are above the regional unconformity then they may represent rocks which have tongued in at the base of the Lower Member of the Riepe Spring. Similar rocks are reported from the Golden Gate Range (Tschanz and Pampeyan 1961).

East of the Schell Creek Range, in northern Lincoln County, gray limestones crop out that cannot be distinguished from limestones of Middle Pennsylvanian age similar to the situation in the Needle Range (Tschanz 1960, p. 204). These may correlate with the Lower Member. Nothing resembling the coralline limestone has been described from Lincoln County and apparently the Riepe Spring as a separate formation does not exist there.

West of the Butte Mountains the Riepe Spring is equivalent to the lower part of the Carbon Ridge Formation, whereas to the northwest of the Butte Mountains, in the Carlin area, it is apparently equivalent to the upper part of the Strathern Formation.

PALEOECOLOGY AND GEOLOGIC HISTORY

Sediments in the Riepe Spring Limestone represent different environments. The Lower Member, in the thicker parts, probably represents a normal marine environment with a relatively quiet, slightly muddy bottom receiving a slight influx of silt. The presence of dark gray shaly limestone may indicate slight stagnation at times. The basal fusulinid coquina was probably deposited in a clear shallow sea with uniform conditions widespread. These conditions returned later as indicated by fusulinid-bearing limestones at the top of the member.

The coralline limestone was deposited as a bioherm or as a reef in a warm shallow sea. The depositional environment of the Upper Member was similar to that of the Lower Member or perhaps a little shallower, as there are more fusulinids and a less normal marine fauna.

The region under study seems to have been near the crest of a positive area. Marginal to the region Upper Pennsylvanian rocks, probably overlapping and converging towards it, were deposited with little or no hiatus (Dott 1955, p. 2289-90). With the continued deepening and transgression of Late Pennsylvanian seas the region by earliest Permian times became a shoal, separating the seas to the north and south, and perhaps serving as a base for reef growth. The effects of what subaerial erosion may have taken place were smoothed by the transgressing seas so that the basal chert breccia was reworked and rapidly redeposited.

The section of the Riepe Spring from the central Butte Mountains south through the Egan Range (plate XIII) resembles diagrammatic sections through the Capitan Reef complex of West Texas. The Upper Member of the Riepe Spring pinches out southward as the Lower Member tongues in. Possibly parts of the three members were deposited contemporaneously, with the coralline limestone being a south-facing east-west trending reef, the Lower Member being deposited south of the reef edge in deeper water while the Upper Member was being deposited in the shallower sea north of the southward-growing reef. It should be pointed out, however, that the top of the Upper Member seems to interfinger with the base of the Riepetown and that probably much of the wedge-shaped nature of the Lower Member results from onlap. The thick coralline limestone described in southern Elko County may be part of a corresponding north-facing reef.

REIPETOWN SANDSTONE

The Reipetown Sandstone was named by Steele (1960, p. 103) after a small settlement northwest of the type section at Rib Hill, NW 1/4 sec. 21, T. 16 N., R. 62 E., west of Ely. The sequence consists of buff to red weathering siltstone with some carbonate and sandstone. These sediments conformably overly the Riepe Spring Limestone and underly the Arcturus Formation. Steele followed the misspelling of the name as presented on the Army Map Service map NJ 11-3; this error has been corrected in the present study.

The Reipetown Sandstone long has been recognized in the region and has been mapped under several names. It extends westward to the Butte Mountains and is present in both the Egan and Schell Creek ranges, and continues eastward into Utah, where it is present in both the Confusion and Needle ranges.

LITHOLOGY

Egan Range

The Reipetown is found throughout the central part of the Egan Rànge from the north end of Radar Ridge to the south end of Ward Mountain. Small scattered outcrops also occur east of Lund and northwest and north of Ely almost to the north end of the range. The formation, which is best exposed on Rib Hill and near North Ward Peak (Section D), generally is covered, forming a slope above or below the Riepe Spring bluff, depending on whether the unit is overturned or not.

The predominant lithology of the formation consists of buff to red weathering very coarse-grained calcareous siltstone that grades into very fine-grained sandstone in a few places. Most of the siltstones probably are massive, but weather to thin slabs. The formation contains a much greater percentage of siltstone than the overlying Arcturus, but the Arcturus contains similar siltstones so that in fault blocks the Reipetown in places may be very hard to distinguish from the Arcturus.

The basal part of the Reipetown Formation is characterized by the brick red and buff weathering siltstone, a small brachiopod fauna in which Crurithyris, Lissochonetes and "Chonetes" are prominent, and a zone with a peculiar type of swirled bedding generally known as "Taonurus" markings. Interbedded within the lower part are a very few intervals of cherty limestone, similar to that in the underlying Upper Member of the Riepe Spring, which are best developed in the northwest part of the Giroux Wash quadrangle. About 300 feet above the base in the vicinity of Ward Mountain, a distinctive crinoidal limestone unit, 50 to 60 feet thick, crops out with a very abundant and varied brachiopod fauna at the base and a distinctive fauna above (see table 2). The limestone is essentially composed of small to very large crinoid columnals which generally are isolated, but in places form stem segments up to two feet long. This unit lenses out into several one and two foot beds within one mile northwest of Section D, at North Ward Peak (plate XIII). In the northwestern part of the Giroux Wash quadrangle some coarse crinoidal limestones are present at about the same horizon (A. L. Brokaw, oral communication). Some appear also near the south edge of the quadrangle (Lloyd 1959, p. 33), but these may be lenticular beds and not connected with those at Ward Mountain.

The middle third of the formation which is poorly exposed in most places, consists mainly of buff weathering calcareous siltstone with a few calcareous sandstones and minor limestone beds. The upper third of the Reipetown, in addition to the dominant calcareous siltstone, contains several horizons of dolomitic siltstone, a number of beds of light gray weathering fine-grained limy dolomite, and a few limestone and silty limestone beds. The dolomitic portions seem to decrease northward in the range.

In the southwest corner of the Reipetown quadrangle a 10 foot interval of limestone lies 121 feet below the top of the formation in the center of NE 1/4 SW 1/4 sec. 15, T. 16 N., R. 61 E. The limestone is light gray brown, weathers light gray, appears fine-grained, forms one foot beds and contains minor light tan weathering chert nodules. Fasciculate corals are present, at least in the lower three feet and at the top, in addition to abundant small crinoid columnals, echinoid spines, a few Omphalotrochus and, at the top, common Pseudoschwagerina?. This unit can easily be confused with limestones in the overlying Arcturus Formation.

The top of the formation may easily and consistently be drawn at the base of the thick basal limestone unit of the Arcturus. On Radar Ridge a three foot bed of laminated siltstone occurs six feet below the contact. The silt laminae, locally cross-bedded, weather differentially to impart a distinctive appearance to the bed. The lime content of this bed appears to increase slightly southward. South of U. S. highway 6 the contact generally is covered and this bed is not seen.

At Ward Mountain, Section D, carbonates form 25 per cent of the formation with most of the limestones in the lower 525 feet and the dolomite limited to the top 365 feet. Steele (1960, p. 103) lists six to eight per cent of carbonate at Rib Hill. This is probably mainly limy dolomite.

The outcrop band along Radar Ridge suggests a thickness of 900 to 1,000 feet for the Reipetown, but there probably is a small strike fault through the formation which may have altered the outcrop thickness slightly. At Rib Hill a diversity of thicknesses are given: 1,172 feet (Wilson and Langenheim 1962, p. 500), 1,100 feet (Blanchard in Bauer et al 1960, p. 226), 1,008 feet (Steele 1960, p. 103), 900 feet (Steele 1959b, p. 107) and 880 feet (Brill 1963, p. 320). It is probably over 1,000 feet thick. At North Ward Peak (Section D) the formation is 1,200 feet thick. Wilson and Langenheim (1962, p. 500) list 1,309 feet for a section on Ward Mountain and 940 feet for what is probably a faulted section to the southeast. Barr (1957, p. 20) lists the formation as only 503 feet thick at the central part of Ward Mountain as he assigned the upper, covered, 700 feet to the Arcturus. A little farther south Wilson (1960, p. 24) gave a thickness of 579 feet to the formation due to measuring a faulted section and nearby Playford (1961, p. 180-2) recorded a thickness of only 470 feet because he misinterpreted the upper contact of the formation and hence assigned the siltstones of the upper part of the Reipetown to the Arcturus. Inspection of

Playford's measured section, number 13, reveals the Reipetown is apparently 1,262 feet thick at the south end of Ward Mountain, with the top of the formation beneath the cliff-forming limestone of his unit 20. West of Ward Mountain, in the low hills west of U. S. highway 6, Lloyd (1959, p. 32) gave 875 feet for an incomplete section of his equivalent Butte Formation.

In summary, the Reipetown is over 1,200 feet thick at the south end of Ward Mountain, latitude 39°, and thins northward to about 1,000 feet along Radar Ridge.

At the northern end of the Egan Range Fritz (1957, plate I) mapped a few patches of Permian rocks, estimated at 1,000 feet plus, which he referred to as the Arcturus Limestone and considered to include the Reipetown as well as the Arcturus. From his descriptions it appears to be all Reipetown and the lower 200 to 300 feet which he ascribes to the Reipetown seems to be the lower brick red weathering unit. Later Fritz (1960) measured 1,975 feet of Arcturus here, but recognized no Reipetown in the section measured. His descriptions, however, again fit the Reipetown much better than the Arcturus, even though the thickness seems to be excessive.

About 18 miles north of Ely, Woodward (1962, p. 99-100) mapped a small patch of Permian rocks on the west side of the northern Egan Range which he called the Arcturus Formation with a measured thickness of 1,700 feet thick. Of this, judging from his descriptions, at least the lower 675 feet represent the Reipetown.

Central Butte Mountains

On the east side of the central Butte Mountains the Reipetown contains much more carbonate and has thinned. A unit about 80 feet thick of buff to orange buff weathering calcareous siltstone, with some "Taonurus" markings on float, overlies the Upper Member of the Riepe Spring. About 100 feet of light gray brown to yellow gray weathering cherty thin to medium-bedded limestone and considerable crinoidal limestone overlies this unit. Approximately 200 feet of alternating limestone and buff to light gray weathering siltstone lies next above. The top of the formation is composed of 275 feet of generally calcareous siltstone, but with some dolomitic zones in the upper 100 feet. The top four to nine feet in places forms a bluff beneath a capping of the basal Arcturus. The total thickness is 660 feet at Section F.

Southern Butte Mountains

In the southern Butte Mountains the Reipetown Sandstone forms a north-south belt that underlies the bottom and east side of a small valley north of U. S. highway 50 in the western halves of secs. 6 and 7, T. 17 N., R. 59 E. The base of the formation which is not exposed, may not even be present as the Reipetown apparently lies in fault contact with the Riepe Spring Limestone inasmuch as the Upper Member of the Riepe Spring, which crops out to the north and south, is missing here. Buff and orange buff weathering calcareous siltstone constitutes the lowest exposed lithology above which are scattered outcrops, in variable attitudes, of crinoidal and other bioclastic limestone, platy silty limestone and calcareous siltstone. The upper part of the formation, which is relatively well exposed, consists of a thick unit of light brown to light gray weathering thin-bedded cherty limestone and brownish weathering siltstone with noncherty bioclastic limestone at the top, overlain by a thinner unit of buff weathering siltstone and light gray brown limestone and capped by limestones typical of the Arcturus. The Reipetown contains considerable limestone and the upper contact here is less distinct than at other places.

The section here is not suitable for measurement, though the estimated thickness seems greater than in the central Butte Mountains, but less thick than in the Egan Range.

Dry Mountain and Carbon Ridge

The Reipetown Sandstone as a distinct mappable formation is not present at either Dry Mountain or Carbon Ridge. The equivalent stratigraphic interval consists mainly of limestone which forms the upper part of the Carbon Ridge Formation.

Pipkin (1956) describes some Parafusulina-bearing cliff-forming limestone which alternates with buff to red weathering fine-grained slope-forming sandstone that unconformably overlies the Ely in the west flank of the northern White Pine Range. He referred to it as Arcturus, but it may possibly be a transitional sequence between the Reipetown and Carbon Ridge formations.

Schell Creek Range

Southeast of Connors Pass parts of the Reipetown are well exposed in four different fault blocks in the main canyon next south of U. S. highway 6-50-93, in sec. 1, T. 13 N., R. 65 E. and secs. 5, 6 and 8, T. 13 N., R. 66 E., where the base, upper half and probably most of the lower half are well exposed.

The basal 35 feet, which rests on the Coralline Member of the Riepe Spring, consists of buff weathering siltstone, medium gray to yellow gray weathering limestone and silty limestone with "Taonurus" markings in the upper half. The overlying unit, a few hundred feet thick, consists of very coarse-grained calcareous siltstone, generally massive, and in places breaking down to plates on weathering. The rock is varicolored, weathers brick red, white, salmon, lavender or buff. Almost all the brighter colors result from alteration. An unaltered sequence probably would be mainly buff, pale buff and light tan. This unit seems to be the same as the thick buff weathering siltstone sequence exposed in the roadcuts on the old and new alignments of U. S. highway 6-50-93 in the SE 1/4 sec. 25, T. 14 N., R. 65 E.

The upper half of the Reipetown consists of light gray to buff weathering calcareous siltstone which alternates with the light gray fine-grained limy dolomite that forms nearly 20 per cent of the interval. At the top of the formation lies a five foot interval of sandy limy dolomite, with sand grains that delineate laminations, which is overlain by ten feet of very light gray weathering siltstone capped by a two foot bed of slightly cherty limestone that forms the base of the Arcturus.

In comparison with the Reipetown at Ward Mountain, the siltstones here are a more uniformly pale buff and buff weathering without the prominent basal reddish zone. Limestone is present only at the base, whereas much more limy dolomite occurs in the upper half.

Although a continuously exposed section was not seen, it is estimated that the thickness is not much different from that at Ward Mountain.

Confusion Range

In the Confusion Range the lower part of the Arcturus as mapped by Hose and Repenning (1959, 1963) constitutes the equivalent of the Reipetown Sandstone. The Reipetown conformably overlies the Riepe Spring or its equivalent and underlies the Arcturus as the name is used in the Ely region. The Reipetown consists of intervals, in most places 20 to 60 feet thick, of yellowish gray, pale buff and buff weathering siltstone, calcareous siltstone and fine-grained sandstone which alternates with light gray weathering fine-grained limy dolomite and, less than five per cent, limestone in five to 25 foot intervals. The carbonates form about 22 per cent of the formation.

One mile south of Indian Pass the Reipetown rests on the coralline limestone of the Reipe Spring. The top of the Reipetown here is placed at the base of three and one half feet of light olive gray to light grayish brown dense limestone which forms a minor ledge that is underlain by a 130 foot calcareous silstone and sandstone interval. The top of the 130 foot layer is 306 feet below mappable Bed A (Hose and Repenning 1959, p. 2177; 1963). The limestone unit above the contact is the lowest light grayish brown limestone typical of those in the Arcturus to the west, and the contact separates the carbonates into dominantly limestone above and dolomite below. Hose (oral communication) considered

The Reipetown is 1,859 feet thick one mile south of Indian Pass. The thickness derived from an unpublished detailed section by Hose and Repenning.

Needle Range

The Reipetown lies in the center of a syncline at the north end of the Needle Range, south of Utah highway 21, where it conformably overlies the equivalent of the coralline limestone of the Riepe Spring, but has no exposed upper contact.

The stratigraphic sequence is very similar to that in the Confusion Range in that it consists of alternating units of siltstone-sandstone and dolomite. The clastic units, one to 50 feet thick, consist of pale buff, pale brown and light gray weathering coarse-grained calcareous siltstone, some fine-grained sandstone and some sandy siltstone, which contains scattered spherical frosted sand grains. A few beds show cross-bedding, in sets about one and one half feet thick, but most beds are massive. The carbonate units, which are approximately one to 20 feet thick, consist of one foot beds of dark to medium with some light gray fine-grained limy dolomite and minor dolomitic limestone, that weathers light to very light gray. A few dolomite beds contain sand stringers and are similar to the bed at the top of the formation near Connors Pass. More dolomite is present towards the base of the formation than above, with the basal 20 to 30 feet composed of moderately to slightly cherty dolomite.

The dolomite to siltstone ratio based on the exposures is roughly 1:2, but most, if not all, of the covered areas are probably underlain by siltstone, so if this is true, the dolomite content is about 25 per cent.

Gould (1959, p. 16) measured slightly over 1,000 feet of Reipetown, over a poorly described section, which was referred to as Arcturus, following the usage of Hose and Repenning. Steele (1959b, p. 111) reports over 1,765 feet of Rib Hill (Reipetown) in the Needle Range and a little to the north in the Burbank Hills, 1,430 feet.

