STRATIGRAPHY OF THE
PALEOZOIC ROCKS OF CENTRAL OREGON

by

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INTRODUCTION

The purpose of this investigation was to establish the ages and stratigraphic succession of a group of Paleozoic rocks in Central Oregon. To accomplish this the three summer months of 1957 were spent in mapping the geology of 39 square miles and in making fossil collections.

The area is located approximately 80 miles southeast of Prineville, Oregon and lies almost wholly within Crook County. An index map is included on the map plate at the end of this paper. The area has about 1000 feet of relief; the hills are dominantly a series of gentle, north-trending ridges and buttes. The major streams transect the ridges, flowing westward. Minor tributaries flow generally north or south into the major streams.

Paleozoic rock exposures are relatively poor. The considerable accumulations of soil and talus and the diastrophism to which the rocks have been subjected, result in pronounced discontinuity of outcrops of the beds. A notable exception to this is the Coyote Butte limestone, which, though discontinuous in outcrop, stands out boldly on hills and ridges. Outcrops of post-Paleozoic rocks are much more continuous and prominent.

In mapping the area formational contacts were plotted on aerial photographs and then transferred to a base map. The northern part of the base map is the south-central part of the Dayville quadrangle; the southern part is a United States Forest Service planimetric map of the north-central part of the Riley quadrangle. In the southwest part of the area, Paleozoic exposures extend about $\frac{1}{4}$ mile beyond the map area.

Because no satisfactory topographic map was available for the area that includes the cross-section, the profile was established by plane-table methods.

About 150 thin sections were made of the fusulinids, bryozoans, and coral collected, and about 30 thin sections were made of the significant rock types represented in the area. A small fauna of microfossils was obtained by etching Coyote Butte limestone, using a dilute solution of hydrochloric acid.

PREVIOUS WORK

The first significant work in this area was done by Dr. Earl L. Packard(25,26,27), who in 1928 and 1932 reported the presence of Paleozoic and Mesozoic strata and their included faunas, although Washburne(39) had discovered them first.

In the summers of 1932 and 1933, field work was undertaken by W. E. McKitrick(22) and B. N. Gonzales(11) under the direction of Packard. McKitrick concerned himself with the geology of the area, and Gonzales worked on the faunas. These workers made no attempt to differentiate between the Mississippian and Permian limestones. McKitrick mapped the limestones as a single unit and followed Packard in assuming an anticlinal structure across the area. Gonzales' work on the faunal material was mostly confined to identification of the brachiopods, but he mentioned the presence of other fossil material.

C. W. Merriam(21) visited the area in the summers of 1937, 1938, and 1939. He mapped a part of the Paleozoic exposures, and named the Coffee Creek, Spotted Ridge, and Coyote Butte formations, designating a type section for each. According to Merriam, all three units bear unconformable relations to each other and to the overlying Mesozoic sediments. Merriam used fossil evidence to determine the age of the Coffee Creek to be Lower Carboniferous, the Spotted Ridge to be Pennsylvanian, and the Coyote Butte to be Permian. Previous to the publication of his geological report, he published a paper on the coral faunas of the Coyote Butte and Coffee Creek formations(20) and, with C. B. Read(30), a paper on the flora of the Spotted Ridge formation.

In 1951, Philip E. Brogan(3) included a part of the area in his mapping of the Suplee area and essentially followed Merriam's interpretations as to stratigraphic relations, lithology, ages, and structure.

STRUCTURE

The structural development of the area is only inadequately known because of complex folding and scarce, discontinuous outcrops. Considerable faulting probably has occurred in the area, but the only evidence for it is the pronounced discontinuities observable in attempting to trace a single lithologic unit throughout the length of the area. These discontinuities are particularly apparent in the Coyote Butte limestone, as may be seen on the accompanying geologic map. Similar discontinuous limestones have been mapped by Gilluly(9) in the Baker quadrangle and by Pardee and Hewett(28) in the Sumpter quadrangle. Both of these workers attribute this outcrop distribution to disruption of the units by faulting.

Somewhat more information is available on the folding in the area. Structure in the Coffee Creek formation consists of a series of northeast-trending folds, which are extremely tight and which may be overturned in some instances. Limited exposures of the Coffee Creek limestone make it impossible to trace fold axes.

Folding in the Spotted Ridge formation is somewhat less severe, although the folds are tight. At least five anticlines and five synclines are discernible within a distance of five miles. A general picture of the distribution of fold axes may be gained by noting the distribution of Coyote Butte limestone outcrops. The general trend of the axes is north to north-northeast. Complicated minor folding is associated with the major folds and probably is drag folding attendant to the major folding process. Pronounced sinuosities and irregularities in the fold axes are probably related to post Mesozoic episodes of tectonism. More complicated structure is observed in the less competent mudstones and limestones of the Spotted Ridge than in the conglomerate-sandstone sequence of the same formation.

Folding in the Mesozoic rocks was probably not restricted to one episode, since the lower Triassic beds are more tightly folded than the overlying Jurassic beds. Structural trends in the Triassic sequence are generally west-northwest, approximately at right angles to the Paleozoic folds. The Mesozoic area on the western edge of the map represents an especially well-defined northwestward-plunging syncline whose axis trends west-northwest. More complex folding on the eastern edge of the area maintains the same structural trends.

Folding in the Tertiary rocks is mild. Dips of the Columbia River basalt are generally westerly or northwesterly five to ten degrees. The Harney tuff dips less than two degrees.

STRATIGRAPHY

Six units are recognized in the area, ranging in age from Mississippian to Recent. The oldest unit is the Mississippian Coffee Creek formation. The Coffee Creek is predominantly limestone and contains thin beds of chert. The Permian Spotted Ridge formation unconformably overlies the Coffee Creek. The Spotted Ridge consists of basal conglomerates and coarse sandstones, chert greywackes, limestone, and siliceous mudstones. The Coyote Butte limestone is interbedded in the mudstone. A series of conglomerates, sandstones, mudstones and shales of Triassic and Jurassic age unconformably overlie the Spotted Ridge. The Columbia River basalt rests unconformably on the Mesozoic sediments. The Pliocene Harney tuff rests unconformably on the Columbia River basalt. Recent alluvium overlies the Harney tuff.

Determinations of the total thickness of the section are somewhat uncertain in view of the complex structure and the lack of knowledge concerning faulting. An attempt was made to ascertain the thickness of individual units where they seem most complete and undisturbed. The estimated total thickness is about 8000 feet.

The only observed intrusive in the area is a small diabase plug in the east central part of the area. It is interpreted to be post-Triassic in age.

A columnar section, representing the stratigraphic relations and lithology of the units follows(Plate 1, Page 7).

Coffee Creek Formation

The Coffee Creek formation is the oldest unit in the area. Only the top 500 feet of the formation are exposed, and so the total thickness is not known. The Spotted Ridge formation unconformably overlies the Coffee Creek, but the discordance is slight. The trend of the Coffee Creek structure is about northeast, whereas the average strike of the overlying Spotted Ridge is north to north-northeast. Folds in the Coffee Creek are somewhat tighter than folds in the Spotted Ridge formation.

The upper part of the formation is a massive to medium-bedded, fossiliferous limestone that contains locally abundant brachiopod shells, solitary corals, and crinoid columnals. The unweathered limestone is medium gray but weathers to a light gray. The rocks are jointed and fractured; many of the fractures are filled with calcite. Beds below the upper, massive member are denser, darker limestones. They are less fossiliferous but locally contain some small brachiopods. The lower part of the formation is more argillaceous than the upper part and contains stringers and lentils of chert $\frac{1}{4}$ to $\frac{1}{2}$ inch thick.