SUMMARY OF FACIES CHANGES

The Reipetown thins not only westward from Utah, but also north-northwestward through the Egan Range and into the central Butte Mountains. This fact probably indicates a general west-northwest thinning of the formation. The decrease in thickness results from thinning and pinching out of the siltstone part.

The limestone content increases westward. East of the Egan Range only minor limestone is seen in the Reipetown. West of the Egan Range, however, cherty limestone and crinoidal limestone tongue in and thicken, with limestone units wedging in first at the base and then higher as the amount of siltstone decreases. West of the Butte Mountains only minor siltstone remains and the dominantly limestone sequence forms the upper part of the Carbon Ridge Formation.

The dolomite, on the other hand, shows the reverse relationship. Southeastward and eastward limy dolomite beds wedge into the formation. Very minor dolomitic horizons are found at the top of the Reipetown in the central Butte Mountains. Dolomite units increase in size and number south and east through the Egan Range becoming more prominent and occurring lower in the formation until, in western Utah, they occur throughout and constitute about 25 per cent of the formation.

The carbonate types overlap within the formation in the Egan Range which thus is characterized by having significant amounts of both limestone and dolomite.

The grain size of the noncarbonates increases slightly to the east so that fine-grained sandstones commonly occur in the Reipetown in western Utah. Also the colors of the siltstone become more somber to the east. This slight color change may be related to the change in grain size, with the iron based pigments being more concentrated in the finer sediments.

PALEONTOLOGY

The important fossil occurrences in the Reipetown at Ward Mountain are: the ubiquitous small brachiopod fauna near the base, consisting predominantly of Crurithyris, Lissochonetes and "Chonetes", probably a new genus; the few fusulinid bearing silty limestones in the lower third; the prolific brachiopod fauna at the base of the crinoidal limestone unit; and the fauna of the rest of the limestone unit. These fossils are shown in their respective stratigraphic positions on the fossil distribution chart for the Reipetown (table 2). Fossils are rare in the upper two thirds of the formation.

The large productid, Reticulatia huecoensis (R. E. King), the trilobite, identified as Ditomopyge sp. by R. J. Ross Jr. of the U.S. Geological Survey, and the sponge root tuft? are commonly found in the crinoidal limestone, but at no other horizon in the Reipetown. The sponge root tuft? is a straw-like mat consisting of tubular needles, about .5 mm in diameter, up to at least two inches long, often in subparallel groupings.

The fasciculate coral Durhamina cordillerensis (Easton) was listed by Playford (1961) from 490 feet above the base and fasciculate corals occur about 400 feet above the base at Ward Mountain, Section D.

Fusulinids are common to abundant at a few horizons in the lower part of the formation. Wilson and Langenheim (1962, p. 501) noted Pseudoschwagerina uddeni, P. sp. and Triticites aff. T. cellamagnus in the basal 340 feet; identified by Barr (1957) and confirmed by M. L. Thompson. At the north end of the White River Valley Triticites, Pseudofusulina, Schwagerina younguisti and Parafusulina have been identified by Leroy Apodaca of Shell Oil Company (in Lloyd 1955, p. 34). Steele (1959b, p. 107) identified Pseudoschwagerina texana and Schwagerina linearis from the lower 250 feet at Rib Hill.

"Taonurus" markings are found throughout the Egan Range wherever the basal part is exposed, in a zone 50 to 100 feet above the base. The markings are well exposed in a stream gully at the head of Sawmill Canyon, just south of the center of NW 1/4 sec. 32, T. 15 N., R. 63 E. These swirling markings have a third dimension, extending into the rock, and the center of the swirl is slightly elevated above the outside edges. On well exposed bedding surfaces the markings cover the surface and were not seen occurring singularly. It is rare to find such markings in place because the siltstone breaks down into slabs on weathering. "Taonurus" markings are not just a surface phenomena and cannot be worm trails or grass markings. They could possibly be marks of a burrowing animal, as mentioned by Henbest (1960), but this would require that at least parts of the bottom be entirely dug up on rather evenly spaced centers, apparently by a fairly large animal. An interpretation as some type of turbulent bedding is preferred. Perhaps a multiple origin is possible.

What may be burrows are present in the lower part of a 35 foot cherty limestone unit near the base of the Reipetown, which is well exposed in the northwest part of the Giroux Wash quadrangle, SE 1/4 SE 1/4 sec. 22, T. 16 N., R. 61 E. Peculiar pipe-like cherts are present that in most places are nearly perpendicular to the bedding, but may deviate up to 45°. These show up as slightly irregular circles and ovals on bedding surfaces. They range from two and one half to 19 inches long and one third to one and one half inches in diameter, the majority being about one inch in diameter. About half of them branch upwards once, with the slightly smaller branch diverging about 30° from the trunk which remains nearly perpendicular to the bedding. These features probably represent silicification between the filling and outer walls of burrows.

Fossils are rare in the Reipetown to the east of the Egan Range and to the west, in the Butte Mountains, fusulinids constitute the main fossils found, with other types, excepting crinoid columnals, being much less common.

AGE

With one exception, fusulinids and most other fossils are limited to the lower third of the formation. Fossils from this part are considered of Wolfcamp age (Lloyd 1959, p. 34; Steele 1959b, p. 107, 1960, p. 103; Langenheim et al 1960, p. 154; Douglass in Playford 1961; Wilson and Langenheim 1962, p. 501; Brill 1963, p. 320). The upper part of the formation also can be considered of

Wolfcamp age because the lower part of the overlying Arcturus is apparently Wolfcamp, also the fusulinids, in the single occurrence near the top, are tentatively identified as Pseudoschwagerina?.

CORRELATION

The Reipetown Formation shows an increase in dolomite content to the east as well as a slight increase southward. If this tendency to increase in dolomite content continues the formation should resemble closely the basal Wolfcamp Pakoon Dolomite as described in the northwestern corner of Arizona and adjacent Utah and Nevada (McNair 1951, p. 524-5; Brill in Steele 1959b, p. 99-100; Brill 1963, p. 316). In the Star Range, near Milford, Utah, the relatively thin sequence of light gray weathering dolomite and minor sandstone, which lies between the Talisman Quartzite and the cherty limestone of Pennsylvanian age, might be considered Pakoon and the overlying Talisman, which is composed of 470 feet of light gray, reddish brown weathering quartzite with some gypsum at the base and middle, is considered to be the Quentoweap Sandstone equivalent (Welsh 1959; Brill in Steele 1959b, p. 116; Brill 1963, p. 323; D. M. Lemmon written communication), although these two units have yet to be accurately by fossils.

The Reipetown, at least the lower part, is correlated with the Pakoon on the basis of lithologic similarities. Brill (1963, p. 316) notes more quartz sandstone interbedded with the dolomite of the Pakoon west of the type area in the Virgin Mountains and north near Minersville, east of the Star Range, than in the type locality, which tends to support a postulated change to a dominantly siltstone-sandstone facies like the Reipetown.

The upper part of the Reipetown may possibly correlate with the Talisman. There is some suggestion of this in that, whereas interbedded dolomite beds occur up to the top of the formation in the Schell Creek Range, 130 feet of siltstone-sandstone are present at the top of the Reipetown in the Confusion Range. If a few dolomite beds were to pinch out in the upper part of the formation to the east and the unit was to become more firmly cemented it would resemble closely the Talisman. The dolomite in the upper part of the Reipetown could pinch out to both west and east if the dolomite is tonguing in from the south and if it extends farthest north along the west edge of Utah. This arrangement would create an illusion of a pinch out to the east and west in an east-west section.

The Reipetown interval appears to thin eastward, to a little more than a third of its thickness, from westernmost Utah to the Star Range.

Near the Utah-Nevada line, almost all of the Arcturus described by Nelson (1959, p. 76-8) at the north end of the Snake Range is apparently Reipetown, and farther northeast in the Gold Hill district the central part of the Oquirrh Formation is considered equivalent, on the basis of lithologic similarity and relative stratigraphic position, to the combined Reipetown and Arcturus by Hose and Repenning (1959, p. 2178).

Equivalents of the Reipetown are present in many places north and northeast of Ely. In the northern Cherry Creek Range Douglass' (1952) description of the lithology of the upper 1,450 feet of the "zone of Pseudofusulina" is similar to that of the Reipetown as is the upper part of the Ferguson Springs described nearby (Steele

1959b, p. 122). In the area north of Curry, part of the Pre-Kaibab(?) as mapped by Snelson (1955), which is dated Wolfcamp to Leonard and which contains a 10 foot bed of chert conglomerate low in the sequence, must include Reipetown equivalents. The description of an estimated 2,000 feet of Permian rocks, called the Ferguson Mountain Formation, in the Antelope Range is very similar to the Reipetown (Avent 1962, p. 29).

Near Carlin, the undifferentiated Permian as described by Dott (1955, p. 2256 & 2260-1) is very similar to the Reipetown, with which it was correlated. This sequence was later named the Buckskin Mountain Formation by Fails (1960, p. 1693 & 1696), who measured about 1,200 feet of it and described a small brachiopod fauna from the base like that in the Reipetown. Fails thought the formation was similar to the Arcturus on Murry Summit in the Egan Range.

The Reipetown changes westward to become the upper part of the Carbon Ridge Formation.

NONCARBONATE SOURCE

The siltstones in the Reipetown pinch out to the west and also thin eastward from the Needle to the Star Range. The very slight increase in the proportion of dolomite from the Confusion to the Needle Range may reflect a minor decrease in siltstone southward. The grain size of the noncarbonates increases slightly to the east. These facts and inferences indicate that the source lay to the north or northeast, perhaps the same as the source which furnished the clastics to the Oquirrh basin. Some support for this idea comes from the generally southwest dips of the cross-bedding in the

Queantoweap Sandstone, which may be a partial correlative, in extreme northwest Arizona and southwest Utah (Brill 1963, p. 320).

A few dolomite and siltstone beds contain well rounded frosted "floating" quartz grains that are thought to have been wind blown, if not to the site of deposition, at least close enough so that currents could transport them the remaining distance. Such beds were most notable in western Utah, hence the sand was probably blown from the east, possibly from eolian sands of the Colorado Plateau.

PALEOECOLOGY AND GEOLOGIC HISTORY

After the Riepe Spring was laid down conditions changed. The new conditions on the sea floor initiated the deposition of the Reipetown by an influx of coarse quartz silt and fine sand from the northeast which was carried by moderate to strong and occasionally turbulent currents. A normal marine environment developed that favored the growth of a small brachiopod fauna. During a cessation in the silt influx, in the vicinity of Ward Mountain, a luxuriant growth of crinoids with a distinct normal marine fauna flourished in relatively quiet clear water, but eventually were overwhelmed by silt. During later pauses in the silt influx carbonate, which is now limy dolomite, was deposited in a relatively sterile environment, judging from the lack of fossils. This type of carbonate deposition migrated westward with time. Occasionally a sandstorm would blow out of the east contributing very minor sand to the eastern part of the region.

To the west, however, where much less silt was carried in, conditions were little changed from the earlier Permian.

CARBON RIDGE FORMATION

The Carbon Ridge Formation was named by Nolan et al (1956, p. 64) after a ridge southeast of Eureka, Nevada where the type section is located. At the type area the formation rests unconformably on the Mississippian Diamond Peak Formation and consists of a 1,750 foot sequence of generally thin-bedded limestones and silty limestones with some interbedded calcareous siltstones which is overlain unconformably by the conglomerates of the Cretaceous Newark Canyon Formation. To the north in the southern Diamond Mountains the Carbon Ridge Formation rests unconformably on the Ely Limestone and, as defined by Nolan et al (1956, p. 64) includes an upper conglomeratic sequence. Herein the Carbon Ridge Formation is restricted to the nonconglomeratic calcareous interval below the conglomeratic sequence. The upper conglomeratic sequence in the Diamond Mountains seems to be stratigraphically higher than all but the top 20 feet at the type area and apparently represents an eastern phase of the conglomeratic Garden Valley Formation, which in turn is transitional to the Arcturus Formation.

The Carbon Ridge Formation crops out in several patches south east of Eureka, discontinuously in the Diamond Mountains, in the southern Sulphur Spring Range, at Dry Mountain and probably in the northern Pancake Range.

LITHOLOGY

Dry Mountain

At Dry Mountain, Section H (plate X), a limestone dominated sequence overlying the Ely Limestone and underlying the Arcturus Formation is assigned to the Carbon Ridge Formation.

A 44 foot unit of slightly cherty limestone lies at the base of the section, which though similar to the coralline limestone of the Riepe Spring contains no visible corals. This 44 foot unit rests on cherty limestone typical of the Ely, but no unconformity could be located so that the exact stratigraphic position of this unit is in doubt.

The overlying rocks of the Carbon Ridge Formation can be divided roughly into three units: a lower and upper unit of thin-bedded cherty limestone, silty limestone and minor calcareous siltstone between which lies a middle unit of more resistant limestones. The lower 385 feet, forming the lower unit, is similar to the Upper Member of the Riepe Spring in that it consists of yellow gray to light olive gray weathering fine-grained limestone and yellow gray to olive buff silty limestone which weathers pale buff to buff in beds two to 18 inches thick, with thin interbeds of buff to orange buff weathering calcareous siltstone in most places. Generally the limestones contain chert lenses, commonly at the top and bottom of beds, some nodules and partially silicified bands and lenses which weather pale to orange buff and resemble siltstone. A few thicker coarse-grained bioclastic limestones also are present. A thin chert sandstone lies at the top.

The middle unit, which is about 100 feet thick, contains a number of more resistant thicker-bedded light gray brown weathering bioclastic limestones, some of which contain scattered chert granules.

The upper unit resembles the lower, but the alternation of the lithologic types appears more uniform and also it contains thicker beds near the top. A distinctive zone of abundant silicified ramose bryozoans and other fossils lies about three quarters of the way up in the unit. The top of the formation is placed at the top of the cherty limestone underlying a coarse-grained bioclastic limestone that contains 5 to 10 per cent chert grains. The upper unit is cut by two faults which results in a pieced section about 400 feet thick. Based on observations of this same interval at Carbon Ridge the thickness seems approximately correct.

A total of 880 feet was measured, but allowing for probable minor omission by faulting, the formation is considered to be 900 feet thick.

Carbon Ridge

The formation at Carbon Ridge is very similar to that at Dry Mountain, except in the thicker lower part. A unit of chert pebble to cobble conglomerate with chert clasts up to five inches long lies at the base. The chert clasts are subrounded, brown, green, with minor black, and the unit resembles the underlying Diamond Peak Formation. A unit of sandy limestone, some with abundant fusulinids, lies next above which in turn is overlain by a hundred feet or so of medium dark gray limestone that weathers to thin light olive gray plates. The three units described at Dry Mountain are next above. The lower of these is poorly exposed, but does contain abundant fusulinids in places. The middle unit with the resistant bioclastic limestone, which also contains some fusulinids, forms the spur extending southwest from the southern end of Carbon Ridge. The upper unit contains a zone of silicified ramose bryozoans and brachiopods very similar to that at Dry Mountain. The upper part of this unit grades upward to thicker bioclastic limestone which lies just beneath the unconformity at the base of the Newark Canyon Formation. The topmost 10 to 20 feet of the limestone, which contains scattered chert granules, is considered correlative with the base of the Arcturus Formation at Dry Mountain.

Nolan et al (1956, p. 65) measured 1,750 feet at Carbon Ridge, whereas Steele (1959b, p. 91) measured 1,650. These measurements reveal a considerable thickening of the formation southwestward from Dry Mountain. Although some thickening may occur in the upper part of the Carbon Ridge, most of the thickening results from an increase in thickness of the lower thin-bedded cherty unit as well as by the addition of beds at the base. Nolan et al (1956, fig. 1) shows the formation, as here restricted, to have thinned northward to about 1,150 feet in the southern Diamond Mountains.

Steele subdivided the Carbon Ridge into four formations in two different ways (1959b, p. 92; 1960, p. 93). This is considered invalid as the subdivisions are extremely poor units to map. The more recent set of names comes from formations to the east which are different lithologically. The top formation utilized, the Pequop Formation, is regarded as having been miscorrelated.