COLUMNAR SECTION

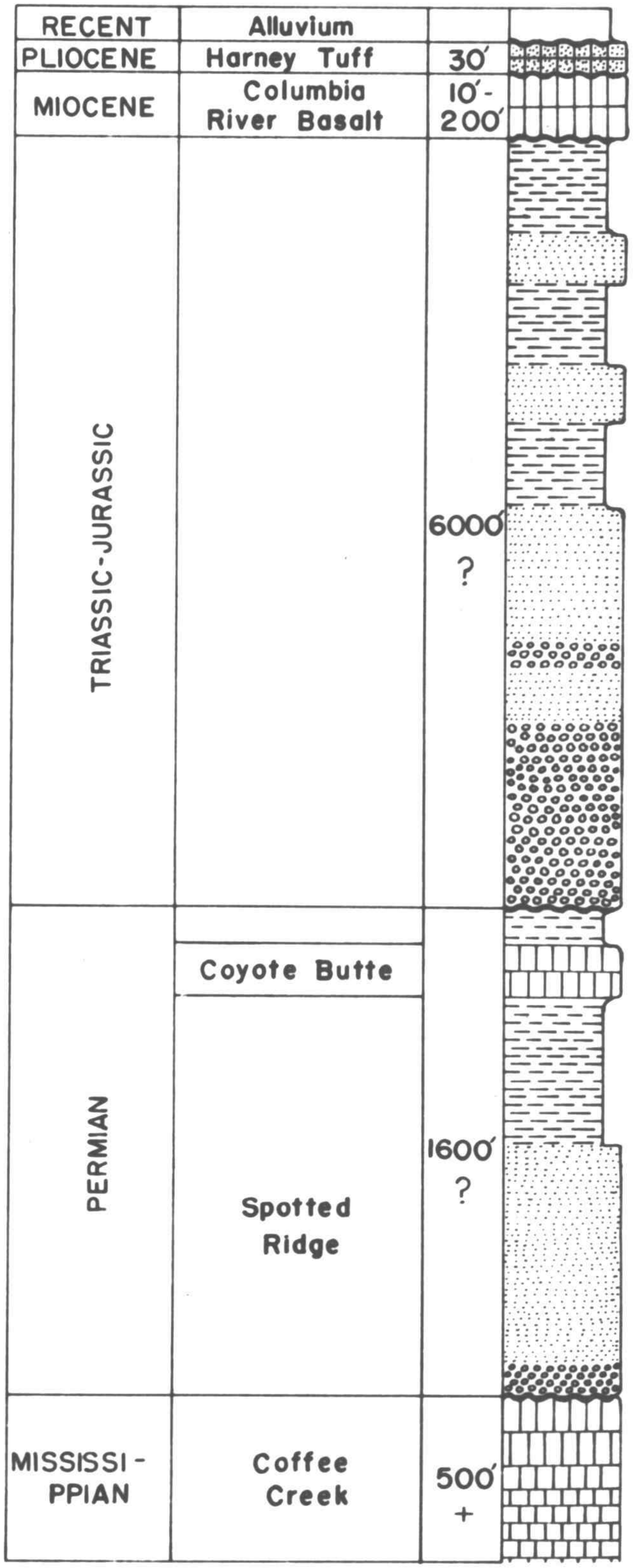


Plate 1

The following average composition for Coffee Creek limestone was determined by examination of thin sections.

Calcite	90%
Chert	3%
Plagioclase	2%
Quartz	2%
Chlorite	$<$ 1%
Magnetite	1%
Hematite	2%

Much of the calcite displays twinning lamellae, characteristic of metamorphosed limestones. The metamorphism appears to have been slight, however, and may be related to the folding. The calcite consists in part of oolites and fragments of fossil material identifiable as the remains of corals, brachiopods, crinoid columnals, and small Foraminifera. The cores of the oolites consist of quartz, chert, fossil fragments, chlorite, and magnetite. Chert occurs as microcrystalline, subangular detrital grains, and as partial replacements of the calcite. Most of the plagioclase grains are euhedral and appear to have been only slightly abraded. Quartz grains are subangular, and chlorite appears as fibrous masses between calcite grains. The chlorite probably represents the chloritization of the originally argillaceous fraction of the rock. Magnetite and hematite are interstitial in the rock, the latter in places imparting a reddish-brown or purplish hue to the limestone.

The fine-grained rocks of this formation consists of the following components:

Calcite	78%
Chert	10%
Clay	10%
Hematite	2%

The calcite is mostly very fine-grained, but has in part been recrystallized to form patches of phaneritic crystals. The chert is distributed in zones parallel to the bedding and is intimately intermixed with calcite. Apparently the chert was introduced along the bedding where the limestone was most permeable. Some of the chert is interstitial and some has replaced part of the calcite. Areas of recrystallized calcite surrounded by a mixture of fine-grained calcite and clay give the rock a mottled appearance.

Packard(26) and Merriam(21) have dated this formation as lower Mississippian, approximately equivalent to the Baird shale of California. This correlation presumably was based on the faunal similarities between the two formations. The author has found no new evidence of the age of the Coffee Creek and tentatively agrees with that age determination, although the fossil evidence accumulated to date is not such as to establish the age precisely.

Apparently from the fossil constituents of the formation and from the presence of oolites in the rock, this formation represents a rather shallow depositional environment subject to considerable agitation.

Spotted Ridge Formation

The Spotted Ridge formation, including the Coyote Butte limestone, consists of approximately 1600 feet of marine conglomerate, chert greywacke, siliceous mudstone, and limestone. It overlies the Coffee Creek formation unconformably and is unconformably overlain by the Mesozoic sediments. Folding of these rocks has produced a complex, tightly folded structure characterized by numerous subsidiary drag folds and sinuous to irregular fold axes. Brecciation is common, especially in the siliceous mudstones and limestones. In view of the intensity of the deformation and the probable existence of complex faulting, estimates of the thickness are only approximate.

So far as determined, no satisfactory stratigraphic section exists in the area, and stratigraphic relationships of the lithologic units have not been positively worked out. Tentative stratigraphic relationships were determined by the synthesis of isolated parts of the formation exposed in the area, and by consideration of the overall aspect of the lithologic distribution. The lithologic units grade almost imperceptibly into each other, although in their most characteristic development they are quite distinct.

Conglomerate. A dark brown to greenish-brown conglomerate occurs at the base of the formation. This unit seems to be lenticular and to grade laterally into a greenish-gray to olive-brown arenite. The arenite is coarse and calcareous, and contains numerous oolites and crinoid columnals. The calcareous material is believed to have been derived from the underlying Coffee Creek formation. The matrix of the conglomerate also is coarse and calcareous, essentially the same as the arenite.

The conglomerate contains pebbles and cobbles of andesite, porphyritic andesite, quartz diorite, andesite breccia, monzonite, porphyritic latite, quartzite, and diorite. These components range in size mostly from 1 to 20 centimeters, and few are larger. The andesite and porphyritic andesite pebbles compose 83% of the total pebble content and range in size from 1 to 4 centimeters.

The mineralogical analyses of specimens 104 and 171 in Figure 1 represent the matrix of two conglomerate specimens. In specimen 104, the calcite is a detrital component. In both specimens 104 and 171, the grains of the matrix are coarse and angular to subangular. Specimen 122 is representative of the basal coarse-grained arenite. The high percentage of calcite in it consists largely of oolites and interstitial material.

Chert greywacke. The predominant rock type in the formation is a buff-brown to olive-brown chert greywacke. The rock is very well indurated and is not readily affected by weathering. The beds are massive in their lower occurrences but become thinner bedded and more fissile upward in the section. The components of the chert greywacke also become finer-grained toward the top of the sequence. The chert greywackes overlie the conglomerate and are overlain by siliceous mudstones.

Specimen 131 in Figure 1 is representative of the chert greywackes. The detrital components are medium- to fine-grained and are subangular. The rock is poor in quartz and feldspar as compared to the average greywacke. Chlorite is interstitial and probably represents chloritization of the originally argillaceous fraction of the rock.

An arenite composed almost wholly of magnetite occurs as a 5-inch bed near the top of the chert greywackes. Only one small outcrop about 10 feet wide was noted. The mineral composition of the arenite is given under specimen 175, Figure 1. This magnetite occurrence suggests that deposition at this place was very near shore and that environmental energies were such that nearly all of the other constituents were winnowed out and only the very heavy magnetite was left as a concentrate. The porosity of this rock is nearly 50%.

Another minor rock type associated with the chert greywacke was observed in a small outcrop about 6 feet long. The rock has a light buff color and shows only poorly developed bedding. In the thin section, detrital grains of subangular to subeuhedral quartz and plagioclase grains are observed set in a matrix consisting of a microcrystalline aggregate of poorly-polarizing chert grains. Large grains of amorphous silica are also visible within the matrix. The matrix is interpreted as representing devitrified pyroclastic material. Specimen 255, Figure 1 gives the mineral composition.

MINERAL	SPECIMEN NUMBER					
	104	122	131	171	175	255
Chert	30%	15%	62%	75%	1%	78%
Hematite	-	3%	2%	2%	-	1%
Magnetite	20%	7%	1%	<1%	93%	1%
Quartz	8%	2%	15%	10%	1%	3%
Amorphous silica	-	1%	-	5%	-	2%
Clay	-	-	-	-	-	10%
Plagioclase	7%	2%	10%	5%	-	1%
Calcite	27%	60%	-	-	-	2%
Chlorite	1%	10%	10%	3%	5%	2%
Diopside	2%	-	< 1%	< 1%	-	-
Hornblende	3%	-	-	-	-	-
Enstatite	2%	-	-	-	-	-

Fig. 1. Mineral Composition of some Spotted Ridge arenites.

Siliceous mudstones. The topmost unit in the formation is a siliceous mudstone, within which is interbedded the Coyote Butte limestone member of this formation. The siliceous mudstone contains an unusually high percentage of silica. The term chert might well be applied to this rock. However, the author wishes to avoid the usual genetic implications of this term. As will be explained later, the source of silica is thought to be different from that of the argillaceous fraction of this rock. To preserve the distinction between these two sources of material, the term siliceous mudstone is used here.

The siliceous mudstone is characteristically grey-green in color, but in places also brown, cream, white, or black. It commonly shows distinct stratification. The silica content of the mudstone increases upward in the section, but its lateral distribution is quite uniform. The silica content seems to increase rather rapidly up to a maximum and thereafter to maintain a quite uniform appearance. In most occurrences the siliceous mudstone is highly brecciated and the fractures are filled with silica. Outcrops are not prominent but the talus from this unit is very durable, occurring as blocks and hackly splinters over large portions of the area.

The composition of one of the green siliceous mudstones is as follows:

Aphanitic groundmass	65%
Chlorite	10%
Unidentified ferrosilicate(?)	10%

Chert	5%
Glass shards	5%
Quartz	3%
Unidentified isotropic substance	2%

In thin section, stratification is clearly apparent. Chlorite appears as flakes, irregular masses, and finely distributed granules throughout the groundmass. The chlorite is generally associated with an unidentified isotropic substance from which it may have altered, since the chlorite occurs as rims and patches around this unidentified substance. The chlorite is probably responsible for the characteristic green color of most of the siliceous mudstone. Numerous small granules of an unidentified ferrosilicate(?) mineral are uniformly distributed throughout the groundmass. Although the individual grains are too small to permit positive identification, it was noted that they are almost opaque and display no birefringence. Chert, in the form of round, irregular, and flattened masses of microcrystalline silica, is distributed parallel to the bedding. This distribution may be due to the greater porosity of the rock along these planes, allowing secondary silica to concentrate there. Medium-sized glass shards are apparent, especially in recurrent zones parallel to bedding. Very small bits of glass are uniformly distributed between these zones. All of the shards are randomly oriented within the groundmass. Quartz occurs as subhedral and subangular detrital grains distributed along bedding planes. For the most part the minerals in this rock are too fine-grained to permit microscopic identification.

Two poorly preserved radiolarians were observed in the thin section.

The notable uniformity of silicification in the Spotted Ridge mudstone has led the writer to consider that the silica was deposited contemporaneously with the argillaceous material. I assume that the source of the argillaceous material is the same as the source of the material in the underlying chert greywackes and conglomerates. Since no silicification has occurred in these coarser-grained rocks, it does not seem likely that the source of the silica is the same as the source of the argillaceous material. I think that the silica was derived from the alteration of volcanic glass. Basaltic glass alters to chlorite through the intermediate stage of the mineraloid palagonite and this process releases silica. The original silica content of the basaltic glass is about 50%, but the alteration product, according to Peacock(29), contains only about 35% silica. More significant is the fact that this silica is in a form which is amenable to solution or transportation as a colloid, whereas the glass itself and the silicates in the argillaceous material are relatively insoluble.

Several workers have discussed the origin of siliceous sediments. Bramlette(2) considers the siliceous nature of the diatomaceous Monterey formation of California to be due to tuff deposits in the area of provenance. These tuffs contributed silica to the depositional environment and as a result encouraged the growth of many silica-secreting organisms. The concentrations of their tests by wave action significantly increased the silica content of the sediments. Rubey(31) considers a similar mechanism in the development of the Mowry shale in the Black Hills, except that he believes that the siliceous organisms indicate, but do not add significantly to, silica in the sediments. He considers that the contemporaneous addition of volcanic ash and its subsequent devitrification produced the silica. Goldstein and Hendricks(10) believe that the source of silica in the Ouachita sediments in Oklahoma and Arkansas is a result of the submarine weathering of volcanic ash and consequent increase of silica-secreting organisms in response to the high-silica environment. The author believes that a process similar to those mentioned above is responsible for the siliceous character of the Spotted Ridge siliceous mudstones.

A suggested source for this pyroclastic material is to the east of the area of this report. Gilluly(9) has reported the presence of Permian greenstones and pyroclastics in the Baker quadrangle. Wheeler (39), reporting on the occurrence of Permian vulcanism along the West Coast, cites numerous examples of pyroclastics and flow rocks, which indicate that Permian vulcanism was common at this time in the region.

Coyote Butte member

The Coyote Butte member of the Spotted Ridge formation is a relatively thin limestone which occurs within the upper half of the Spotted Ridge. While mapping these limestones, the writer observed that many outcrops which exhibit very high dips (80-90 degrees) are completely surrounded by Spotted Ridge siliceous mudstone. Many outcrops are lenticular, tending to pinch out laterally within a short distance. In those instances where dips are less than 80 degrees, the limestone is both overlain and underlain by the siliceous mudstones. In no instance was a discordance of dip or strike observed between the Coyote Butte limestone and the Spotted Ridge siliceous mudstone. Merriam(21) considered the Coyote Butte to be an unconformable unit overlying the Spotted Ridge, citing one locality where angular discordance was observed. The author's investigations have led him to consider the Coyote Butte to be a conformable unit interbedded within the upper Spotted Ridge.

The limestone ranges in thickness from about 5 feet up to a maximum of about 50 feet. Apparently the unit does not maintain a constant position within the Spotted Ridge, but becomes progressively higher in the section toward the east. This interpretation derives from the fact that in the western part of the area only a relatively small distance separates the top of the chert greywacke sequence from the base of the limestone, whereas in the central part a significantly greater thickness of siliceous mudstone separates the two units. In the eastern part of the area, no outcrops of chert greywacke were observed but the siliceous mudstone below the limestone is believed to attain an even greater thickness there.