Newark Canyon Formation

Some workers consider the overlying Newark Canyon Formation, both here and in the Diamond Mountains, as of Permian age. The age determination is based on sparse fusulinids found in the lower part as well as lithologic similarities (Dott 1955, p. 2272-3; Divens 1957; Riva 1957; Steele 1959b, p. 91-2 & 172, 1960, p. 93; Larson and Riva 1963, following Steele). Reworked Pennsylvanian and Permian fusulinids, however, are not unusual in the region in the basal Cretaceous-Tertiary chert and limestone conglomerates. Chert conglomerates, which are all fairly similar, occur in the Mississippian, Pennsylvanian, Permian as well as Cretaceous-Tertiary. Moreover the Newark Canyon rests on underlying formations with a pronounced unconformity, which is not found in the Permian section to the east. Also it contains some of the red matrix which characterizes similar, though much thinner, Cretaceous-Tertiary basal conglomerates to the east. The Newark Canyon contains Late Cretaceous fossils near Eureka (Nolan et al 1956, p. 69). In addition, Cretaceous fossils have been found on the east side of the Cortez Range and at the south end of the Pinon Range, which definitely indicates the presence of Cretaceous rocks in the area (Smith and Ketner 1961). Chert conglomerates apparently identical with the Newark Canyon unconformably overlie Paleozoic rocks on the east side of Newark Valley, north of Pogonip Ridge. These are well described by Rich (1956, p. 60), who referred to them as lower clastics of a Tertiary lakebed sequence.

Northern Pancake Range

In the Pancake Range, 13 miles southeast of Carbon Ridge, Rich (1956, p. 56-9) describes a sequence of thin-bedded shaly limestone, sandy limestone, platy calcareous siltstone and argillaceous limestone nearly 1,500 feet thick. These beds are overlain by interbedded chert pebble conglomerate in two to 10 foot beds interbedded with medium to coarse-grained arenaceous and shaly limestone estimated to be 800 feet thick, but with no top exposed. The upper half, which contains _Schwagerina_ and _Parafusulina_ was referred to the Arcturus, whereas the lower half was assigned only tentatively to the Arcturus. The lower 1,500 of sediments seems to be the Carbon Ridge Formation which is overlain by 800 feet or more of Garden Valley-Arcturus transitional sediments.

Diamond Mountains

The Carbon Ridge Formation, present in the central and northern portions of the Diamond Mountains, was mapped as Unit A by Riva (1957) and Larson and Riva (1963). Riva's (1957, p. 13-16) description of Unit A is very similar to the Carbon Ridge with which he equated it. He divides the formation into two members: a Lower Member, 440 feet thick, which probably corresponds to the lower and middle units at Dry Mountain, and an Upper Member, 100 feet plus, corresponding to the upper unit. The whole formation rests unconformably on the lower half of the Ely Limestone and is overlain by Riva's Unit B, which is a sequence of limestone and some chert conglomerate which seems to be equal to the lower part of the Arcturus at Dry Mountain.

Riva measured two sections, 2,500 and 540 feet thick, in the middle part of the Diamond Mountains. The difference in thickness is explained by eastward thinning in which the variation occurs in the Upper Member. The maps and cross-sections of Riva (1957), Larson and Riva (1963) and Divens (1957) indicate that these thickness figures are respectively too large and too small. A cross-section (Larson and Riva 1963, E-E') passing near the location where the thick section was measured portrays the formation as thickening to only 1,700 feet. Cross-sections both to the north and south of the measured sections depict the formation as being more uniform, with thicknesses ranging from 800 to almost 1,400 feet, averaging 1,100 to 1,200 feet with only a very slight thinning to the east. Dott (1955, p. 2271) describes the formation as 800 to 1,000 feet thick in the northern Diamond Mountains, but thicker south of Telegraph Pass, with the variation in thickness probably due to northwestward convergence and onlap over the pre-Wolfcamp erosion surface. Thus the Carbon Ridge seems to be approximately the same thickness in the northern Diamond Mountains as it is at Dry Mountain and it is slightly thicker in the central part of the Diamond Mountains.

Southern Sulphur Spring Range

In the southern Sulphur Spring Range the lowest member of the Garden Valley Formation as defined by Nolan et al (1956, p. 67) is here considered the westward equivalent of the Carbon Ridge Formation.

The Basal Limestone Member of the Garden Valley is composed of thin-bedded commonly cherty limestone, silty limestone and calcareous siltstone that is similar to the lithology of the Carbon Ridge Formation at Dry Mountain and Carbon Ridge. The base of the Garden Valley Formation rests with a pronounced unconformity on chert of the Ordovician Vinini Formation and contains chert cobbles scattered in the lower foot of limestone and scattered granules in the lower few feet near Tyrone Gap. North of Tyrone Gap, 12 miles, DeJoia (1952, p. 28) shows a thin chert conglomerate which tongues in at the base and thickens northward to 52 feet in three quarters of a mile. The Basal Limestone Member is overlain disconformably with some channeling at the contact (Nolan et al 1956, p. 67) by the second member of the Garden Valley, the lowest of the chert conglomerate bearing members.

The Basal Limestone Member is 450 to 500 feet thick (Nolan et al 1956, p. 67; DeJoia 1952).

The Basal Limestone Member is correlated with the Carbon Ridge on the basis of similar lithology, stratigraphic position and age. Lithology like the cherty limestone in the upper part of the member has only been seen, to the east, in the Carbon Ridge and beyond in the equivalent Riepe Spring and Reipetown formations, whereas similar rocks occur in the underlying Ely, to the east, they have not been seen in the overlying Arcturus. The Basal Limestone Member rests unconformably on pre-Permian rocks, as does the Carbon Ridge Formation and underlies a sequence considered the equivalent of the beds above the Carbon Ridge. The age of the Basal Limestone Member is most probably Wolfcamp as is the Carbon Ridge. Both contain similar fusulinids.

Based on the above considerations, the Basal Limestone Member is assigned to the Carbon Ridge Formation and the Garden Valley Formation is restricted to the overlying conglomeratic sequence.

The thinning of the Carbon Ridge in the southern Sulphur Spring Range is thought to result from onlap and only the upper part of the Carbon Ridge Formation at Carbon Ridge is represented here. The interpretation has some faunal support. The erosion at the top is thought to be insignificant.

SUMMARY OF FACIES CHANGES

From the type area at Carbon Ridge the formation thins northeastward, northward and northwestward, primarily by thinning and loss of strata near the base, which is thought to result from onlap and consequent pinching out of beds. The formation does not appear to thin as rapidly northward in the Diamond Mountains as it does eastward and westward from the range. This may indicate that a slight trough had existed here. Eastward of Newark and Long Valleys coralline limestone tongues into the lower part and calcareous siltstones into the upper part of the sequence. The interval is recognized as the Riepe Spring Limestone and Reipetown Sandstone, with the Upper Member of the Riepe Spring being an eastern tongue of the Carbon Ridge facies. Some of the northward thinning of the Carbon Ridge may correspond to the northward thinning of the Lower Member of the Riepe Spring.

PALEONTOLOGY

At Dry Mountain the Carbon Ridge Formation contains only a few scattered fossils, except in an horizon where silicified ramose bryozoans occur along with some brachiopods, gastropods and pelecypods. The only other notable occurrence is a starfish from the lower unit. The probable Carbon Ridge in the Pancake Range is mainly unfossiliferous (Rich 1956, p. 57). At Carbon Ridge a number of horizons contain fusulinids in addition to the zone of moderate-sized ramose bryozoans and brachiopods. Fusulinids also are present in the Diamond Mountains and, to a limited extent, the southern Sulphur Spring Range.

The most comprehensive paleontologic data on the Carbon Ridge Formation is presented in Nolan et al (1956, p. 65-6 & 68). From the Eureka district they list fusulinids, corals, crinoid columnals, echinoid spines, ramose and fenestrate bryozoans, pelecypods, cephalopods, triobites and a variety of brachiopods. Four fusulinid faunal zones, in ascending order, were delineated by L. G. Henbest; the first characterized by Triticites sp., some specimens of which approach the morphology of Schwagerina; the second and third zones characterized by Pseudoschwagerina and Schwagerina, respectively; and the fourth by Parafusulina. The highest zone was found only in the southern Diamond Mountains and may be above the formation as here restricted. Also, in the second zone, Schwagerina sp., Schubertella? sp., and Schwagerina? aff. S. compacta (White) were found and in the third zone, Schubertella and Schwagerina? of the S. compacta (White) group are present in many places. Dott (1955, p. 2272-3) also identified fusulinids from Carbon Ridge. He lists Schwagerina cf. S. providens and Triticites sp. from cherty limestone 65 feet above the Diamond Peak and Pseudofusulina cf. P. huecoensis, P. cf. P. nelsoni (Dunbar and Skinner) and Schwagerina sp. from the overlying 1,000 feet of rock, which was near to the top as Dott considered the formation 1,300 to 1,500 feet thick here.

In the central Diamond Mountains Dott (1955, p. 2271) notes Schwagerina and Riva (1957, p. 15 & plate II; Larson and Riva 1963) identifies Schwagerina younquisti, S. modica, S. aff. S. elkoensis, S. aff. S. providens, and S. aff. S. wellsensis.

In the southern Sulphur Spring Range two faunas were found: one near the base and the other about 100 feet from the top. The lower fauna contains abundant Schwagerina sp., large numbers of Leiorhynchoidea n. sp., some Chonetina sp., "Avonia"? cf. A. subhorrida (Meek), Composita sp. and Hustedia sp. (Nolan et al 1956, p. 68). Also present are small ramose bryozoans and abundant small crinoid columnals. In the upper fauna, L. G. Henbest (in Nolan et al 1956, p. 68) finds Parafusulina sp. intermediate between Schwagerina linearis Dunbar and Skinner and Parafusulina lineata Dunbar and Skinner, the dominating genus. He also finds "Triticites" sp. with Pseudoschwagerina sp. restricted to local pockets. The former two were also identified from this horizon by DeJoia (1952, p. 32), Dott (1955, p. 2273) and Knight (1956, p. 791). DeJoia and Dott preferred to call the dominant fusulinid Schwagerina.

AGE

The lower three fusulinid zones and their associated brachiopod faunas in the Eureka district are of probable Wolfcamp age, although some fossils suggestive of Late Pennsylvanian age are present in the lower zone. In the southern Sulphur Spring Range both faunas, on the basis of the fusulinids, probably are of late Wolfcamp age, though some of the fusulinids and brachiopods indicate that rocks of Leonard or even younger Permian age are present (Nolan et al 1956, p. 65-6 & 68). Dott's (1955, p. 2273) findings at Carbon Ridge agree with those of Nolan et al. In the southern Sulphur Spring Range DeJoia (1952) and Dott (1955, p. 2273) listed the formation as of Wolfcamp age and Knight (1956, p. 791) considered the upper fauna latest Wolfcamp. Riva (1957, p. 15; Larson and Riva 1963) assigned the Carbon Ridge in the central Diamond Range to late Wolfcamp.

In summary, the Carbon Ridge is of Wolfcamp age, probably with more older Wolfcamp rocks included at the base in the type area than are present to the north or northwest.

CORRELATION

The Carbon Ridge Formation, as restricted, correlates eastward with the Riepe Spring and Reipetown. To the north it correlates, at least in part, with the Permian part of the Strathern Formation and probably the Buckskin Mountain Formation as well. The Strathern Formation which is 1,200 to 1,500 feet thick contains the Upper Pennsylvanian-Permian boundary in its middle or upper part (Dott 1955, p. 2253-4). Dott (1955, p. 2273) notes

> "the basal (70 feet at Tyrone Gap) ... is strikingly similar to and may be identical with the upper (Wolfcampian) part of the Strathern Formation near Elko".

Moreover Dott considers that the lowest Permian strata (Carbon Ridge) in the Diamond Mountains may correlate with uppermost Strathern. However, if Dott's correlation of the Buckskin Mountain Formation with the Reipetown is correct (see p. 53), then only the lower part of the Carbon Ridge correlates with the upper Strathern and the upper part correlates with the Buckskin Mountain Formation. Fails (1960, p. 1696) thought this probable.

To the west the Carbon Ridge is the time equivalent to a part of the Havallah Formation (Roberts et al 1958, p. 2848; Silberling and Roberts 1962, p. 16-18).

PALEOÈCOLOGY AND GEOLOGIC HISTORY

The Carbon Ridge was deposited under normal marine conditions similar to those of the Lower and Upper members of the Riepe Spring, but with minor silt detritus carried periodically into an area dominated by lime deposition.

Deposition onlapped northward as the sea transgressed. In the vicinity of the Diamond Mountains an embayment, that extended northward, seems to have existed for a while. The slightly deeper water in an embayment could have helped limit the western extent of the Coralline Member of the Riepe Spring.

To the northwest, and probably also the west, sediments overlapped on the east flank on the Antler Orogenic Belt, which was inactive and also probably submerged as it contributed only very minor clastic chert to the sediments.

GARDEN VALLEY FORMATION

The Garden Valley Formation was named by Nolan et al (1956, p. 67) for the valley west of where the formation crops out in the southern end of the Sulphur Spring Range for Permian rocks previously reported on by Merriam and Anderson (1942, p. 1691-2) and DeJoia (1952). Patches of the formation also occur at Lone Mountain, west of Eureka (Nolan and Merriam 1961) and outcrops transitional to the Arcturus Formation are present in the Diamond Mountains and the northern Pancake Range.

LITHOLOGY

Southern Sulphur Spring Range

The formation can best be seen at Tyrone Gap in the southern Sulphur Spring Range where the top of the section is in covered fault contact with the Ordovician Eureka Quartzite.

The Garden Valley consists of conglomerate, sandstone, calcareous siltstone, some shale and a basal limestone unit, and was divided into four members by Nolan et al (1956, p. 67), of which, at least the lower three can be readily identified on DeJoia's sections (1952, plate 3). The basal Limestone Member is herein considered the western extension of the Carbon Ridge Formation and the Garden Valley is restricted to the conglomeratic sequence above.

To summarize from Nolan et al (1956) and DeJoia (1952); the second member is a weak unit with chert conglomerate at the base and calcareous siltstone, sandstone and shale above, 800 to 1,000 feet thick, overlain by a resistant ridge forming chert conglomerate member 900 to 1,000 feet thick, with a sequence of purple and red shales and limestone conglomerate above, at least 550 feet thick forming the top member. A marked disconformity is reported between the lowest conglomerate and the top of the Basal Limestone Member with conglomerate filled channels up to 20 feet deep cut into the limestone.

The reddish brown weathering chert conglomerates and coarse-grained sandstones are like the few in the Arcturus Formation at Dry Mountain (plate X, units H117 & H145), except that the ones here are generally much coarser and have less well rounded clasts. Cobbles of angular to subrounded chert up to six inches in diameter occur in the third member. The chert conglomerates of the second member are finer with most chert clasts less than one inch in diameter (DeJoia 1952) and many chert granule conglomerates have some lime matrix. Interbedded with the conglomerates are narrow bands of pale buff to buff calcareous coarse-grained siltstones that are like typical siltstones in the Arcturus Formation to the east. By the base of the third member is a bed, roughly 60 feet thick, of very pale buff to pale buff siltstone that weathers light gray to pale buff.

The top member was not seen and fossils suggest it may not be of Permian age (Nolan et al 1956, p. 68).

Diamond Mountains

Within the Diamond Mountains lies the transition zone between the facies of the Garden Valley and the Arcturus formations. These rocks have been described by Dott (1955), Divens (1957), Riva (1957) and Larson and Riva (1963). Their combined descriptions and maps give a good picture of the lithologies present and a short selective summary of their combined work is presented below.

Overlying the Carbon Ridge Formation is a sequence of mostly chert-bearing limestone with thin discontinuous beds of chert pebble conglomerate alternating with some reddish weathering calcareous siltstone and lesser crinoidal and fusulinid limestones (Riva 1957; unit Pb; Larson and Riva 1963, unit Pb; Divens 1957, unit Pc). Riva (1957, p. 19) noted

> "the texture of the conglomerates decreases gradually from pebbles to granules (eastward), probably ... derived from sources west of the mapped area".

A maximum of about 1,500 feet was measured.

The next unit consists of massive to thin-bedded medium to dark gray fine-grained limestone to coarse-grained crinoidal limestone alternating with some grayish red weathering siltstone (Riva 1957, unit Pc; Larson and Riva 1963, unit Pc; Divens 1957, unit Plsa). This unit is 800 to 850 feet thick.

Above is a unit, 400 to 420 feet thick, with 10 to 15 feet of alternating calcareous quartz sandstone and chert pebble conglomerate at the base overlain by calcareous siltstone and platy sandy limestone with a few more massive limestone beds and thin layers of chert granule and pebble conglomerate (Riva 1957, units Pd & Pe; Larson and Riva 1963, unit Pd; Divens 1957, units Pca, east side only, & Plsb). A coquina of Euphemites and Pseudorthocerus? occurred at one horizon in the lower part.

The top unit consists of a sequence of fine-grained calcareous quartz sandstone and siltstone which weather pale reddish brown with some pale yellowish brown or grayish orange and minor light olive gray (Riva 1957, unit Pf; Larson and Riva 1963, unit Pel; Divens 1957, unit Prb, east side only). Some coarse-grained chert sandstone and chert pebble conglomerate occurs in the upper part. A few beds have ripple marks which trend north-south. The thicknesses given for this unit range from 715 to 1,350 feet.

Overlying the Permian rocks with a pronounced angular unconformity are chert conglomerates of the Newark Canyon Formation (Riva 1957, unit Pg; Larson and Riva 1963, units Peu, Pgl & Pgu; Divens 1957, units Pcb & on west side Pca & Prb) and this unconformity accounts for most of the variability in the thicknesses listed for the Permian units. This formation was called Permian by the authors cited above, but is almost certainly of Late Cretaceous age (see p. 58). Some limestone conglomerate also occurs which probably overlies the Newark Canyon Formation and is Tertiary in age (Larson and Riva 1963, unit Pf; Divens 1957, unit Plc).

The lower two units apparently are similar to the Lower Member and the upper two units to the Upper Member of the Arcturus with the addition of chert conglomerate beds. The red color of the top unit may possibly indicate affinites with the reddish fourth member of the Garden Valley, but using red coloration for correlation is very unreliable.

Whether these rocks are designated Garden Valley or Arcturus appears to be arbitrary, but perhaps they should be assigned to the Garden Valley and the term Arcturus restricted to sections with essentially no chert conglomerate.

SUMMARY OF FACIES CHANGES

The most significant change in the Garden Valley Formation is the pinching out of the chert conglomerates to the east. The conglomeratic second and third members, at least, are equivalent to the lower portion of the non-conglomeratic Arcturus Formation. Between the Butte Mountains and Dry Mountain, clastic chert is introduced into the Arcturus as scattered granules in bioclastic limestones and as a very few thin coarse-grained sandstone and pebble conglomerate beds. To the west, in the Diamond Mountains, many chert pebbly limestone and thin chert conglomerate beds are described in the section which may here termed the Garden Valley Formation. Farther west, in the type area, chert conglomerates have replaced the clastic limestones and thus, what was a limestone-siltstone sequence to the east has become a chert conglomerate-siltstone sequence.

The conglomerate beds undergo changes to the west, becoming thicker, coarser-grained and, in the coarser grades, much less rounded and sorted.

Post-Permian Thrusting

Nolan et al (1956, p. 68) states that

> "Indirect evidence suggests that the major movement along the Roberts Mountain thrust, was of post-Permian age. The notable difference between the section at Tyrone Gap and the late Paleozoic sections, a short distance to the east and south in the Diamond Mountains and south of Eureka, seem to require that a thrust of the magnitude of the Roberts Mountains fault must separate them".

However, the lithologic difference between the Permian by Tyrone Gap and that in the Eureka district does not raise as serious a problem as thought by Nolan et al, as most of the Permian rocks in the Eureka district are apparently older than the conglomeratic parts of the Garden Valley and correlate only with the lithologically similar Basal Limestone Member. The eastern correlatives of the chert conglomeratic parts of the Garden Valley are found in the Diamond Mountains and the differences between the rocks in the southern Sulphur Spring Range and the Diamond Mountains can be explained by normal facies changes without any need of telescoping facies by thrusting. The eastward tonguing out of the conglomerates in the Garden Valley is comparable to the eastward tonguing out of the conglomerates in the Mississippian Diamond Peak Formation and in the Pennsylvanian Ely Limestone, which are generally considered due to normal facies changes.

In addition, J. Fred Smith and K. Ketner (in Gilluly 1963, p. 140-1) have conclusively dated the main movement on the Roberts Mountains Thrust to the north as of Early Mississippian age. Also, there is no evidence that any Mesozoic or Tertiary thrusting has telescoped the Permian section.

PALEONTOLOGY

In the southern Sulphur Spring Range a central shale unit in the second member contains fish plates and plant remains in places and the top member contains poorly preserved pelecypods (Nolan et al 1956, p. 67-8). Steele (1959b, p. 171) lists advanced Parafusulina and primitive Polydiexodina from the second member. Possibly these actually came from the Basal Limestone Member and were the fusulinid elements indicative of Leonard or even younger Permian mentioned in Nolan et al (1956, p. 68).

In the central Diamond Mountains Riva (1957) identified advanced species of Schwagerina ranging through the basal unit and in the upper half of the basal unit Parafusulina, Schwagerina cf. S. guembeli pseudoirregularis and Schubertella?, also a few brachiopods and bryozoans are present. In the upper half of the second unit he found Parafusulina sp., P. sp. A. Knight, P. aff. P. apiculata, Schwagerina aff. S. guembeli, S. sp., bryozoan fragments and near the top Omphalotrochus and Lonsdaleoidal corals. In the third unit he found a few brachiopods, bryozoans fragments and crinoidal columnals besides Euphemites and Pseudorthocerus?. From the second unit Divens (1957, p. 13-4) identified S. cf. S. subinflata Knight, S? mucronata Knight, and near the base Hustedia, Crurithyris planoconvexa (Schumard) and Glabrocingulum? grayvillense (N. & P.).

AGE

Nolan et al (1956, p. 68) considered the Garden Valley Formation as Permian(?), although the poorly preserved pelecypods found in the top member might equally well be interpreted as Mesozoic rather than Permian species. In the Diamond Mountains Riva (1957) considered the base Wolfcamp and the upper half of the lower unit and the second unit Leonard on the basis of the Parafusulina, also the higher units were assigned to the Leonard. Larson and Riva (1963) considered all the units, assigned here to the Garden Valley, Leonard in age.

CORRELATION

The Garden Valley Formation is considered the direct lateral equivalent of the Arcturus to the east. But the top member of the Garden Valley in the Sulphur Spring Range was not seen and is hard to evaluate; it could possibly be correlative with the Upper Member of the Arcturus or with the Triassic rocks present in the Butte Mountains, both contain pelecypods; the former is considered the more probable.

To the north, in the Carlin area, the formation appears to correlate in part with the Beacon Flat-Carlin Canyon sequence (see p. 107-8).

To the northwest the formation may be partially correlative to the upper part of the Havallah Formation, but for the most part the interval is represented by a hiatus as it is to the west (Silberling and Roberts 1962, fig. 2).

NONCARBONATE SOURCE

The formation is thought to have had two separate and independent sources of noncarbonate clastic material. The coarse-grained quartz siltstones apparently had the same source area as they did in the Arcturus. The siltstones do not contain any noticeable chert grains, and this is thought to rule out a western source.

The chert clastics were derived from the west. The thickness, angularity and coarseness all increase in this direction. The chert is similar to that in the Vinini Formation and was apparently derived from the Vinini or a similar western facies chert west of the Sulphur Spring Range, where appropriately enough, the Garden Valley interval is represented by a hiatus below rocks of Guadalupe age (Silberling and Roberts 1962, fig. 2).

PALEOECOLOGY AND GEOLOGIC HISTORY

The limestones and siltstones in the eastern part of the formation were deposited under the same conditions as they were farther east in the Arcturus. The coarse chert conglomerates in the west were probably all deposited in a near shore marine environment with tongues extending eastward into deeper water.

The Antler Orogenic Belt to the west became active at this time and clastic chert was shed eastward off of the emergent area scouring the top of the previously deposited limestone and interfingering with siltstones from the northeast. The deposits of clastic chert graded rapidly eastward into bioclastic limestones that were forming in a normal marine environment. The influx of clastic chert ceased from time to time and allowed the currents to cover the bottom with coarse silt and for one period, at least, mud accumulated. Later the chert influx decreased greatly and limestone debris was contributed to the shallow sea in the western edge of the area studied.

ARCTURUS FORMATION

The Arcturus Formation was first defined by Lawson (1906, p. 294) and named apparently after the Arcturus mining claim in the eastern part of the old townsite of Ruth. Lawson included the Reipetown in the formation, but present usage in the Egan Range restricts the formation to the interval above the Reipetown and below the Kaibab Limestone. No type section was given by Lawson and Sections A and B would serve as good reference sections (plates IV & V).

The formation is divided into two members: a Lower Member of alternating medium-bedded limestone and pale buff siltstone and an Upper Member of alternating thin-bedded molluscan-bearing limestone and silty limestone, buff to red weathering siltstone and some gypsum. These members can be separated fairly consistently in the Egan Range, but only in a very general way to the west or east of the range.

The formation crops out on the southeast flank of Buck Mountain, at Dry Mountain, many places in the Butte Mountains and the central Egan Range, in several localities near Connors Pass in the Schell Creek Range and in many places in the Confusion Range.

LITHOLOGY

Egan Range

The Arcturus Formation is present along the west side of Radar Ridge in a large overturned isoclinal syncline. Extensive exposures occur southward from Radar Ridge to Ward Mountain.

Lower Member

The Lower Member forms a predominantly limestone sequence conformably overlying the siltstones of the upper part of the Reipetown. The Lower Member is more resistant and better exposed than either the Reipetown or the Upper Member of the Arcturus and generally forms somewhat of a ridge or bluff between the two slope-forming units. Whereas the lithology of the Lower Member does not vary greatly, subtle distinctions allow the member to be divided into several units which give greater stratigraphic control when mapping.

The basal limestone unit of the Lower Member is the most resistant part of the formation and is generally a ridge former. It contains the highest percentage of limestone of any part of the member and consists predominantly of light gray brown limestone, which weathers lighter to medium gray, with yellow gray silty limestone, which weathers slightly lighter, and some buff weathering siltstone. At the top of the unit is a horizon of coralline limestone three to 18 feet thick. This zone, known as the "*Corwenia*" zone, after a widely used misidentification, contains very abundant fasciculate corals which may reach a diameter of three feet and one foot in height, but generally are about one and one half feet in diameter and eight to 10 inches high. The corals are most prolithic at the top of the zone where an interval two to three feet thick is commonly composed essentially of corals, apparently in growth position. Another much narrower zone of fasciculate corals, with moderate-sized ramose bryozoans, occurs 40 feet above the base in an interval of buff weathering calcareous siltstone along

Radar Ridge and a similar zone is present on Ward Mountain also (Section D). The corals in the lower zone are almost always squashed due apparently to greater compaction in the siltstone. Locally fasciculate corals are found at different horizons, but no other zones are present in this unit. A one foot thick zone of Lithostrotion-like corals occurs near the base of the formation in the southwest corner of the Reipetown quadrangle, but is not present on Radar Ridge. A moderately cherty horizon lies just below or slightly below the "Corwenia" zone and contains abundant brachiopods and echinoid spines. This is the chertiest part of the formation. The unit is about 155 feet thick along Radar Ridge (Sections A and C) and 190 feet thick at Ward Mountain (Section B).

The overlying nondescript unit is composed of a sequence of alternating buff weathering siltstone, limestone, silty limestone and minor dolomitic horizons. Abundant echinoid spines occur locally and, near Ward Mountain, several horizons contain crinoidal limestone and common to abundant fusulinids. Along the central portion of Radar Ridge, a thin zone of fasciculate corals is present about 450 feet above the base of the formation and what appears to be the same zone, only more prominant, is present in the southwest part of the Reipetown and the northwest part of the Giroux Wash quadrangles. The unit is about 475 feet thick at Radar Ridge (Section A) and thins southward to 325 feet at Ward Mountain (Section B), thinning, for the most part, by grading laterally into the unit above.

The big bryozoan unit next above is characterized by rocks, gradational from limestone to siltstone, containing large to very large ramose bryozoans, abundant echinoid spines and a few small Lithostrotion-like corals. This unit is variable in thickness with the large bryozoans occurring through a greater interval to the south than to the north. It is about 140 feet thick at Radar Ridge and 280 feet thick at Ward Mountain.

The overlying speckled unit contains alternating limestones and calcareous siltstones with minor yellow gray weathering dolomitic intervals in both rock types. Along the northern half of Radar Ridge a limestone near the middle (A-111, Section A) forms a ledge, 10 feet high in places, and the limestone intervals above and below form low ledges protruding through a generally covered interval. Southward along Radar Ridge, two other limestones make prominent ledges and farther south all the ledges become subdued. A number of the limestones in this unit are speckled with light gray to white calcite spots, one to four millimeters in diameter, scattered through the rock. Along the northern half of Radar Ridge the limestone at the top of the unit forms a low double ledge with the lower ledge containing prominent speckles and serving as a good mappable bed, the "Speckled Bed". Farther south some of the lower beds in the unit develope prominent speckles and the Speckled Bed cannot be followed nearly as well, but the uppermost speckled limestone is probably it. The speckles are small patches of recrystallized calcite. Partially recrystallized small crinoid columnals and fusulinids, in other beds, resemble the speckles and the complete recrystallization of these fossils may be the origin, although no evidence for this was seen in the sections. A silty zone immediately above the Speckled Bed contains common Omphalotrochus and rare fusulinids.

This unit is about 500 feet thick at Radar Ridge and 550 feet at Ward Mountain.

The uppermost transition unit, 140 to 155 feet thick, is gradational to the Upper Member. The unit consists of yellow gray to olive gray weathering limestone, in six to 12 inch beds, alternating with calcareous siltstone, and no platy molluscan-bearing limestone is present. The few contained fossils are almost all similar to the types found in the rest of the Lower Member of the Arcturus. Without good exposures it is hard to distinguish this transition unit from the overlying beds of the basal part of the Upper Member. The upper contact chosen is where the greatest lithologic change takes place. The top limestone interval forms a slight ledge and the contact along Radar Ridge is below a thick yellow buff weathering siltstone interval that forms a yellow soil zone. The upper contact is hard to follow north of U. S. highway 6 without good exposures. To the south of the highway the unit is even more gradational and the upper contact is hard to choose with good exposures.

The Lower Member is fairly uniform throughout the central part of the Egan Range and is here, as elsewhere in the region, typified by the medium-bedded light gray brown medium-grained limestone which weathers slightly lighter to medium gray. The differences between the sections at Radar Ridge (Section A) and Ward Mountain (Section B) are relatively minor. In the vicinity of Ward Mountain the Lower Member contains many horizons with common to abundant fusulinids, but along Radar Ridge fusulinids are rare and have only been found immediately above the Speckled Bed and in the top limestone. Also, the Lower Member at Ward Mountain is slightly limier than at Radar Ridge.

At Radar Ridge (Section A) the member is 1,420 feet thick, whereas it is 1,490 feet thick at Ward Mountain (Section B). The difference in thickness is insignificant, except in the basal limestone unit. In the White River Valley west of Ward Mountain Lloyd (1959, p. 36) assigned a minimum thickness of 1,500 feet to the Robbers Roost Formation which is apparently equivalent to the Lower Member. The top 1,008 feet of what Playford (1961, p. 180-1) measured as Arcturus south of Ward Mountain can be assigned to the Lower Member of the Arcturus; the lower part being Reipetown. In the northern Egan Range, 18 miles north of Ely, the upper 1,020 feet of Woodward's (1962, p. 99-101) Arcturus, judging from his description, is probably the Lower Member of the Arcturus.

The north-south uniformity of the member through the range is in contrast to the changes that take place in an east-west direction. At the west edge of the Reipetown quadrangle, where the Lower Member is exposed on the west limb of the syncline, the units discussed above could not be recognized, except in a very general way. A few miles farther west, across a thrust, in the NE 1/4 sec. 36, T. 17 N., R. 60 E., the Lower Member contains many more crinoidal limestones, more chert and many more fusulinids than at Radar Ridge and is somewhat transitional to the Lower Member of the Arcturus in the southern Butte Mountains.

Upper Member

The Upper Member is relatively nonresistant and generally forms low pale yellow to buff slopes at the foot of ridges formed by more resistant limestone sequences. The best exposures in the area are west of Radar Ridge near Section A and on the west side of Ward Mountain in the south part of sec. 14, T. 15 N., R. 62 E.

The member consists of thin-bedded to platy limestone and silty limestone that grade into, and alternate with, buff to red weathering coarse-grained calcareous siltstone with minor gypsum. The poorer exposures and greater uniformity of the Upper Member does not allow it to be discussed by units and the member is described below by lithologic types.

Siltstones form a greater percentage than in the Lower Member and almost invariably break down to form a yellow or red soil covered interval. The siltstones, like those in the Lower Member and the Reipetown, are composed of quartz and a very small amount of feldspar in a calcareous matrix. They appear massive where exposed in cuts and trenches. The red siltstones contain thin bands of greenish reduced areas below the surface. The red siltstones occur at the top of the member, probably all within the top 300 feet. The siltstone interval immediately below the Kaibab is invariably red, but the next few intervals below may or may not be red and no consistent horizon, based on the red color, can be followed. The siltstones are almost entirely unfossiliferous.