The limestone exhibits pronounced brecciation in virtually all of its occurrences. The brecciation seemingly is related to the intense folding which the whole formation has undergone.

The limestone is dominantly a bioclastic calcarenite, but includes minor calcilutites. Considerable recrystallization and dolomitization has occurred. The limestones are medium gray in color, weathering to light gray or white. The dolomitized limestones are much lighter in color, being pale pink, cream, or yellow. The limestones contain very little argillaceous material, but some of the beds contain significant amounts of well-rounded chert and quartz grains. The contact between the limestone and the partly contemporaneous siliceous mudstone of the Spotted Ridge is a sharp one, as no rocks gradational between the two were observed. Mineral compositions of some Coyote Butte limestones are given in Figure 2.

The limestone is highly fossiliferous, containing fusulinids, brachiopods, corals, crinoid columnals, bryozoans, and ostracods. Most of the fossil material is silicified. In the more intensely recrystallized and dolomitized limestones, practically all fossil remains have been destroyed.

Some of the limestone shows in thin section an intimate mixture of microcrystalline silica and calcite, which is not apparent in the hand specimen. Recrystallization of the limestone is apparently more pronounced in the originally finer-grained rocks than in the calcarenites.

In some of the limestone exposures chert forms as much as 50% of the mass. The cherts are dark gray or dark brown and translucent. They occur in zones parallel to the bedding and as fillings in joints across the bedding. The chert ranges from a few inches to a foot in

MINERAL	SPECIMEN NUMBER								
	133	135	187	220	221	226	268	289	371
Calcite	90%	66%	85%	82%	65%	92%	85%	97%	20%
Dolomite	10%	30%	-	5%	-	3%	5%	-	78%
Chert	<1%	3%	15%	2%	35%	2%	2%	3%	2%
Quartz	-	1%	-	<1%	-	1%	2%	<1%	<1%
Hematite	-	-	-	10%	<1%	2%	1%	<1%	<1%
Plagioclase	-	-	-	-	-	-	<1%	-	-
Chlorite	-	-	-	-	-	-	5%	-	-

Fig. 2. Mineral Composition of some Coyote Butte limestones.

thickness. The contact between the chert and the limestone is very uneven. Irregular protrusions of chert extend into the limestone and locally the chert forms irregular masses within the limestone. Silicified fossils identical to those found in the limestone are included in the cherts, presumably replaced at the time that the cherts were formed. Some of the cherts are disjointed and limestone fills the space between each disconnected piece.

Because of the very irregular contact between the chert and the limestone and because silicified fossils are included within the chert, the writer believes that the chert has replaced the limestone along bedding planes and joints. The presence of fairly pure cherts in the limestone probably is accounted for by migration in solution of silica derived from the highly siliceous surrounding mudstones. The time of origin of the secondary chert appears to have been sometime between lithification of the limestone and its subsequent deformation.

Dating of the Spotted Ridge formation is difficult because fossil material is almost absent. The only good evidence is provided by the richly fossiliferous Coyote Butte member. An upper Wolfcampian age is assigned to this limestone unit based mainly on its fusulinid fauna. Read and Merriam(31) reported the existence of a plant flora in the sandstone in the middle part of the Spotted Ridge, and this material was studied by Read and Merriam(31) and by Mamay and Read (19). Both of their reports indicate that the flora appears to be Pennsylvanian in age but do not rule out other possible ages. Plant material collected in the course of field work for this report is poorly preserved, and no satisfactory identifications can be made from it. However, the Coyote Butte member of the Spotted Ridge formation can be dated as late Wolfcampian, and therefore lateral equivalents of the Coyote Butte are also late Wolfcampian. The unfossiliferous conglomerate and chert greywacke below the Coyote Butte possibly is Pennsylvanian in age. However the fact that they are of the same depositional sequence as the Coyote Butte and the fact that the lower, coarser members of the Spotted Ridge probably required only a short time to be deposited, lead the author to conclude that the whole Spotted Ridge formation is Permian in age. Some time-correlatives of the Spotted Ridge formation are given in Figure 3.

The area of provenance of the Spotted Ridge sediments is not definitely known, primarily because of the restricted area available for study. A westerly source for the sediments is suggested by the fact that the sediments are coarser grained in the western part of the area than in the eastern part. Conglomerates and coarse sandstones are almost entirely restricted to the western border. The eastern and southern parts of the area consist of mudstones and limestones. The Coyote Butte limestone seems to represent a near-shore, biostromal accumulation of bioclastic debris.

To sum up the conditions of deposition of the Spotted Ridge sediments, the following paleogeographic, depositional, and faunal environment is postulated: 1) the area of provenance of the Spotted Ridge sediments was to the west, 2) an area of active vulcanism existed to the east, 3) a shallow, submergent sea occupied the area between these two land masses, 4) the rate of sedimentation was

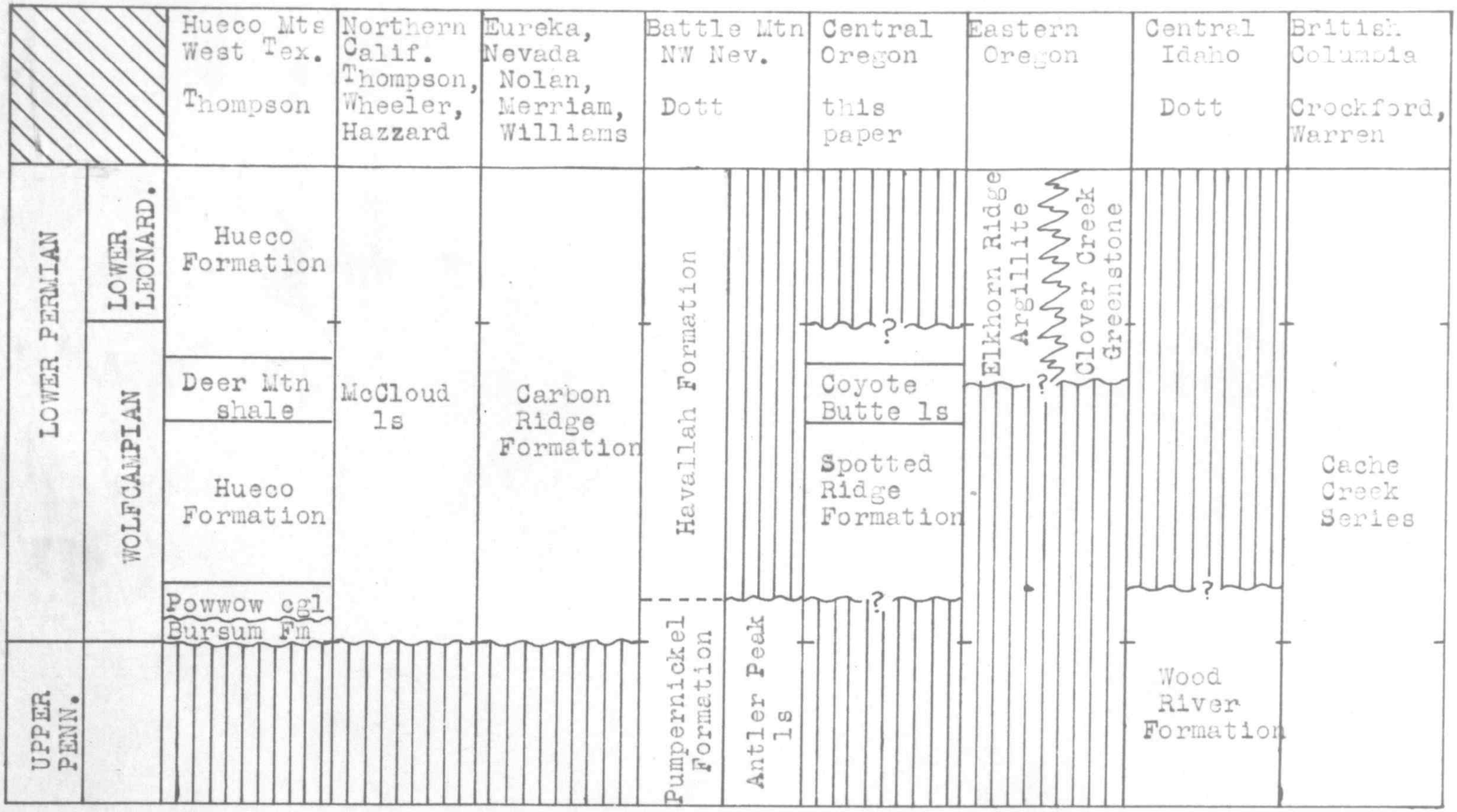


Fig. 3. Correlation Chart of the Lower Permian.