Thin-bedded to platy limestones and silty limestones, which weather yellow gray to light olive gray and contain an abundant molluscan fauna, are characteristic of the Upper Member. The most common fossil found is the small pelecypod Nucula, which commonly occurs as small dark brown fragments along with other pelecypods and small high spired gastropods. Another common association is abundant bellerophontacean gastropods with a smattering of other fossils. At some horizons the fossils are highly varied with many types of pelecypods, gastropods, scaphopods and rare nautaloids and brachiopods. It is not uncommon to find slabs completely covered by fossils. One interval (A-281, Section A) contains an abundant fauna including common very large scaphopods. This interval may be useful as a stratigraphic marker, as common large scaphopods were not found elsewhere in the section. The limestones above and below a gypsum bed are especially fossiliferous (table 3; collections 20544 & 20923-PC from the limestone unit below the gypsum; 20542, 20545 & 20924-5-PC from the limestone unit above). One or two limestone intervals contain a very peculiar type of calcite veinlet with a three pronged shape resembling narrow, broad based sharks teeth. These symmetrical triaxial forms may occur singularly, but are generally strung together with the point of one central prong joining the base of another.

Another type of limestone commonly seen is dark brown and weathers to light olive gray. It is commonly laminated and has a strong petroliferous odor. This type forms a very small percentage of the total limestone and occurs mainly towards the top of the member. A few thin beds of sedimentary breccia crop out and are composed of generally tabular pieces of the laminated limestone which may be mud crack plates that have been jumbled and washed together.

A few narrow intervals of thicker-bedded limestone, more typical of the Lower Member, are present, mainly towards the base. A relatively thick interval is present at the center of the syncline.

opposite the southern portion of Radar Ridge. This interval, roughly two thirds up in the member, is composed of two resistant medium to thick-bedded limestones, each 30 to 35 feet thick, separated by a silty zone. The limestones contain a small ramose bryozoan and brachiopod fauna. This interval could only be traced a short distance and may possibly become silty and break down. Locally thin vuggy limestone is associated with the siltstone, either within the siltstone near a contact or at a contact. The limestone is greenish to yellow gray weathering with buff to orange partial vug fillings. The vugs which appear to be solution cavities, are irregular and range up to about an inch in diameter.

Gypsum occurs at two horizons: approximately 580 feet above the base of the member (about 750 feet above the Speckled Bed) and by the top. No other gypsum zones were found, but thin ones could be associated with some of the siltstone intervals. The lower gypsum is exposed in and by a small prospect pit on the north side of a small valley at NE 1/4 SE 1/4 SW 1/4 sec. 34, T. 16 N., R. 62 E. Only a few feet are exposed, but the gray spongy soil above and below may conceal 20 to 30 feet of gypsum. The zone is bracketed by very fossiliferous limestones and silty limestone and may be followed a short distance to the south and a couple of miles to the north. The lower gypsum zone could not be found along the west side of Radar Ridge. A small depression, which appears to be a sinkhole, occurs on a ridge top just southeast of the center of NE 1/4 sec. 33, T. 17 N., R. 61 E. and may be over this gypsum horizon, but it is more likely to be over a higher part of the section.

The gypsum at the top of the member occurs in the red siltstone interval just below the Kaibab. It is exposed in one pit west of Rib Hill (T. L. Heidricks, oral communication). This red interval is always a zone of dislocation which prevents its measurement with any accuracy. The attitude on both sides of the interval is different and the overlying Kaibab generally has a warped appearance. Limestone beds within the interval are highly contorted and may show any attitude. This contorted interval is well displayed in the S 1/2 NW 1/4 SE 1/4 sec. 14, T. 15 N., R. 62 E. The thickness of this interval is variable and jumbled greenish gray weathering vuggy limestone blocks are often present in the lower part. These features seem to be all due to slumping brought about by the solution of gypsum, but minor tectonic movement along this weak zone may have also occurred. This red siltstone interval is at least 40 feet thick and possibly a 100 feet thick. Blanchard (in Bauer et al 1960, p. 226) gave a thickness of 90 feet for the interval.

The Upper Member is about 1,800 feet thick at Radar Ridge (Section A) and although the measured section is incomplete, very little section is considered missing and the thickness is as good or better than can be obtained from the apparently continuous, but very poorly exposed section west of Murry Summit.

The total thickness for the Arcturus Formation is about 3,350 feet by Radar Ridge.

Semiquantitative spectrographic analyses of seven siltstone samples from the Lower Member and six from the Upper Member, from Radar Ridge (Sections A & C), show only very slight differences between the two members. Siltstones in the Upper Member contained traces of yttrium and ytterbium while yttrium only showed up in one sample from the Lower Member. Zirconium showed a very slight increase in the Upper Member. Slight boron was present in four Upper Member samples and none detectable from the Lower Member. There is a very slight upward increase in iron content; samples of two red weathering siltstones near the top contained 1.0 per cent iron, two buff weathering siltstones just below the lowest red weathering siltstones contained 1.0 and 0.7 per cent iron, respectively, and the rest of the siltstones in the Upper and Lower members contained 0.5 per cent or less iron. Three samples of siltstone from the top of the Reipetown were like those in the Lower Member.

Analyses of 19 samples of different types of limestone from the Lower and Upper members showed no significant differences, nor were any found with two samples from the base of the Kaibab.

Central Butte Mountains

The Arcturus Formation is present on the east and west flanks of the central Butte Mountains and has been penetrated in the center of the mountains by the Summit Springs well. On the east flank of the range the Lower Member contains the same types of lithology as in the Egan Range, but none of the units, except for the lowest, are recognizable. The ridge forming basal limestone unit is a little more massive and contains common fusulinids at the base and an especially thick "*Corwenia*" zone at the top. The Lower Member consists of three resistant ridge forming parts separated by two weaker portions which reflects directly the distribution of the thicker limestone intervals. Within the lower nonresistant part occurs an interval with several light gray weathering calcareous siltstones that form low ledges. Above this interval a few large ramose bryozoans were found and a little higher, 891 to 1,049 feet above the base, is a sequence in which dolomitic beds are present. Near the base of the middle resistant part is a bed with very abundant Omphalotrochus (F-89, Section F). The contact with the Upper Member is gradational and was chosen just above the highest group of medium-bedded limestones and below the lowest thin-bedded limestone containing the molluscan fauna (Section F, plate VIII).

On the west flank of the range the "Corwenia" zone is present at the very edge of the range near the center of the boundary between secs. 21 and 22, T. 20 N., R. 59 E. The base of the formation is covered and all, except for a minor patch to the south, of the Ely Limestone mapped on the west flank by W. B. Douglass Jr. (1960, p. 182) is the Lower Member of the Arcturus. About a mile to the north of the "Corwenia" near the top of the first ridge and close to the middle of the Lower Member is a cross-bedded sandstone about five feet thick with another two foot sandstone bed slightly higher. The sandstone is light gray, weathers brownish gray and has well rounded medium grains. In the upper part of the Lower Member are a number of buff weathering silty limestone to calcareous siltstone horizons containing abundant fusulinids and, near the top, some fusulinid coquinas. The fusulinid-bearing horizons were not seen on the east side of the range.

The Lower Member is 1,775 feet thick on the east side of the range (Section F).

The Upper Member on the east flank of the central Butte Mountains is very similar to that in the Egan Range. On Section F the member is poorly exposed and appears to be less fossiliferous and contain slightly less limestone. However, the character of the Upper Member is well displayed on the north side of the wash in sec. 23, T. 20 N., R. 60 E., where fossils are very abundant in some horizons, more limestone is exposed and, at the top, the red weathering siltstone interval with associated pale olive green limestone is relatively well exposed.

The Upper Member of the Arcturus was measured at approximately 1,800 feet on Section F, making the entire formation about 3,580 feet thick. However, there are many covered intervals in the Upper Member, in which the attitudes may vary, and there may also be repetition amounting to about 100 feet in the Upper Member.

On the west side of the range the Upper Member is very thin, which is apparently the result of faulting, but which was considered due to an angular unconformity beneath the Kaibab by W. B. Douglass, Jr. (1960, p. 182).

Summit Springs Well

In 1951 and 1952 Standard Oil Company of California and Continental Oil Company drilled No. 1 Summit Springs Unit well near the middle of the central Butte Mountains, in the NE 1/4 NW 1/4 NW 1/4 sec. 32, T. 20 N., R. 60 E., to a total depth of 11,543 feet, passing through about 8,540 feet of Permian rock which contains a number of evaporite beds. In reviewing the lithologic log (in Lintz 1957, p. 64-80), the upper part of the section penetrated is here considered almost certainly the Gerster Formation and the Kaibab Limestone with the Kaibab-Arcturus contact at

1,367 feet. The next 1,785 feet below (interval 1,367-3,152) is assigned to the Upper Member of the Arcturus. This interval consist of interbedded limestone, siltstone, dolomite, anhydrite and gypsum, with brownish red to red gray siltstone present between 2,03[illegible] and 2,415 feet below the surface. The underlying 1,156 feet (interval 3,152-4,308) consists mainly of limestone with lesser siltstone and dolomite and with only minor evaporite veinlets found in cores. This interval is apparently the Lower Member of the Arcturus and is probably faulted at the base against the Upper Member, as the next 1,582 feet below (interval 4,308-5,890) is lithologically like the Upper Member above (interval 1,367-3,152) and is an apparent repetition of the Upper Member of the Arcturus. Below, to the first Pennsylvanian fusulinids at 8,545 feet in depth, are 2,655 feet of limestones with some dolomite (interval 5,890-8,545). This lowest interval is probably equivalent to the 2,700 feet of Riepe Spring, Reipetown and Lower Member of the Arcturus that was measured on Section F, although the siltstones in the Reipetown are not described. The siltstones are locally friable and, if this is the case here, they could easily be masked by limestone in the well cuttings.

The dips encountered in the well are considered gentle (McJannet and Clark 1960, p. 250) and the thicknesses penetrated should be close to the true thicknesses.

The above interpretation that the well penetrated a faulted section in which the lower part of the Upper Member and two thirds of the Lower Member of the Arcturus are repeated, fits the surface stratigraphy and thicknesses well and requires no significant stratigraphic changes at depth beneath the central Butte Mountains. Slight additional evidence for faulting in the well is the reversal of the direction of the gentle dips across the interpreted fault position (McJannet and Clark 1960, p. 250).

Steele (1960, p. 106) considered the section penetrated in the well as unfaulted. He assigned the upper interval with evaporites (1,400 to 2,550) to the Loray Formation and he named the lower interval (4,400 to 5,400) the Summit Springs Evaporite Member of the Pequop Formation. Steele explained the absence of the Summit Springs Evaporite Member on the surface as due to leaching and collapse of the anhydrite and gypsum. However, no signs of leaching or collapse at the surface, other than just below the Kaibab, were seen. If the section penetrated by the well is unfaulted and the entire 1,000 foot Summit Springs Evaporite was absent at the surface by leaching and collapse, there would still be over 1,600 feet of sediments, in the well, with negligible, if any evaporites, that are not present at the surface.

The evaporite cored in the interval 1,613-5,733 amounts to 50.5 feet, forming 24 per cent of the cored rock, and occurs generally as one to five foot beds. This indicates that there are a number of thin gypsum and anhydrite beds associated with the siltstones in the Upper Member of the Arcturus that are not exposed at the surface.

Southern Butte Mountains

The lower part of the Arcturus Formation forms a north-south belt of outcrops that extends down the west side of the central Butte Mountains, crosses to the east side of the southern Butte

Mountains as the range makes a bend to the southwest, and continues farther south along Moorman Ridge. North of U. S. highway 50 a north-south trending graben valley near the west edge of T. 18 N., R. 59 E. divides the Lower Member of the Arcturus into two bands. The faulted nature of this valley is very easily seen. A pile of Tertiary volcanics, centered in sec. 6, T. 18 N., R. 59 E., is present at the north end of the valley between the two ridges of Permian rock. Also, scattered outcrops of the Cretaceous-Tertiary conglomerate, which underlies the volcanics and has a bright red weathering matrix, are present in the valley southward to within one half mile of the highway.

A number of workers have not recognized the graben nature of the valley and have described the Lower Member of the Arcturus on both sides of the valley as part of one continuous unfaulted section and thus have nearly double the thickness and have greatly misinterpreted the stratigraphy of the area (Brill and Steele in Steele 1959b, p. 130-2, 135-45 & 265-78; Brill 1963, p. 324; Easton 1961 & 1963, p. 723; and Steele 1960, p. 106).

On the west side of the graben valley, north of U. S. highway 50 in the eastern part of sec. 7, T. 17 N., R. 59 E., a faulted, partial section of the Lower Member conformably overlies the Reipetown to the west and is faulted against a sliver of the Upper Member to the east. The "Corwenia" zone is well exposed a little east of the ridge crest.

On the east side of the valley, north of the highway, is the well exposed and often described Moorman Ranch section, (Section G, plate IX), which Knight (1956, p. 773) correctly identified as the Arcturus Formation. The section is nearly flat lying and occurs in two main fault blocks which are each cut by numerous small faults with five to 50 feet of stratigraphic displacement. The lower contact of the Lower Member is not exposed and the upper contact is missing by erosion. No upper evaporite-bearing sequence nor Kaibab, as reported by Brill (1963, p. 324), is present.

The Lower Member is much more uniform in appearance and contains a great deal more fusulinids than to the north or in the Egan Range. Much of the difference in appearance is due to the very good exposures here. The section consists of alternating intervals of limestone and light gray to orange buff weathering calcareous siltstone. The limestones are the typical light gray brown limestones of the Lower Member and are generally in one to three foot beds with numerous horizons of rare to very abundant fusulinids. Much of the limestone is medium to coarse-grained crinoidal limestone, but a little over half of it appears fine-grained, although it is, actually medium-grained, and is slightly darker. Nearly all of the limestone is bioclastic. The middle portion of part II of Section G contains two intervals of cross-bedded sandstone, the lower of which is very similar to and is probably the same as the cross-bedded sandstone seen on the west flank of the central Butte Mountains. This middle portion also contains a few scattered very large ramose bryozoans.

Parts I and II of Section G are separated by a northeast trending fault through the saddle in the northwest corner of sec. 9. The upper part of part I has been correlated with the lower part of part II, by matching two horizons in which Lithostrotion-like corals were found and general lithologic similarity. There is approximately 320 feet of overlap between the two parts which gives a measured total of 1,627 feet for the section. It is estimated that about 150 to 200 feet are missing at the base of the section and that an additional 50 to 100 feet at the top would have reached the contact with the Upper Member. This gives thickness of about 1,850 feet for the member as a rough estimation.

For a distance of ten miles north of Section G the lithology remains very similar to that of the section, although fusulinids become less abundant. Farther north the lithology changes slightly, and approaches that on the west flank of the central Butte Mountains.

A thin sliver of the Upper Member is present at the west side of the graben valley overlain by Cretaceous-Tertiary conglomerate. It contains the typical lithology and molluscan fauna as found to the north and east.

Dry Mountain

A highly faulted band of Arcturus is present along Dry Mountain and at the southeast edge of Buck Mountain. A section was pieced together at Dry Mountain (Section H, plate X) and, although the section is incomplete and an accurate thickness not attained, the section shows well the lithology of the formation and the changes it has undergone. The most significant change from the sections to the east is the presence of clastic chert here.

The Lower Member, conformably overlying the Carbon Ridge Formation, is an alternating succession of limestone and calcareous siltstone. It is not too different from the section at Moorman Ranch and the varicolored siltstone intervals in both sections may correlate (H-160, Section H & G-36-37, Section G). The limestones differ in that many of them at Dry Mountain, especially the crinoidal limestones, contain scattered light green, gray, brown, and some black, angular to subangular chert granules.

The contact of the Lower with the Upper Member is gradational and a division between the members has been made arbitrarily at the top of the highest medium-bedded limestone below the lowest platy silty limestone with a molluscan fauna, although platy limestone first occurs about 100 feet lower. This gives a minimum thickness of 1,025 feet for the Lower Member.

There is not nearly the distinction between the Lower and Upper members at Dry Mountain as there is to the east, because of the presence within the Upper Member of light gray brown weathering limestones, many of them fusulinid-bearing, that are more typical of the Lower Member. Along with the introduction of the fusulinid-bearing limestone is a sharp reduction in the abundance of the molluscan fauna, as would be expected.

Clastic chert bearing limestones also occur in the Upper Member, plus two chert sandstone and pebble conglomerate intervals (H-117 & H-145, Section H). The conglomerate has fairly good sorting within layers and the largest pebbles are well rounded.

The Arcturus at Buck Mountain consists mainly, if not entirely of platy weathering calcareous siltstone and silty limestone of the Upper Member.

The pieced section of the Upper Member, with no exposed top, gives a minimum thickness of 1,530 feet and the entire formation a minimum thickness of about 2,550 feet at Dry Mountain (Section H).

Schell Creek Range

The Arcturus Formation crops out in several patches near Connors Pass. Most of the Lower Member is poorly exposed in two fault blocks on the east side of the range south of U. S. highway 6-50-93, in the center of the SE 1/4 sec. 1, T. 13 N., R. 65 E. and the southeastern part of the SW 1/4 sec. 6, T. 13 N., R. 66 E. In both blocks the member conformably overlies the Reipetown on the west and is cut by a fault on the east. The Lower Member is similar to that in the Egan Range, although the units discussed there could not be delineated here. The basal limestone unit was not noticeable here and an horizon of abundant fasciculate corals, seven to eight feet above the base, could possibly be the "Corwenia" zone. A few large ramose bryozoans occur just above the base and near the exposed top, and echinoid spines are present in several beds. Near the exposed top of this member of alternating limestone and siltstone some speckled limestone beds are present.

The topmost part of the Upper Member is exposed southwest of the big bend in U. S. highway 6-50-93, in the SW 1/4 sec. 30, T. 14 N., R. 66 E. Present is a bright red weathering soil zone with scattered outcrops of laminated greenish gray weathering limestone containing a few gastropods, thin to medium-bedded medium gray weathering limestone and laminated buff weathering siltstone.

Unconformably overlying the Arcturus here, with as much as a 60° discordance, are thin patches of nearly flat lying Cretaceous-

Tertiary chert pebble conglomerate which has been preserved in a few small downdropped fault blocks. This conglomerate is medium gray in color, but has been altered to red, buff or lavender over most of the area. In the roadcut, at the big bend in the highway, the conglomerate is apparently interbedded with gray shale and sandstone of dated Cretaceous or Paleocene age (Axelrod in Van Houten 1956, p. 2808). Drewes (1960 & manuscript) considers the conglomerate as part of the Arcturus, although he recognized the unconformity beneath it, but this is rejected due to the angular unconformity and interbedding with the shale.

Confusion Range

The Arcturus conformably overlies the Reipetown in the Confusion Range and is equivalent to the upper part of the Arcturus as mapped by Hose and Repenning (1959, 1963).

The formation contains a greater proportion of siltstone and fine-grained sandstone and considerably more gypsum than to the west. In addition, there is not the noticeable increase in proportion of carbonate above the Reipetown and the division between the Arcturus and the Reipetown is not nearly as obvious as it is to the west. Also, whereas differences between the upper and lower parts of the Arcturus exist, they are not as great as they are to the west and the formation cannot be readily divided into Upper and Lower members. In general, carbonate intervals, two to 10 feet thick, alternate with intervals of siltstone and sandstone, 20 to 40 feet thick. A few distinctive limestones are present and were used as mappable beds, A through D in ascending order, by Hose and Repenning (1959, p. 2177; 1963). The typical light gray brown limestones of the Lower Member of the Arcturus are present, beds A and B for example, but they form a much smaller percentage and yellow gray and olive gray weathering limestones are more common. A minor amount of limy dolomite crops out, which is light olive gray and weathers slightly browner or yellowish gray, in contrast to the light gray weathering dolomite in the Reipetown.

The upper part of the formation is similar to the Upper Member in the Egan Range, except for one major change. The thin-bedded to platy molluscan-bearing limestones that characterize the Upper Member of the Arcturus to the west are almost entirely lacking here and the lack of these beds seems to account for most of the thinning of this part of the formation. Dark gray laminated limestones with strong petroliferous odors are relatively more common than in the Egan Range. Two thin-bedded medium gray weathering cherty limestones, a type of rock never seen near the top of the formation to the west, crop out just below the Kaibab south of Indian Pass.

Near Desolation anticline about 80 feet of gypsum are exposed approximately 850 feet above the base of the Arcturus and some gypsum occurs lower in the section, also some is thought to be present higher, a little below the Kaibab (Hose and Repenning 1959, p. 2177). The red weathering siltstones are present at the top and a dislocated zone occurs within them here also, 50 feet or so beneath the Kaibab (Hose and Repenning 1959, p. 2175).

A thickness of about 1,190 feet for the Arcturus is derived from Hose and Repenning's measurements (1959), with the base of the formation placed about 300 feet below Bed A (see p. 45). They considered the thickness measured a minimum, not knowning how much might be missing in the dislocated zone at the top. This dislocated zone is present wherever the top of the Arcturus was seen in the region and the zone is considered to be due to slumping caused by the solution of gypsum at this horizon and not to major faulting. Therefore only minor stratigraphic thickness is thought to be missing and the total thickness of the Arcturus is probably about 1,300 feet.

SUMMARY OF FACIES CHANGES

The Arcturus Formation thins eastward from the Butte Mountains to the Confusion Range. This thinning has primarily taken place by the loss of medium-bedded limestone from the lower part and thin-bedded to platy molluscan-bearing limestone from the upper part of the formation (plate XIV). Southwestward from a line between North Ward Peak on Ward Mountain and a point a little north of North Spring in the southern Butte Mountains the limestone percentage increases slightly and fusulinids become common to abundant in the Lower Member. West of the Butte Mountains a number of fusulinid-bearing limestones tongue into the Upper Member and the molluscan fauna is less abundant. Eastward, in the Confusion Range, gypsum is more prominant and the formation as a whole is much less fossiliferous.

The most significant facies change is the introduction of clastic chert into the limestones west of the Butte Mountains. The amount of clastic chert increases westward until many of the limestones have been replaced by chert sandstones and conglomerates in the Diamond Mountains, where the lithology is transitional to the conglomeratic facies of the Garden Valley Formation.

PALEONTOLOGY

The faunas of the Lower and Upper members are quite different, corresponding to the difference in lithologies and reflecting the difference in depositional environments. The Lower Member contains a normal marine fauna for the most part, whereas the Upper Member contains a shallow water molluscan fauna.

Important faunal elements in the Lower Member include: fusulinids, fasciculate corals, ramose bryozoans, Composita, Omphalotrochus, echinoid spines and crinoid columnals. The variability of the abundance of the fusulinids over the region is most notable change within the Lower Member, but other elements have as much or nearly as much variability. At Moorman Ranch fusulinids are abundant whereas the large ramose bryozoans and echinoid spines are relatively rare and the brachiopod fauna is reduced; all reflecting a variation in environmental conditions.

Fusulinid identifications by R. C. Douglass for the sections measured are incomplete and a comparison between the forms present in the different sections cannot be made at this time, but fusulinids collected from several spot localities in the Lower Member of the Arcturus in the central and southern Butte Mountains correspond well with fusulinids from the Lower Member in the Egan Range that have been studied. Collections from the upper part of the Lower Member on the west side of the central Butte Mountains, in the SE 1/4 sec. 9, and SW 1/4 sec. 10, T. 20 N., R. 59 E., contain Climacammina sp., Parafusulina sp., a large _Schwagerina_ sp., and advanced _Schwagerina_ sp. and a small undescribed schwagerinid. These collections are from above the cross-bedded sandstone and would correspond stratigraphically to the upper portion of part II of the Moorman Ranch section (Section G, plate IX). To the south, in the NE 1/4 NE 1/4 sec. 30 and NW 1/4 NW 1/4 sec. 29, T. 19 N., R. 59 E., _Boultonia_ sp., _Climacammina_ sp., _Pseudofusulina_ sp., _Schwagerina_ sp. and _S._ aff. _S. diversiformis_ were identified from the Lower Member. Farther south, at the north end of the ridge on which part II of Section G was measured, in the SW 1/4 sec. 8, T. 18 N., R. 59 E., _Climacammina_ sp. and a large schwagerinid related to some of the advanced _Schwagerina_ from the Lower Member at Ward Mountain (Section B). On the west side of the graben valley, from the band of rocks formed by the Lower Member of the Arcturus, _Climacammina_ sp. and a large elongate _Schwagerina_ sp. or primitive _Parafusulina_ sp. were collected from the middle of the SW 1/4 NE 1/4 sec. 1, T. 18 N., R. 58 E., and, to the south, in the center of the N 1/2 NE 1/4 sec. 7, T. 17 N., R. 59 E., _Bradyina_ sp. and a _Schwagerina_ sp. were collected.

The fusulinids at Moorman Ranch were studied by Knight (1952, 1956) and at many localities by Steele (1959b). _Parafusulina_ and _Schwagerina_ are usually important forms. Knight's sections 1 and 2 (1956, fig. 2) correspond in position approximately to parts I and II of Section G, except that part II was not offset to the east at the top, as was Knight's section 2. By offsetting the section Knight crossed a fault, east side down, and may have included some repetition in the section. Probably part II contains more strata at the base than section 2, which may have been started at a horizon near unit G-29 on part II. With the above approximations, Knight's collections can be fairly well tied into Section G.

The common fasciculate coral in the basal part of the Lower Member was named Lonsdaleia cordillerensis by Easton (1960, p. 580) and revised as Durhamina cordillerensis by Wilson and Langenheim (1962, p. 504-7). In the vicinity of Ward Mountain other corals have been identified from the Lower Member by Wilson and Langenheim (1962, p. 502-3 & 510): the horn coral Stereostylus sp., from the basal 70 feet, the fasciculate corals Heritschioides woodi, about 500 feet above the base, and H. hillae, fromthe upper third of the member, and the small Lithostrotion-like coral Orionastrea hudsoni, from the upper third of the Lower Member. Lithostrotion-like corals are very abundant at one horizon in the Moorman Ranch section (G-83, Section G) and they are also present at approximately the same stratigraphic horizon to the north, in the SE 1/4 SW 1/4 SW 1/4 sec. 8, T. 18 N., R. 59 E. on the north side of the valley, where Easton (1960, p. 580 & 582) lists the Lithostrotion-like coral Lonsdaleia illipahensis.

Echinoid spines are very common in places and range from one to three inches in length in both smooth and spiny varieties. Dr. P. M. Kier, of the U.S. National Museum, reports that most spines and plates appear to be from cidaroid echinoids, but too poor for further identification. At several localities, in the big bryozoan unit, echinoid spines were found completely and evenly encircled by bryozoa. The even growth around the spines suggests the spines were upright, probably in growth position, as the bryozoans grew.

The molluscan fauna of the Upper Member is very distinctive and can be broken down into slightly differing assembledges. On the bases of the collections from Radar Ridge (Section A), E. L. Yochelson and M. Gordon, Jr. (written communication) considered four assemblages present: 1) abundant Euphemitopsis and Straparollus commonly with other gastropods, 2) abundant Plagioglypta commonly associated with Bellerophon and other gastropods, 3) abundant Meekospira commonly with pectenoids, 4) abundant pelecypods commonly poorly preserved. They further state that the few specimens that are not mollusks appear to have been reworked or floated.

Three types of scaphopods are present: a small curved species, one to one half inches long, a medium sized curved species, two to three inches long, and a large straight species one half to one inch in diameter and four to six inches long. Generally only one type is present in a bed.

A somewhat similar molluscan fauna is described from the upper, Alpha, member of the Kaibab at Walnut Canyon, Arizona (H. Chronic 1952) and from the Supai Formation in eastern Arizona (Winters 1963).

The distribution of many of the fossils, especially in the Egan Range, is discussed under lithology, as the fossils are a very important part of the lithology. The stratigraphic distribution of the fossils is shown on the Arcturus sections and on the fossil distribution chart for the Arcturus in the Egan Range (table 3).

AGE

The Arcturus Formation is probably Wolfcamp to Leonard in age with the Series boundary falling within the Lower Member, although this is not yet settled. The ranges of some fossils in West Texas and east-central Nevada is apparently different and different types of fossils have yielded different Series boundaries. E. L. Yochelson and R. C. Douglass (written communication), in reference to the collections from Ward Mountain (Section B), state

> "in the Arcturus Formation we now have a new association of forms ... (and for the present) the stratigraphic unit can be assigned to the Early Permian which includes Wolfcamp and Leonard equivalents. Later, ... it may be possible to recognize finer units within the Early Permian".

At Ward Mountain (Section B) and elsewhere, Omphalotrochus, considered a guide fossil of the Wolfcamp, occurs considerably above fusulinids thought to be of early Leonard age. Fusulinids typical of early Leonard are present in units B-24 and B-25, Section B, about 340 feet above the base, and the Wolfcamp-Leonard boundary could fall as low as between units B-10 and B-9, about 130 feet above the base, based on the fusulinids, according to R. C. Douglass (written communication).

The Upper Member contains some evidence that it is of Leonard age. In referring to a collection from the Upper Member at Dry Mountain (unit H-146, Section H, plate X), E. L. Yochelson reports that

> "the faunal elements contain those reported from the Supai (Winters 1963) and Kaibab (Chronic 1952). Some of the species also occur in the Leonard and early Bone Spring ... (and with more material) ... I am convinced that this part of the Arcturus can be fixed as of Leonard age".

Wilson and Langenheim (1962, p. 501 & fig. 4) assigned similar ages to the Arcturus based on fusulinids found at Water Canyon, south of Ward Mountain. They list Schubertella kingi and Schwagerina aff. S. grandensis at the base and Schwagerina wellesensis and Paraschwagerina aff. P. acuminata near the base, which were considered Wolfcamp. Parafusulina communis and Schubertella sp. were identified from rocks 1,024 feet above the base and assigned to the Leonard. Wilson and Langenheim state that the Wolfcamp-Leonard boundary probably occurs somewhere near the base of the Lower Arcturus, but drew it in the middle of the lower part.

R. C. Douglass (in Playford 1961, section 13), identified Wolfcamp fossils from an horizon in a section, also in Water Canyon, that is equivalent to about 740 feet above the base of the Arcturus.

To the west, in the north end of the White River Valley, the equivalent of the Lower Member was considered Middle to Late Wolfcamp based on Schwagerina sp., S. neolata, S. youngquisti, S. diversiformis, Ozawainella, Pseudofusulina sp., Oketella sp., Pseudoschwagerina sp., Pseudoschwagerina texana, Boultonia and Triticites identified by Leroy Apodaca (in Lloyd 1959, p. 37 & 40).

A number of workers have noted that Parafusulina occurs much lower in Nevada than in Texas; Lloyd (1959, p. 34), Wilson (1960, p. 36) and Douglass (1964) found Parafusulina in the zone of Pseudoschwagerina which Thompson (1948, p. 24) used to define the Wolfcamp. Many workers have assigned rocks in this region to the Leonard on the basis of finding Parafusulina. This does not now appear to be justifiable. Knight (1956, p. 775) also noted that Parafusulina occurs lower in Nevada, however, he assigned the Lower Member at the Moorman Ranch section to the upper Leonard and lower Word based upon almost equal proportions of Parafusulina and

Schwagerina, although Pseudofusulina is present.

Steele (1959b and 1960, p. 94) considered the Arcturus post-Wolfcamp. He placed the top of the Wolfcamp at the last occurrence of fusulinids having identifiable cuniculi, but Schwagerina linearis was not used as it is generally found in association with an upper Wolfcamp age Pseudoschwagerina.

In summary, the basis for choosing the Wolfcamp-Leonard boundary in east-central Nevada is not yet fully known, although the boundary probably lies within the Lower Member of the Arcturus, and the presence of Parafusulina does not necessarily indicate a Leonard age.

CORRELATION

To the east, the Arcturus Formation, at least in part, is equivalent to the Toroweap Formation in the Star Range near Milford, Utah. The Toroweap Formation is composed of light to medium gray limestone, which weathers medium gray, some brown weathering sandstone interbeds, that increase upwards, and, at the top, some gypsum, which is up to 100 feet thick (D. M. Lemmon, oral communication). Brill (1963, p. 326) shows the Toroweap to be about 510 feet thick in the Star Range. The two formations are correlated on the basis of position, both being conformably beneath the Kaibab, and general lithologic similarity. The Talisman Quartzite, below the Toroweap in the Star Range, is possibly correlative with the basal part of the Arcturus, but it is more likely to be equivalent to the upper part of the Reipetown (see p. 52). The Toroweap contains mollusks typical of the Upper Member of the Arcturus, although rare (Steele 1959b, chart 21).