such as to maintain a fairly constant shallow depth in the sea, 5) a moderate to shallow water fauna flourished in this sea, 6) as the limestone was deposited, it transgressed time horizons as a result of the balance between sinking and sedimentation, 7) the basin was probably elongated north and south from this area as indicated by similar Permian sediments in northern California, British Columbia, and Alaska.

Mesozoic Sediments

The Mesozoic sediments consist of a series of conglomerates, sandstones, mudstones, and shales, whose greatest development is in the eastern portion of the map area. A few small limestone lenses are included in the mudstones. A thickness of approximately 6000 feet was measured by scaling distances from the map and utilizing dips obtained during the determination of the cross-sectional profile. Possibly faulting has caused a repetition of the beds where measured, but faults, if present, were undetected.

The Mesozoic sediments overlie the Permian rocks unconformably; the strike of the Permian folds trends generally north-northeast and fold axes in the Mesozoics generally trend west to west-northwest. Columbia River basalt overlies the Mesozoic rocks with angular unconformity.

Conglomerates. Conglomerates, interbedded with sandstones, comprise the lowest part of the sequence. The sandy matrix of the conglomerate is composed principally of chert and lesser amounts of quartz. The cobbles and pebbles of the conglomerate consist of siliceous mudstone and minor amounts of limestone derived from Spotted Ridge, Coyote Butte, and Coffee Creek rocks. These conglomerates form prominent strike ridges on both the east and west sides of the area. Some of the limestone cobbles contain fossils which are identical to those found in the Coyote Butte and Coffee Creek limestones, thereby establishing the source of the limestone cobbles.

Sandstones. The middle part of the Mesozoic sequence is composed of coarse- and medium-grained sandstones. These sandstones alternate with conglomerate beds in the lower part and with mudstones in the upper part. The sandstones are generally rather poorly indurated and weather readily to a brown, sandy soil. Outcrops are few and poorly exposed.

Mineral constituents of the sandstone are as follows:

Coarse sandstone		Fine sandstone	
Chert	95%	Chert	76%
Amorphous silica	4%	Quartz	10%
Quartz	1%	Amorphous silica	10%
		Hematite	3%
		Chlorite	<1%
		Hypersthene	<1%
		Plagioclase	1%

The particles are generally subrounded to subangular and are almost all of sand size, indicating a depositional environment capable of removing most of the fines. The angularity of the grains, however, seems to indicate a nearby source. No doubt some of the material is reworked from Permian sediments. The sandstones are commonly brown, although the coarse-grained specimens are multicolored as a result of the visible chert grains.

Mudstones and shales. The upper part of the sequence consists of black and brown siliceous mudstones and shales. The mudstones are massive and fracture into splintery or hackly masses, breaking as readily across bedding as along it. These mudstones occur below the shales. The overlying shales display considerable fissility and are less siliceous than the mudstones.

The composition of the mudstone is as follows:

Aphanitic fraction	85%
Chert	10%
Chlorite	5%

The rock contains numerous spherulites of silica, which are somewhat flattened and elongated along well-defined bedding planes. The aphanitic fraction contains considerable hematite, giving the rock a reddish-brown color in thin section.

The Mesozoic sediments are contiguous with those in the areas to the northeast studied by Schenk(32), Lupher(18), Nesbit(23), and Waisgerber(38), who dated the included ammonite faunas as Triassic and Jurassic. Separation of the Mesozoic formations mapped by these workers is not attempted in this paper.

Diabase

A small diabase plug in the NE$\frac{1}{4}$ sec. 22, T. 18 S., R. 25 E. protrudes through the Mesozoic sediments. The constituents of the rock are as follows:

Plagioclase	80%
Diopside	8%
Chlorite	8%
Magnetite	3%
Quartz	1%

The plagioclase laths form a felted texture; the diopside, chlorite, and magnetite are interstitial. Inasmuch as the plug is surrounded by the Triassic portion of the Mesozoic sediments, one cannot determine its exact age, except that it is post-Triassic.

Columbia River Basalt

A few ill-defined rims of Columbia River basalt occur in the western part of the area. The basalt is platy and coarsely scoriaceous. It tends to thin toward the east. Probably the basalt flows never were continuous over the whole area. Apparently the flows originated to the north and west, and, when they reached the topographic high present in the area during the Miocene, lapped against it. The basalts have low dips toward the west that average less than 10 degrees. Immediately underlying the basalts are thin, discontinuous zones of red, baked soil.

The Miocene Columbia River basalt in places overlies the Mesozoic sediments unconformably but in some areas it rests on Permian sediments. This indicates that the Mesozoic rocks had been considerably eroded before the basalts were extruded. Harney tuff overlies the basalt with slight unconformity.

The thickness of the basalt ranges from 10 to 300 feet as a result of the irregularities in the topographic high against which it flowed.

Harney Tuff

The Harney tuff is a well-indurated vitric tuff that unconformably overlies the Columbia River basalt. The tuff is approximately 30 feet thick, but erosion has probably reduced its original thickness. Its outcrops are limited to caprocks on a few small buttes in the southwest part of the area. To the southwest of the area, however, the Harney tuff covers large expanses of low-relief topography.

The type area of the Harney formation is in the Harney Basin, Harney County, Oregon. The formation was originally described by Piper, Robinson, and Park(29) in their investigations of the geology and groundwater resources of that area. In the Harney Basin the formation consists of tuffs, sandstones, basalt, volcanic breccia, and basal sands and gravels. Only the tuff member of the formation occurs in the map area of this report.

In the hand specimen this tuff is vitreous silver-gray or brown and weathers to dark brown. Large pumic fragments are characteristic. Thin sections of the rock show the following composition:

Glass	96%
Quartz	1%
Plagioclase	2%
Hematite	1%

The glass is shardy to somewhat vermicular but shows little evidence of welding. There is no evidence of flowage. Large, frothy grains of pumice are surrounded by shardy glass. Plagioclase occurs as subhedral grains and quartz as subhedral to anhedral grains. Brown hematite surrounds many grains and fills interstitial spaces.

In the type area, the Harney formation is considered to be Pliocene in age. Because of its stratigraphic position, it is considered to be of that same age in the area of this report. The Harney tuff is lithologically and stratigraphically similar to the Rattlesnake formation of north-central Oregon, but the author does not wish to imply a formational equivalence. However, this similarity seems to indicate that coincident explosive volcanic activity prevailed over much of Central Oregon during Pliocene time. Likely the sources of Rattlesnake and Harney materials were different and geographically separated by many miles.

PALEONTOLOGY

The following information represents a summary of the fossil material obtained from the area of study. Lists of the fossil identified and some conclusions as to the significance of the fauna are presented. No attempt is made to describe the fauna systematically, as this is beyond the scope of this paper.