Equivalents of the Arcturus are present to the north and northeast of Ely. In the northern Cherry Creek Mountains the lithology described by Douglass (1952) within the "zone of Parafusulina" is apparently the basal part of the Arcturus. The Arcturus correlates with most of the Permian below the Kaibab in the area north of Currie (Snelson 1955; Harlow 1956) and in the East Humboldt Range (Snelson 1957). In the central Pequop Mountains the description of the Pequop Formation (Steele 1959b, p. 279-289) appears to be a less silty equivalent of the Lower Member of the Arcturus and the thickness, 1,525 feet, is similar. This last correlation is strengthened at Ferguson Spring where the lower contact of the Pequop Formation was defined by a 14 inch biostromal "Corwenia" coral bed at the top of the Ferguson Spring Formation (Steele 1959b, p. 126), as this type of coral in abundance is suggestive of the basal portion of the Arcturus. At Ferguson Spring and in the northern Toana Range Steele (1959b, p. 160-161) described the "Summit Springs unnamed evaporite" equivalents which are lithologically and faunally very similar to the Upper Member of the Arcturus and are probably correlative. Later Steele (1960, p. 106-7) named these rocks in the northern Toana Range the Loray Formation.

To the northwest, in the Carlin area, Fails (1960, p. 1697-9) named the Beacon Flat Formation for 2,800 feet of predominantly limestone, but with the middle third covered, that conformably overlies the Buckskin Mountain Formation Fails considered it Wolfcamp to Leonard in age. Overlying the Beacon Flat Formation is a sequence of 1,225 feet of yellow tan silty limestone and some massive beds of brown chert, named the Carlin Canyon Formation, which is unconformably overlain by Tertiary rocks (Fails 1960, p. 1699-1702). The Carlin Canyon Formation contains a molluscan fauna very similar to that in the Upper Member of the Arcturus and was considered upper Leonard and possibly Guadalupian in age. The Beacon Flat and Carlin Canyon formations are probably correlative with the Lower and Upper members of the Arcturus, respectively.

The Arcturus in the Confusion Range was first mapped as the Supai equivalent (Newell 1948, Campbell 1951a & b), which also included the Reipetown, and to the south the Arcturus may in part be equivalent to the upper part of the Supai and the Hermit shale in addition to the Toroweap.

Westward the Arcturus grades laterally into the Garden Valley Formation.

NONCARBONATE SOURCE

The source area for the quartzose silt is considered to be to the north or northeast as it was for the Reipetown. The ratio of siltstone to carbonate increases to the east, yet the probable correlative to the east, in the Star Range, contains too much carbonate and is too thin to indicate a direct eastern source.

Indications of a northward increase in silt content are also present. In the Egan Range the basal limestone unit of the Lower Member shows a slight, but definite increase in silt content to the north and in the Butte Mountains the Lower Member in general appears to contain more silt to the north. Thus a northeast source seems most probable.

The cross-bedded sandstone units in the southern and central Butte Mountains are seemingly anomalous features. Regardless of source some sort of sedimentary bypassing is apparently involved; perhaps as "dunes" moving across the sea floor, which is known to occur in modern seas.

PALEOECOLOGY AND GEOLOGIC HISTORY

As the Lower Member of the Arcturus was being laid down conditions alternated between periods of siltstone influx and deposition of predominantly bioclastic limestone. The echinoid spines that are so common in the member are considered very good indicators of a normal marine environment (E. L. Yochelson, written communication). At times the sea floor was widely covered by growths of fasciculate corals, probably washed by moderate currents, and on rare occasions high energy conditions produced local oolite deposits. Moderate currents prevailed for the most part and reworked crinoidal and other organic debris. Local variations of the environment occurred, which in the southern Butte Mountains favored the growth of fusulinids over that of the more normal marine fauna. The optimum conditions for the brachiopods, bryozoans and echinoids were apparently different from those of the fusulinids, possibly a difference in preferred depths was the main difference, as no particular difference was noted between the rocks the two groups occur in. there is a slight indication that fusulinids preferred a shallower environment than the other fauna, in that fusulinid-bearing limestones interfinger with shallow water molluscan-bearing limestones in the Upper Member of the Arcturus at Dry Mountain (Section H).

Some evidence has been cited for an offshore, open water habitat for fusulinids (Thompson 1948, p. 7) in depths of perhaps 160 to 180 feet (Elias 1937, p. 428).

The depths in general are considered to increase to the west, because of the higher limestone to siltstone ratio and greater thickness in this direction. The sea shoaled eastward in the Confusion Range which inhibited the development of normal marine faunas, but which allowed some gypsum to be deposited.

As the top of the Lower Member was being deposited changes began to occur and, whereas an alternation of siltstone and limestone deposition continued to take place, the environment became much shallower. According to E. L. Yochelson and M. Gordon Jr. (written communication), a change to an increasingly hypersaline and shallowing condition took place until finally a further fouling of the water allowed only the hardiest of pelecypods and soft bottom dwelling gastropods to survive. Much of the Upper Member must have been deposited in a broad near mudflat or tidal falt environment which was periodically covered by silt. Rarely the surface may have been permitted to dry and crack and when resubmerged the mud plates became tumbled into a thin breccia layer. Some of the silts were deposited in a high saline environment that gave rise to evaporites, especially to the east. Some of the silt may have even been exposed subairelly at times before its burial. Eastward in the Confusion Range the water depth was too shallow or the usual salinity too great, or both, to encourage a flourishing molluscan fauna like that which grew in the vicinity of the Egan Range and Butte Mountains. Westward at Dry Mountain the depth was too great and the salinity too near normal to produce an abundant molluscan fauna, but which allowed fusulinids to flourish occasionally.

Four different molluscan assemblages were recognized in the Egan Range (see p. 103) and as explanation for these differing assemblages E. L. Yochelson and M. Gordon Jr. (written communication) remark

> "The differences in the gastropods can be explained in part by their presumed living habits. Meekospira was probably a member of the infauna burrowing through a soft mud bottom. Most of the other gastropods and the scaphopod Plagioglypta were members of the epifauna. Some gastropods may have lived on sea plants rather than on or in the bottom. The occurrence of relatively few kinds of fossils in the associations suggest less than optimum living conditions ... (with the pelecypod) group probably indicating the least enviable living conditions".

The Alpha Member of the Kaibab near Walnut Canyon, Arizona has a general lithologic and faunal similarity to the Upper Member of the Arcturus and, except for the belief that the salinity was greater than normal rather than less than normal in the Upper Member of the Arcturus, the detailed discussion of the paleoecology of the Alpha Member by H. Chronic (1952, p. 106-111) would generally apply to the limestones of the Upper Member. She concluded (1952, p. 110-111) the fauna

> "developed in a warm, shallow, epeiric sea of nearly normal or slightly reduced salinity, not very far from land. A gradual retreat of the sea was taking place, a fluctuating retreat probably only slightly modifying the depth of the sea. Agitation was at a minimum, but probably was sufficient to stir the flocculent muds of the bottom. The land to the east was of low relief and the climate warm and possibly arid. Fine sands from the land were washed or blown into the sea in limited quantity only. It is likely that seaweeds grew in abundance, and that many of the small mollusks

lived upon them, while others burrowed in the silty clayey, calcareous mud of the bottom, mud composed primarily of fragmentary shells of dead organisms".

KAIBAB LIMESTONE

The Kaibab Limestone was named by Darton (1910, p. 21, 28 & 32), given a type section by Noble (1928, p. 41) in the western Grand Canyon region and restricted by McKee (1938, p. 12) to the rocks overlying the Toroweap with a slight disconformity and unconformably overlain by the Moenkopi Formation. The name was first extended into this region by Newell (1948) in the Confusion Range. Hose and Repenning (1959, p. 2178) consider the Kaibab, along with the overlying Plympton and Gerster formations, as forming the Park City Group in west-central Utah.

The Kaibab consists of light gray to very pale brown weathering limestone, silty limestone and dolomitic limestone with some cherty beds. It is widely distributed in northern Arizona and southern Utah. In the region under study, the Kaibab is present in the central Butte Mountains, central Egan Range and Confusion Range.

LITHOLOGY

Egan Range

The Kaibab Limestone crops out in a band west of Radar Ridge above a low angle fault along which the formation has been moved over the west limb of a syncline, composed here of the Upper Member of the Arcturus. To the west, southwest and south of the Ruth mine, west of Ely, the Kaibab is present in the center of the syncline mentioned above.

The Kaibab consists of very light brown, medium to coarse-grained bioclastic limestone that is composed mainly of crinoid columnals. It is massive in appearance and only near the base, at a few localities can bedding be seen. Above a horizon approximately 50 feet from the base, the limestone contains silicified patches one half to three feet in diameter. These are generally white to light gray, but browns and reds also occur. Because of these silicified areas this part of the formation has sometimes been mistakenly identified as Plympton or Phosphoria, as done by Ward (1962) and Seward (1959).

The formation presents a warped appearance because of slumping at the top of the underlying Arcturus and faulting or possible faulting. Because of the warping and massive character of the rock the formation cannot be measured, but roughly 100 feet are considered to be present with the top open to erosion or capped by Tertiary rocks. Blanchard (in Bauer et al 1960, p. 226) listed 300 feet for the Kaibab interval.

Butte Mountains and Confusion Range

In the central Butte Mountains the formation is similar to that in the Egan Range, but with more silicification in the upper part. On the east side of the range, above the top of Section F, a sequence of completely silicified rock, overlying the basal limestones, appears to be a few hundred feet thick, but neither the attitude nor the extent of structural complications could be determined. W. B. Douglass, Jr. (1960, p. 182) mapped the silicified part as the Lower Chert Member of the Gerster Formation which he thought was probably equivalent to the Rex Chert. The Phosphoria Formation is reported to be present in the Butte Mountains (Cheney in Steele 1959b, p. 177) and, if so, would overly the Kaibab. The Kaibab is at least 100 feet thick.

formation was found beneath a Phosphoria equivalent, which is considered to correlate with the entire Guadalupe, in the Confusion Range (Dunbar et al 1960, p. 1775 & 84).

CORRELATION

East of the Confusion Range the nearest Kaibab outcrops are in the Star Range where the Kaibab is very cherty in places. North of the Confusion Range the Kaibab is regarded as a partial correlative of the massive carbonate sequence close to the top of the Oquirrh Formation of the Gold Hill district, and to the northeast the entire Park City Group is considered correlative to the Park City Formation (Hose and Repenning 1959, p. 2178 & 80). North of Ely the Kaibab is reported from the area north of Currie (Harlow 1956; Snelson 1955) and in the East Humboldt Range (Snelson 1957).

PALEOECOLOGY AND GEOLOGIC HISTORY

Conditions changed considerably by the time the Kaibab began to form. Normal marine conditions had returned to the area and the influxes of silt had ceased. Marine invertebrates lived and died on the sea floor and their shells accumulated to form limestone.

HIGHER PERMIAN FORMATIONS

Higher Permian rocks, forming the upper part of the Park City Group, crop out in the central Butte Mountains and in the Confusion Range. The Plympton Formation, a partial Phosphoria equivalent which consists predominantly of dolomite and chert, was named by Hose and Repenning (1959, p. 2181) in the Confusion Range, where it overlies the Kaibab. Rocks equivalent to the Phosphoria are reported to be present in the Butte Mountains.

The Gerster Formation, composed of distinctive productid-bearing cherty limestone, was named by Nolan (1935) in the Gold Hill district. The Gerster overlies the Plympton or equivalents and is overlain by remnants of Triassic rock. It is very similar in both the central Butte Mountains and the Confusion Range. The Plympton and Gerster are well described by Hose and Repenning (1959, p. 2181-85 & 95) in the Confusion Range where the Plympton is 690 to 700 feet thick and the Gerster is about 1,000 feet thick.

In the Butte Mountains, T. M. Cheney (in Steele 1959b, p. 177) reports the presence of the Phosphoria Formation and stated that the lithology is more sandy and calcareous than equivalent beds to the north in Elko County, Nevada. The Gerster in the central Butte Mountains contains a fauna that is characteristic of the formation elsewhere (E. L. Yochelson and M. Gordon, Jr., written communication), which includes very abundant and varied ramose bryozoans, fenestrate bryozoans, _Bathymyonia nevadensis_ (Meek), _Composita_ sp., _Derbyia_ sp., _Echinauris subhorrida_ (Meek), _Muirwoodia multistriatus_ (Meek), _Neospirifer pseudocameratus_ (Girty), _Spiriferina pulcher_ (Meek), _?Pseudomonotis_ sp. and crinoid columnals collected from sec. 22, T. 20 N., R. 60 E. This same fauna is present in the Confusion Range (Hose and Repenning 1959, p. 2194-5). The Plympton and Gerster are considered Guadalupe in age (Dunbar et al 1960, p. 1775 & 82).

SUMMARY

Lower Permian rocks of east-central Nevada and adjacent Utah disclose many facies changes. The lithologic changes are discussed from west to east for both the lower and upper parts of the Permian section.

The Carbon Ridge Formation (Nolan et al 1956) at Carbon Ridge near Eureka, Nevada is composed of predominantly thin-bedded cherty and silty limestones. It thins to the north in the Diamond Mountains and to the northwest in the southern Sulphur Spring Range where it forms the Basal Limestone Member of the Garden Valley Formation of Nolan et al (1956). Eastward, coralline limestone tongues into the lower part of the Carbon Ridge Formation and calcareous siltstone into the upper part, forming the Riepe Spring Limestone below and the Reipetown Sandstone above in the Butte Mountains (plates XIV & XV). The easternmost tongue of the Carbon Ridge facies forms the Upper Member of the Riepe Spring. Beyond to the east the typical Carbon Ridge limestones pinch out and the section consists essentially of coralline limestone below and calcareous siltstone, with minor carbonates, above.

The coralline limestone which forms the middle, Coralline, member of the Riepe Spring continues eastward nearly unchanged to the Confusion Range in western Utah, but thins and is nearly unrecognizable in the northern Needle Range. North-south changes also occur. Below the Coralline Member of the Riepe Spring, cherty limestones tongue in, south of a line between the central Confusion Range and the southern end of the Butte Mountains, and form the Lower Member of the Riepe Spring (plate XIII).

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Thin limy dolomites pinch into the calcareous siltstones of the Reipetown Sandstone near the Egan Range and increase in number to the east, where limy dolomite forms about 25 per cent of the formation in the Confusion and Needle Ranges of western Utah. In the Confusion Range, the Reipetown is equivalent to the lower part of the Arcturus Formation as mapped by Hose and Repenning (1959, 1963) from the base up to 300 feet below Bed A. It is equivalent to all of the Arcturus as mapped by Gould (1959) in the Needle Range.

The Garden Valley Formation consists mainly of chert conglomerate and calcareous siltstone above the Basal Limestone Member in the southern Sulphur Spring Range. The formation changes eastward by a loss of chert conglomerate and grades into the bioclastic limestones and calcareous siltstones of the Arcturus Formation through an area of transitional lithology in the Diamond Mountains. The top 20 feet of Nolan et al's Carbon Ridge Formation at Carbon Ridge is part of this transitional facies.

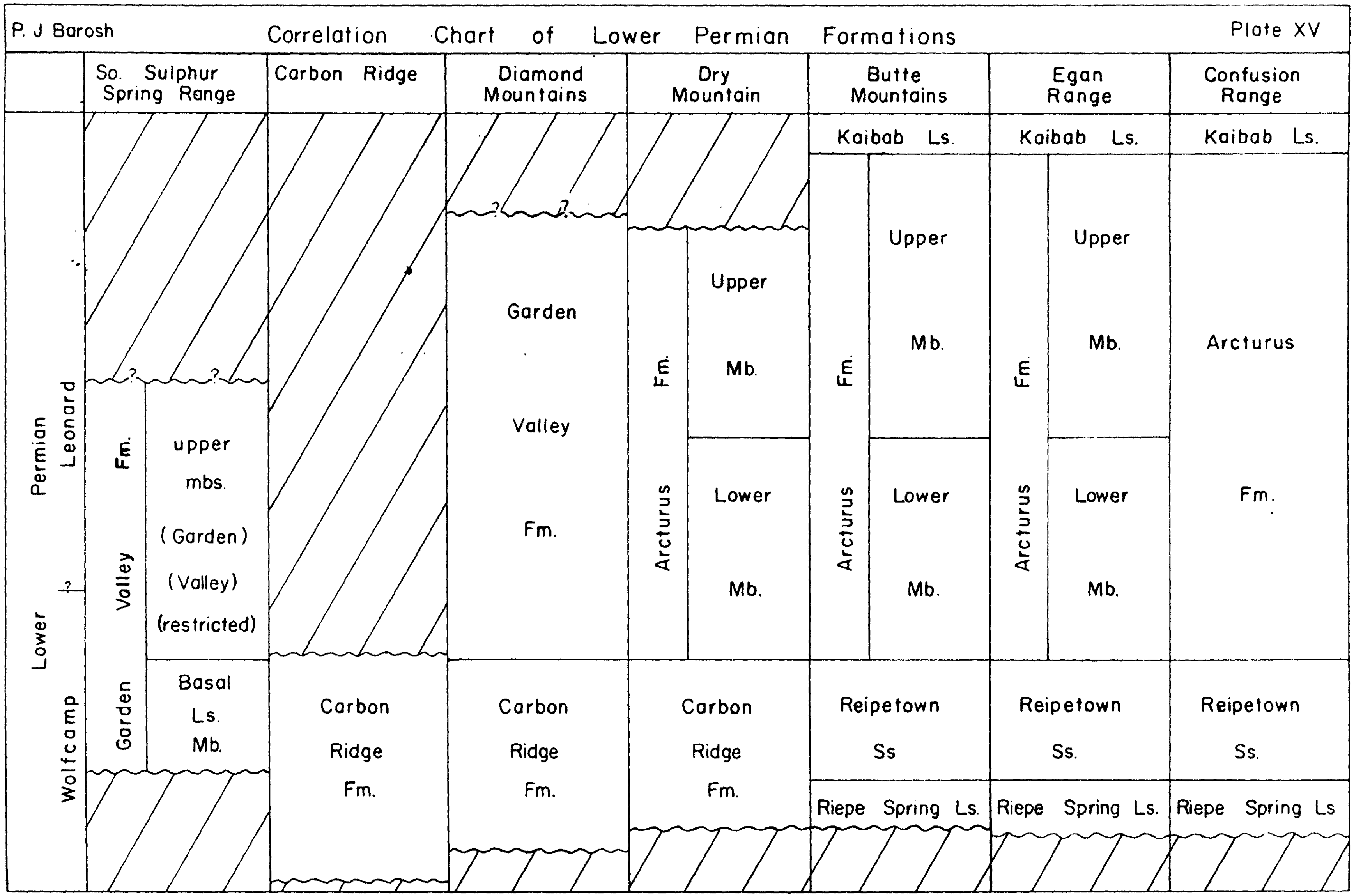
The Arcturus Formation consists of two members: a Lower Member of alternating medium-bedded limestone and calcareous siltstone and an Upper Member of alternating molluscan-bearing thin-bedded limestone and calcareous siltstone with some gypsum. The Arcturus Formation thins eastward from the Egan Range with a loss of limestone, but with an increase in gypsum, to the Confusion Range, where the formation constitutes the upper part of the Arcturus Formation as mapped there.