Fauna of the Coffee Creek Formation

The limestones of the Coffee Creek formation contain fairly abundant fossils, especially corals and brachiopods. Microfossils were noted but not identified. Merriam reports the following fossils gathered from the Coffee Creek formation:

Dibunophyllum oregonensis Merriam

Lithostrotion (*Lithostrotion*) *packardi* Merriam

Lithostrotion (*Siphonodendron*) *oregonensis* Merriam

Campophyllum readi Merriam

Gigantella sp.

Striatifera sp.

Spirifer cf. *striatus* (Martin)

Tetrataxis sp.

Small loxonemoid gastropods

Lithistid sponge spicules

The only identifiable material collected by the author from this formation was specimens of the corals *Dibunophyllum oregonensis* and *Campophyllum readi*. Numerous brachiopod fragments, probably *Striatifera* sp., were noted.

Among the forms reported by Merriam, only the brachiopods are suggestive of a definite age. The corals are all long-ranging and appear to be distinct from previously reported forms. The brachiopods are well known in Europe and Asia, although localities in

Alaska, British Columbia, and California have yielded similar brachiopod faunas. The author accepts Merriam's suggestion that the fauna is Mississippian in age but believes that further fossil evidence is necessary before the age can definitely be established.

Fauna of the Coyote Butte Limestone

The Coyote Butte limestone contains many fossils, some of which are silicified. Fossils are rarely found free of the matrix and so they had to be studied in thin section or freed by etching in dilute hydrochloric acid. Among those fossils present in the limestone are fusulinids, brachiopods, corals, bryozoans, crinoid columnals, and ostracods. Identification of the material has been made on a generic level, excepting the fusulinids, which were specifically identified.

Fusulinids. About 150 thin sections of fusulinids from the Coyote Butte limestone were cut. Eleven species of four genera were recognized. Specimens of these forms are illustrated in Plates 2, 3, 4, and 5. The forms identified are listed below.

Minojapanella aff. *M. elongata* Fujimoto and Kanuma

Pseudofusulinella cf. *P. occidentalis* (Thompson and Wheeler)

Pseudofusulinella cf. *P. utahensis* Thompson and Bissell

Pseudofusulinella sp. A

Schwagerina aff. *S. cervicalis* (Lee)

Schwagerina cf. *S. diversiformis* Dunbar and Skinner

Schwagerina cf. *S. pusilla* (Schellwein)

Schwagerina cf. *S.* sp. C of Thompson and Miller

Pseudofusulina aff. P. nelsoni nelsoni (Dunbar and Skinner)

Pseudofusulina aff. P. nelsoni optima Thompson

Pseudofusulina sp. A

In addition to fusulinids, foraminifers referred to Ammodiscus sp., Polytaxis sp., Tetrataxis sp., and unidentified endothyroid forms were obtained from the etch-residue of some blocks of Coyote Butte limestone.

Part of the fusulinid fauna appears to be related to forms considered to be typically American, and part resembles forms characteristically Asiatic. Specimens referred to Schwagerina cf. S. diversiformis, Pseudofusulina aff. P. nelsoni nelsoni, and Pseudofusulina aff. P. nelsoni optima seem most closely comparable to forms described from the Wolfcampian of Texas. Schwagerina aff. S. cervicalis and Schwagerina cf. S. pusilla seem most closely comparable to forms described from the Permian of North China. Pseudofusulinella cf. P. utahensis compares well with a form reported from the upper Oquirrh formation of northern Utah and Pseudofusulinella cf. P. occidentalis compares closely with forms reported from the McCloud limestone in northern California. The genus Minojapanella, seemingly rare in the Coyote Butte limestone, has heretofore been reported only from the Permian of Japan.

Since the forms most closely comparable to those found in the area are widely distributed, the question arises as to the origin of these forms. The possibility exists that these forms are migrants from the Permian seas extending northwest from the Texas-Mexico area and from the seaway which presumably extended southward from Alaska and ultimately from China. It is also possible that the forms developed independently from already existing progenitors within the area. Few fusulinid faunas from areas west of the northern Rockies have been described, and the relations of the mixed Asiatic and American fauna of Central Oregon to those described from other American areas do not seem clear at this time.

On the basis of the apparent relations to forms described from the other areas mentioned, this fusulinid fauna is dated as upper Wolfcampian.

Brachiopods. Twenty-three genera of brachiopods were recognized in the Coyote Butte limestone. The forms obtained were identified as follows:

Athyris sp.

Avonia sp.

Buxtonia sp.

Camarophoria sp.

Chonetes sp.

Composita sp.

Dictyoclostus sp.

Echinoconchus sp.

Leiorhynchus sp.

Leinoproductus sp.

Marginifera sp.

Meekella sp.

Neospirifer sp.

Orthotetes sp.

Productus sp.

Punctospirifer sp.

Pugnoides sp.

Spirifer sp.

Spiriferella sp.

Spiriferina sp.

Squamularia sp.

Streptorhynchus sp.

Waagenoconcha sp.

A number of these genera are common to Permian faunas of West Texas, but certain elements, notably the productids, seem to relate the fauna to the Euro-Asiatic Permian. It seems possible that the population represents migrant elements from both areas. The most abundant brachiopods occur in what appears to be the upper portion of the Coyote Butte limestone. Where the brachiopods are most abundant, fusulinids and bryozoans are scarce or absent.

Corals. Corals are fairly common in parts of the area, and are represented by both solitary and colonial types. Merriam(20) reports representatives of the genera *Waagenophyllum* and *Lithostrotion* (*Lithostrotionella*), and these genera also were recognized by the author. Merriam has interpreted these forms as having Asiatic affinities. Much of the fossil coral material is silicified and readily weathers out of the limestone.

Bryozoans. Four genera of bryozoans were recognized from the Coyote Butte limestone:

Cheilotrypa sp.

Fenestella sp.

Polypora sp.

Rhomboporella sp.

The bryozoans ordinarily occur with the fusulinids, where they appear both as silicified and unreplaced remains.

Crinoid columnals. Unusually large crinoid columnals are fairly common in parts of the Coyote Butte limestone, some as much as one inch in diameter. No calices were found.

Ostracods. The ostracods occur as silicified replacements, and were prepared by etching. The following species were identified:

Bairdia sp.

Coryellina sp.

Ellipsella sp.

Healdia sp.

Kellettina sp.

Kirkbya sp.

Monoceratina sp.

Paraparchites sp.

Polytylites sp.

Sanniolus sp.

Silenites sp.

Identification of the Coyote Butte ostracods was based upon studies of Kansas and Texas material made by Kellett(13,14,15) and Sohn(33).