Higher Permian rocks, the Kaibab Limestone and the Gerster Formation, extend to the east and southeast from the central Butte Mountains with little change.

In Late Pennsylvanian times most of the region studies underwent a period of nondeposition and mild erosion, whereas to the west erosion was more vigorous, cutting down at least into Mississippian rocks. A broad positive area extending eastward from west of the Diamond Mountains into the Confusion Range resulted from this relatively mild activity, and sediments lapped onto this positive area from the north and south in latest Pennsylvanian times and reached the area under study from the south in earliest Permian. An east-west trending south-facing reef developed over most of the area and was later buried under a blanket of silt and very fine sand from the north or northeast. In the western part of the region, however, limestone was being deposited throughout this interval.

The area west of the region under study now became active orogenically, probably part of the Sonoma Orogeny, and clastic chert was shed into the western part of the region. To the east, noncarbonate deposition lessen and bioclastic debris accumulated on the sea floor with only occasional influxes of silt from the northeast. Farther east, in Utah, the sea shallowed to such an extent that some gypsum was formed. The sea later began a retreat and the water became so shallow that much of the region approached mudflat conditions and some gypsum was formed over much of the area.

Later the sea deepend over the region and bioclastic debris again accumulated under normal marine conditions.


P. J Barosh
Correlation Chart of Lower Permian Formations
Plate XV
So. Sulphur Spring Range
Carbon Ridge
Diamond Mountains
Dry Mountain
Butte Mountains
Egan Range
Confusion Range
Lower Permian
Leonard
Wolfcamp
?
Garden Valley Fm.
upper mbs. (Garden) (Valley) (restricted)
Basal Ls. Mb.
Carbon Ridge Fm.
Garden Valley Fm.
Arcturus Fm.
Upper Mb.
Lower Mb.
Kaibab Ls.
Reipetown Ss
Reipetown Ss.
Riepe Spring Ls.
Riepe Spring Ls
Arcturus Fm.

STRATIGRAPHIC RECOMMENDATIONS

A few recommendations are presented in the following paragraphs to modify existing formational terminology in the light of the correlations presented in this paper and a few suggestions are included on the usage of some of the formational terms. Also, several recommendations are made against the use of certain stratigraphic terms that have been applied to the Permian rocks in this region by a few authors.

It is recommended that the Carbon Ridge Formation be restricted to the type of lithology found at its type section, Carbon Ridge, and should not be subdivided into other formations, except for the recognition of the top 20 feet as equivalent to the basal Garden Valley-Arcturus transitional sediments. East of Long Valley the terms Riepe Spring and Reipetown should be used for the Carbon Ridge interval.

It is suggested that the Garden Valley Formation be restricted to the conglomeratic part above the Basal Limestone Member, which is here considered a westward extension of the Carbon Ridge Formation. The term Garden Valley should perhaps be used in the Diamond Mountains for the lithology which is transitional between the Garden Valley and the Arcturus facies, as chert conglomerates are prominent here. East of Newark Valley, where clastic chert is minor or absent from the interval, the term Arcturus should be used. With the above recommended changes the Garden Valley would overly the Carbon Ridge rather than be a partial correlative of it.

Within the Riepe Spring Limestone the coralline limestone of the Coralline Member is the distinctive lithology and is what

Steele (1960, p. 102) described at the type section. Where the coralline limestone is absent or can no longer be recognized the term Riepe Spring should not be used. Westward, where the coralline limestone is no longer recognized the interval constitutes the lower part of the Carbon Ridge Formation. Eastward, in western Utah, in areas where the coralline is altered and cannot be successfully separated lithologically from the underlying Pennsylvanian limestone, the interval should be mapped as part of the unrestricted Ely Limestone and no attempt should be made to separate it on the basis of age alone. Trying to separate the formation on the basis of age, where it cannot be recognized lithologically, is invalid, inaccurate and obscures stratigraphic relationships. An additional problem exists to the south, as in the Needle Range, where the coralline limestone is recognizable, although thin, but the thick Lower Member of the Riepe Spring cannot be readily separated from the Ely. In this case too, it might be best to include the interval in the unrestricted Ely Limestone.

In further work in western Utah the Reipetown and the Arcturus should be separated. Westward where the Reipetown interval consists predominantly of limestone it should be considered the upper part of the Carbon Ridge Formation.

It is strongly recommended that the Lower and Upper members of the Arcturus not be raised to formational rank. The members are gradational and criteria for mapping a consistent contact is poor within a range and extremely poor between ranges. In places, as in the Confusion Range, they cannot be separated.

The term Loray Formation should not be used in this region in place of the Upper Member of the Arcturus for the reason given in the above paragraph. Also the Loray is not well enough described in its type area in the northern Toana Range, the interval has not been adequately traced into the region under study, and the Loray has been misapplied by some workers in this region to the top, red weathering, portion of the Upper Member of the Arcturus, which, although striking on a section, cannot be mapped with any consistency. Steele (1959b, p. 160-1) regarded the Loray, which overlies the Pequop Formation in its type area, to be equivalent to the Summit Springs Evaporite, which he included as a member within the Pequop at Moorman Ranch (Steele 1960).

The terms Lower and Upper members of the Moorman Ranch Formation are invalid, being based on structural misconceptions of the Lower Member of the Arcturus in the southern Butte Mountains. Also the term Summit Springs Evaporite Member should not be used as it was named from a probably faulted section within the Summit Springs well. Where the Summit Springs Evaporite Member was used on the surface in the faulted section near Moorman Ranch, it was applied to rocks in a fault block, that consists mainly of Cretaceous-Tertiary rocks and some from the Upper Member of the Arcturus (Steele 1960, Brill 1963).

The term Pequop Formation should not be used in this region and perhaps should not even be used in its type area until further studied and better defined. Steele (1959a, p. 1105 & 1960, p. 106) named the formation in the central Pequop Mountains and used a type section he felt had considerable repetition by faulting. Robinson

(1961) did not like Steele's type section and proposed a reference section nearby which R. C. Douglass (1963a) feels may include repetition by faulting. Steele thought the formation was about 1,570 feet thick after eliminating repetition (in Thorman 1962, p. 86); and Robinson (1961) assigned a thickness of 3,087 feet to the formation. Thorman (1962, p. 83-8), who mapped in the Pequop Range a little north of the type area, noted discrepancies concerning the proposed formational boundaries and did not try to separate out the Pequop Formation. Thus, until further study, it seems the formation cannot even be used in its type area. Steele (1960, p. 106) used the Pequop to include all the fault slices in the faulted section near Moorman Ranch, whereas Brill (1963, p. 324) restricted the Pequop to what he thought was the lower part of this faulted section and referred the upper part, which includes some of the same rocks as in the lower part, to the Arcturus. Thus, as used in the region under study, the term has no meaning.

The Garden Valley, Carbon Ridge, Riepe Spring, Reipetown and Arcturus formations, as amended herein, represent all the main lithologic facies within which the pre-Kaibab Permian rocks of this area fall and no further formational terms are needed, as they would only serve to confuse relationships. Any additional subdivisions should be made on a member level only.

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APPENDIX

DESCRIPTION OF SECTION LOCALITIES

Section A

Location: Sec. 4 and 5, T. 17 N., R. 61 E., Reipetown 7.5' quadrangle, Radar Ridge, Egan Range, White Pine County, Nevada. Start section on ridge top in center of west half of sec. 4, about 6,200' N. 25° W. of Peak 8,720, proceed west down ridge to ledge-forming limestone unit, A-111, near west edge of sec. 4, shift south about 1,600' along ledge to southwest corner sec. 4, then proceed west 2,850' along low ridge north of main stream gully to just west of quadrangle boundary in south central sec. 5, about 7,800' N. 57.5° W. of Peak 8,720'.

Method: Tape and brunton

Dates: July 18-20, 23, 25 & 26, 1962

Comments: Vertical to steeply overturned east dipping beds, fair to good exposures, fairly accurate measurements, doubtful if any, but very minor displacement by faulting other than on low angle west dipping fault just east of the Kaibab outcrops. North-south isoclinal synclinal axis through unit A-301 and the 615' of section west of the axis and east of the Kaibab is repetition and is not shown on the section. Very little section is thought to be missing between A-301 and the Kaibab.

Section B

Location: Sec. 23, T. 15 N., R. 62 E., Ely 7.5' quadrangle, Ward Mountain, Egan Range, White Pine County, Nevada. Start section at top of talus slope at nose of ridge through central part of sec. 23, proceed east to saddle about 1,400' northeast of South

Springs along ridge crest.

Method: Jacob's staff

Dates: August 8, 9 & 10, 1962

Comments: Steep, east dipping beds, well exposed

Section C

Location: Sec. 16, T. 17 N., R. 61 E., Reipetown 7.5' quadrangle, Radar Ridge, Egan Range, White Pine County, Nevada. Start section about 2,900' S. 43° W. of Peak 8,720', in north central part of sec. 16, on ridge crest, proceed southwest along ridge.

Method: Jacob's staff

Date: August 21, 1962

Comments: Beds steeply dipping to east, well exposed

Section D

Location: Sec. 19, T. 15 N., R. 63 E., Ely 7.5' quadrangle, Ward Mountain, Egan Range, White Pine County, Nevada. Start sectio on south side of small saddle on ridge crest about 1,050' north of North Ward Peak (Peak 10,803), proceed northward along ridge crest, along the west edge of Sec. 19, to a point about 3,500' north-northeast of North Ward Peak and about 50' south of Peak 10,180.

Method: Tape and brunton

Date: August 28, 1962

Comments: Beds dip east about 50°, apparently unfaulted, fair exposures, but best exposures known for this interval in the central Egan Range.

Section E

Location: Sec. 4, T. 17 N., R. 61 E., Reipetown 7.5' quadrangle, Radar Ridge, Egan Range, White Pine County, Nevada. Section in north-central part of sec. 4 on east side of crest of the main north-south ridge, section ends on crest about 100' south of Peak 8,340.

Method: 6' steel tape

Comments: Beds steeply dipping to west, well exposed, except at contacts.

Section F

Location: Sec. 35, T. 21 N., R. 60 E. and secs. 2, 3 and 4, T. 20 N., R. 60 E., A.M.S. Ely 2° sheet, 1959, central Butte Mountains, White Pine County, Nevada. Start section on ridge near center of sec. 35, proceed in a west-southwest direction through NW 1/4 sec. 2, N 1/2 sec. 3 to the SW 1/4 NE 1/4 sec. 4, T. 20 N., R. 60 E.

Method: Jacob's staff

Dates: July 23-26 & 29, 1963

Comments: Beds dip moderately to the west, moderately well exposed some east-northeast trending faults cut the section with the south side moved relatively west; do not believe any unnoticed faults were crossed below the upper third of the Lower Member of the Arcturus, but many covered areas in the upper part of the section, possibly a fault recrossed in the Upper Member of the Arcturus which, if so, would cause about 100' of repetition.

Section G

Location: Secs. 4, 8 and 9, T. 17 N., R. 59 E., Illipah 15' quadrangle, southern Butte Mountains, White Pine County, Nevada. Part I starts by telephone pole about 100' northeast of the guard rail on U. S. highway 50, near center of NE 1/4 sec. 8, proceeds to peak in NW 1/4 NW 1/4 sec. 9, Part II starts near center of NW 1/4 sec. 9 and proceeds with many along strike shifts, to main stream gully in NW 1/4 NW 1/4 sec. 9, and on uphill, northeastward, close to ridge on the south side of the gully to Peak 7,789' in center of SW 1/4 sec. 4.

Method: Jacob's staff

Dates: July 30, 31, August 1, 2, 5 & 29, 1963

Comments: Beds nearly flat lying, very well exposed, the two parts are separated by a northwest trending fault passing through saddle in the northwest corner of sec. 9. At the saddle the fault is marked by a 10'-15' brecciated zone and places a horizon 24' up in unit G-20, southwest of the fault, against unit G-39 to the northeast. Each of the parts of the section give the appearance of being unfaulted, but upon close inspection are found to be cut by a great many faults, with 5' to 50' of stratigraphic displacement, that are hard to recognize and cross successfully.

Section H

Location: Secs. 10 and 3, T. 19 N., R. 57 E., and secs. 26, 27 and 35, T. 20 N., R. 57 E., Buck Mountain 15' quadrangle. Dry Mountain, White Pine County, Nevada. Section in four parts:
Part I, start east edge NW 1/4 NE 1/4 sec. 10, T. 19 N., R. 57 E. proceed northeast to very northeast corner of sec. 10; Part II,

start at west edge of ridge, proceed east along south edge sec. 10, T. 19 N., R. 57 E., to bend in road at the west edge of sec. 11; Part III, start at west edge of low hill north of stream gully in the NE 1/4 NE 1/4 NE 1/4 sec. 3, T. 19 N., R. 57 E. and proceed northeast into the SW 1/4 SW 1/4 sec. 35, T. 20 N., R. 57 E. crossing road and ending several hundred feet northeast of road; Part IV, start at west base of spur in SE 1/4 NE 1/4 sec. 27, T. 20 N., R. 57 E., proceed east along ridge to center of NW 1/4 sec. 26, shift across stream gully to south and then proceed east up ridge toward Peak 7,516', just below peak shift northward gradually to end of section at small peak in NE 1/4 NE 1/4 sec. 26.

Method: Jacob's staff

Dates: August 12-16 & 30, 1963

Comments: Beds dip moderately to the east, fair to good exposures, Parts I and II probably fit together with possibly slight overlap, some section missing between Parts II and III, could be slight overlap between top of Part III and base of Part IV. Internally Parts I and III good, Part II faulted at top of H41 with probably very slight omission, Part IV cut by 30 or so northeast trending faults with individual displacements up to 40', stratigraphically, these were successfully crossed, also, three large north-south trending faults are considered to cut the section, dividing it into four portions, the top of the topographically lowest portion (H62-H91) and the base of the third portion (H129-H147) overlap, the units H80-H83 apparently the same as H129-H133, the second portion (H93-H127) apparently fits above the third with an unknown amount of section missing between the fourth and topographically highest portion (H141-H154) is probably a duplication of part of the lowest portion.

Section I

Location: NE 1/4 SE 1/4 NE 1/4 sec. 2, T. 16 N., R. 61 E., Reipetown 7.5' quadrangle, Radar Ridge, White Pine County, Nevada. Start east edge sec. 2, proceed southwest down ridge to where the end of the ridge starts to drop off to the stream gully to the west.

Method: Tape and brunton

Dates: August 24 and 25, 1963

Comments: Beds dip steeply to the west, well exposed and unfaulted, best Riepe Spring Limestone section known in central Egan Range.