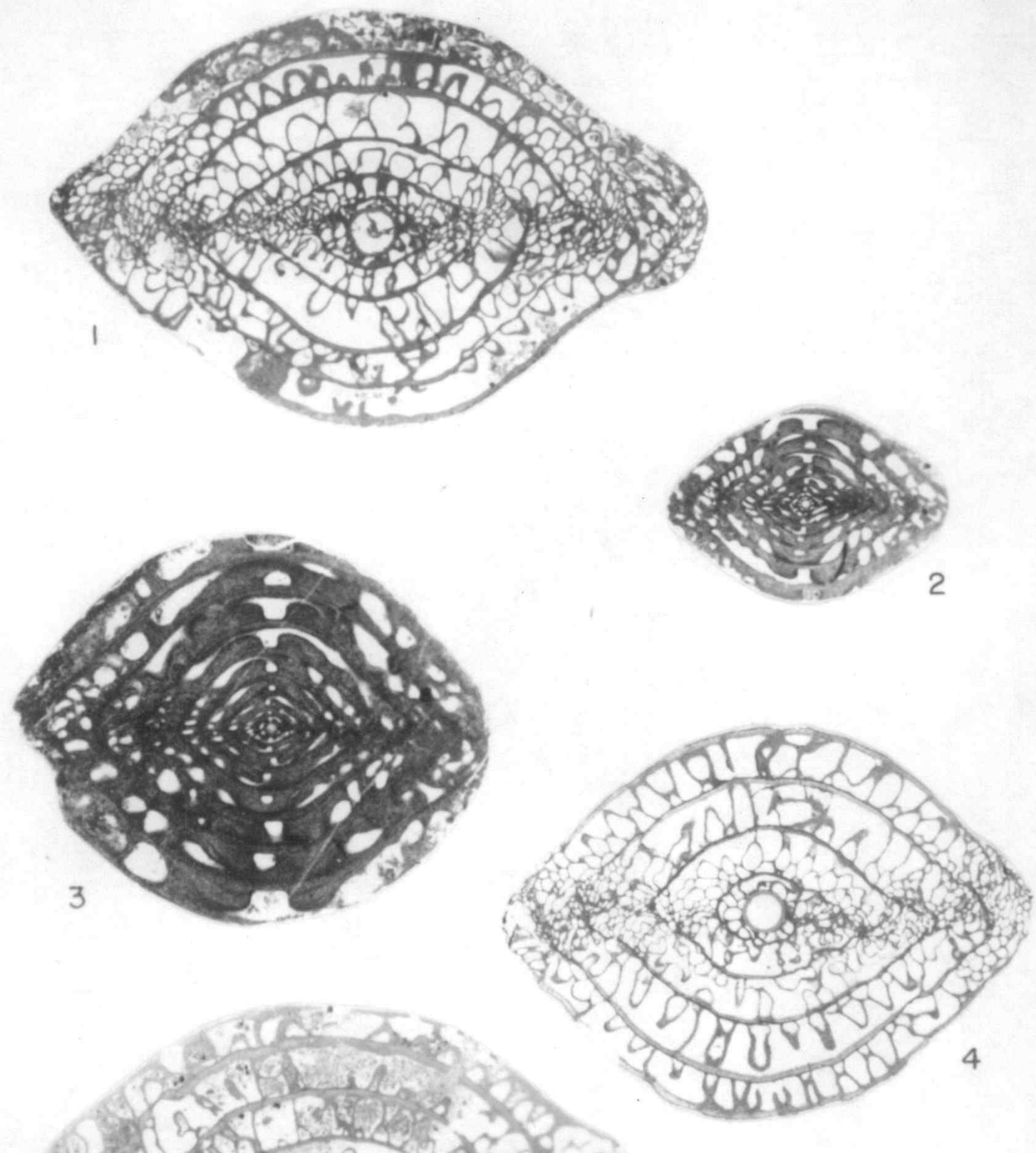
Explanation of Plate 2

All figures are axial sections.

Figs. 1,4,5. *Pseudofusulina* aff. *P. nelsoni optima* Thompson. Coyote Butte limeston. x10.

Figs. 2,3. *Pseudofusulinella* sp. A. Coyote Butte limestone. 2, x10; 3, x20.

PLATE 2



Explanation of Plate 3

All figures are axial sections.

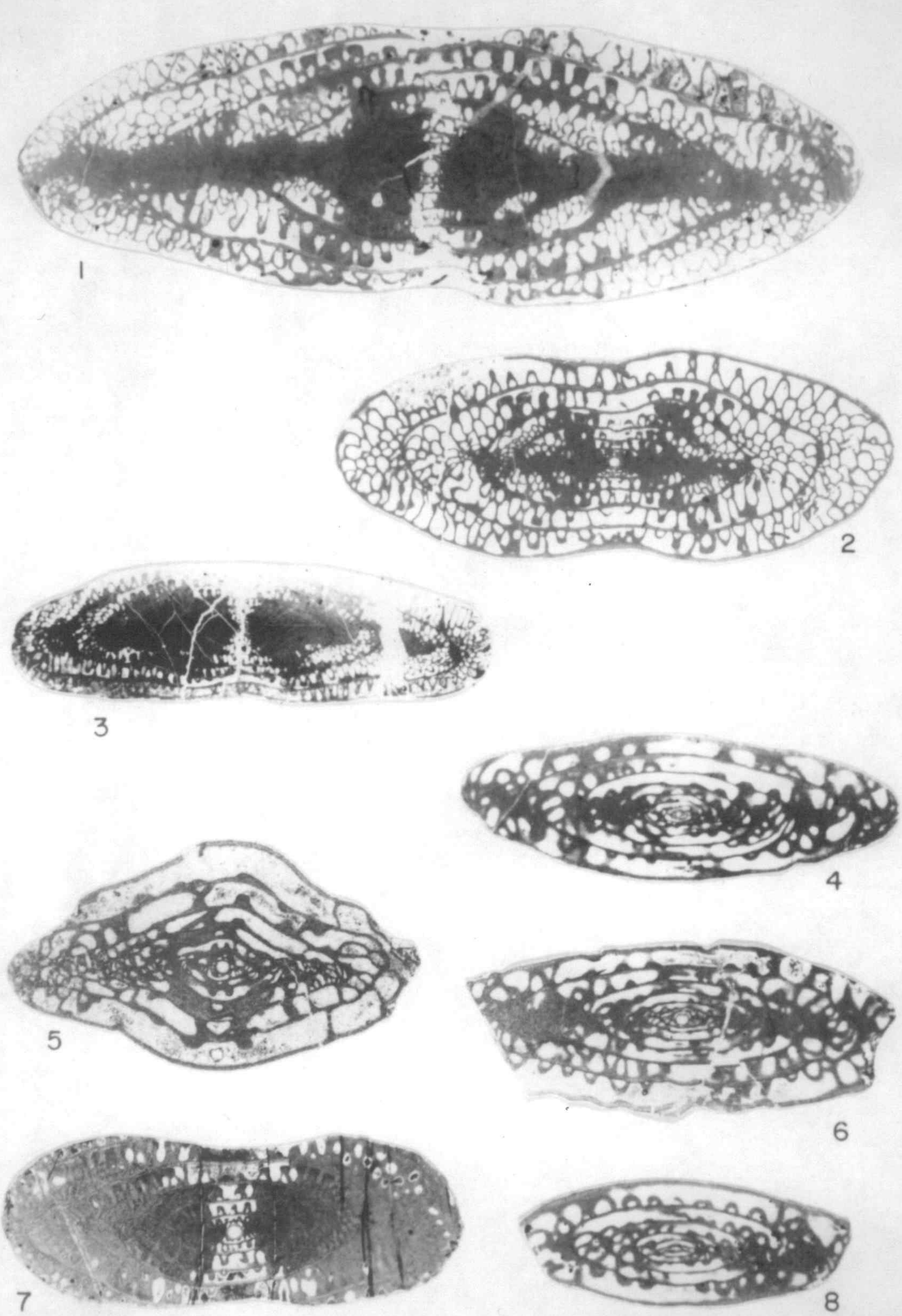
Figs. 1-3. *Schwagerina* cf. *S. diversiformis* Dunbar and Skinner. Coyote Butte limestone. 1 and 2, x10; 3, x5.

Figs. 4,6,8. *Schwagerina* cf. *S. pusilla* (Schellwein). Coyote Butte limestone. x20.

Fig. 5. *Pseudofusulinella* cf. *P. utahensis* Thompson and Bissell. Coyote Butte limestone. x20.

Fig. 7. *Schwagerina* cf. *S.* sp. C of Thompson and Miller. Coyote Butte limestone. x10.

PLATE 3



Explanation of Plate 4

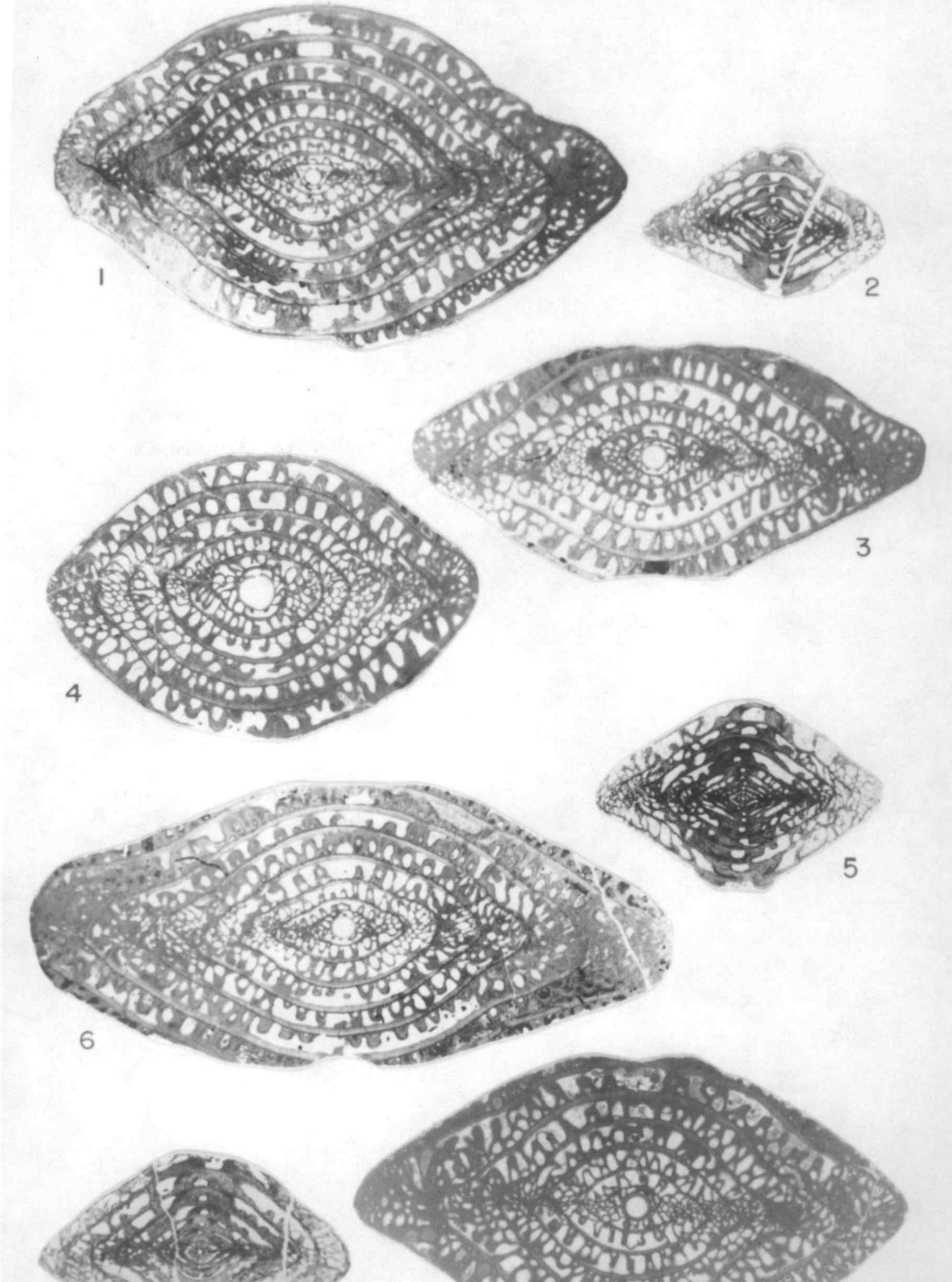
All figures are axial sections.

Fig. 1. *Pseudofusulina* sp. A. Coyote Butte limestone. x10.

Figs. 2,5,7. *Pseudofusulinella* cf. *P. occidentalis* (Thompson and Wheeler). Coyote Butte limestone. x10.

Figs. 3,4,6,8. *Pseudofusulina* aff. *P. nelsoni nelsoni* (Dunbar and Skinner). Coyote Butte limestone. x10.

PLATE 441



Explanation of Plate 5

All figures are axial sections.

Figs. 1,2,4-6. *Schwagerina* aff. *S. cervicalis* (Lee).
Coyote Butte limestone. x10.

Fig. 3. *Minojapanella* aff. *M. elongata* Fujimoto and Kanuma.
Coyote Butte limestone. x50.

PLATE 5 43

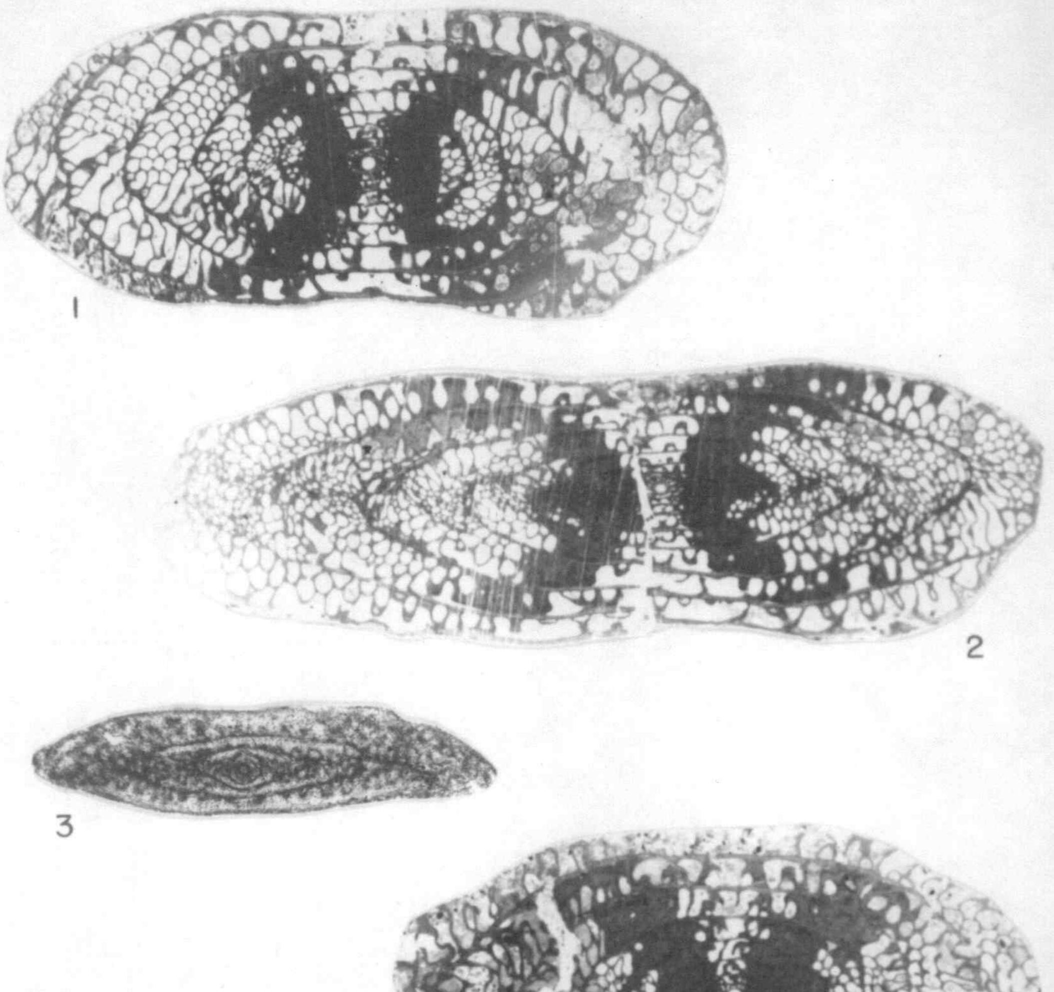


Plate 6 attached as separate file

PLATE 6

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